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Special Issue Reprint

Rural Land Use in China

Edited by
Yongsheng Wang, Qi Wen, Dazhuan Ge and Bangbang Zhang

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Preface

Land use is the projection of human activities in space, and it has become an important window for insight into the transformation and reconstruction of human society and economy. Rural land use in China is undergoing rapid transformation driven by the rapid development of science and technology. Effectively grasping the change and transformation process of rural land use and its internal mechanism will provide an important reference for revealing the inherent laws of China's rural development. Rural land use is closely related to the rural vitalization strategy and urban–rural integration in the New Era. An in-depth study of China's rural land use and policy reform will provide a basis of knowledge for optimizing urban–rural relations.

Rural land use research provides theoretical and technical support for the development of rural spatial planning and governance. At present, the pattern and state of rural land use in China are obstacles in meeting rural development needs. Carrying out comprehensive territorial improvement in rural areas has become an important measure to optimize the allocation pattern of rural land use, and has already produced a good demonstration effect. Rural spatial governance is the core component of modernizing the national governance system, and its importance in high-quality urban and rural development has become increasingly prominent. Starting from the resource and environmental effects of rural land use, it will be of great practical significance to analyze the inherent laws of urban–rural transformation in China.

This reprint focuses on the changes, effects, and regulation of rural land use in China. The purpose is to point out the main contradictions of rural land use in China and their solutions, aiming to build a cooperative network and a sharing platform for rural land use research from a multidisciplinary perspective so as to further deepen the theoretical innovation and practical application of rural land use research. We hope that the reprint will attract more scholars to pay attention to rapid rural restructuring, especially land use in rural China.

Yongsheng Wang, Qi Wen, Dazhuan Ge, and Bangbang Zhang
Editors

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Editorial

Rural Land Use Progress and Its Implication for Rural Revitalization in China

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Land is the solid basis for human existence, living, and production activities. Through agriculture, forestry, mining, and other uses, land provides the food, water, and energy necessary for human survival, as well as substantial economic returns. Land use is susceptible to long-term anthropogenic changes. Sustainable land use is significant to the economic development of human society, while unsustainable land management results in a decline in ecosystem services and brings about negative impacts on regional sustainable development [1,2].

China faces an intense human–land relationship, with little average cultivated land per capita. Rapid urbanization and industrialization have induced various land issues with respect to the degradation of cultivated land, the expansion of constructed land, and the loss of ecological land. As an agricultural country with a large rural population, the type and structure of China's rural land use have undergone significant changes, mainly due to rapid socio-economic development in recent decades [3]. Especially since 2000, some measures and projects have been carried out to prevent issues of rural decline. The improving infrastructure and essential public services in rural areas not only involve the greatest investments but also occupy valuable land resources. For example, targeted poverty alleviation and rural revitalization strategies significantly promote the development of the rural economy, which needs abundant land as a space carrier and is accompanied by rapid land use changes and modifications [4]. However, in the meantime, rural restructuring is usually associated with changes in farmland and rural housing land, even affecting ecological land use. By 2050, China's rural areas should have robust agriculture, beautiful landscapes, and prosperous farmers. Although rural land engineering can be adopted to optimize the human–land relationship and promote rural sustainable development [2]. Land use sustainability is still listed as a priority in the aspects of the coordinated development of rural regional functions, rural transformation, and urban–rural integration [5].

Agriculture, rural areas, and farmers are known as the "Three rural issues" which are fundamental to China's development and the well-being of rural people. The modernization of agriculture and rural areas will place more emphasis on the use of overworked rural land. Therefore, this themed Special Issue mainly focuses on the evolution processes, spatial–temporal patterns, and eco-environmental effects of rural land use in China, and the influencing factors and mechanisms of rural land use transition are also addressed. A total of twenty-three articles were successfully peer-reviewed in this Special Issue. The published articles can be classified into three topics, including land consolidation and land system reform, land use patterns and their eco-environmental effects, and land transfer and its influencing factors. The results and prospects will propose useful theories and practical policies for the consolidation of rural settlements, the sustainable use of farmland, and land system reform in the context of rapid urbanization and urban–rural development.

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There are nine articles within this section. Land consolidation mainly refers to hollow villages, rural settlements, sandy land, and pilot projects, while land system reform was studied from the perspectives of farmers and social investors, agricultural modernization, and scale and revenue.

Qu et al. (Appendix A, 1) adopted a typical village-investigation method and the actor–network theory to obtain a rural governance policy and its application conditions. The diversified governance modes and dynamic governance process of hollow villages provided targeted suggestions to resolve the problems during the consolidation and governance of hollow villages. Cao and Song (Appendix A, 2) divided the spatiotemporal variations in a rural settlement into an expansion pattern, merge pattern, retreated pattern, and urbanization pattern. Chinese policies for homesteads have played profoundly regulating and guiding roles in the spatial distribution changes and evolution stages of rural settlements. In China's metropolitan fringe area, rural settlements showed the morphological types strip, arcbelt, cluster, and scatter. These distribution patterns were related to agricultural production, rural economic development, and cultural and policy factors (Appendix A, 3). In an arid sandy area, the limiting factor exclusion method was used to reveal the appropriate tillage of sandy land and regional desertification prevention (Appendix A, 4).

Social capitals investments and farmers' willingness play important roles in land consolidation. The concerns and needs of social investors and farmers in decision-making for comprehensive land consolidation projects (Appendix A, 5) and the remediation of contaminated farmland (Appendix A, 6) were explored using a methods of evaluation index system, an empirical analysis, and structural equation and random forest models, respectively. The results indicate that land consolidation should consider social investors' attention to transaction income and industrial operating income and farmers' attention to perceived benefits and suitable technologies. Sun et al. (Appendix A, 7) found that land certification programs had significant effects on the farmland "stickiness" of rural labor due to the enhanced land production function. The results also suggest that a land certification program can improve the relationship between smallholders and modern agriculture. Cai et al. (Appendix A, 8) explored the promotion of the reform of the farmland rights system to agricultural modernization, examining the practice of Yuyang District in Northwestern China. Administrative intervention in the reform of the farmland rights system from decentralization to centralization can help achieve agricultural modernization. Jin et al. (Appendix A, 9) used a quadratic econometric model to analyze the relationship between the scale and revenue of the land-use balance quota. The inverted "U" relationship and spatial heterogeneity results indicate that the appropriate size of the land-use quota should be comprehensively considered during governmental policy making.

Nine articles focused on driving forces, spatiotemporal changes, and crop planting and production. At the provincial level, Wu et al. (Appendix A, 10) analyzed the effects of changed territorial spatial patterns on eco-environmental quality based on the functional classification system of "production-living-ecological. However, the steady improvement of the eco-environmental quality was directly affected by the annual average precipitation, the proportion of non-agricultural area, and socio-economic factors. The coupled interaction between human and nature factors had enhancing effects on changes in the eco-environmental quality in Qinghai Province, China. At the family farm level, efficiency and influencing factors were studied from the perspectives of different regions and operation types, using the Data Envelopment Analysis model and Tobit model, respectively. Breeding family farms had the highest efficiency compared to other types of family farms. In addition, the varied factors influencing family farms' efficiency in different regions and types suggested that local governments and operators should choose differentiated management measures to improve the lower efficiency of family farms (Appendix A, 11). The conversion of cultivated land into non-agricultural land in China's Karst mountainous areas faces trade-offs between social development and ecological risk. Han et al. (Appendix A, 12) indicated that the conversion of cultivated land into forest land and shrub–grassland can reduce the ecological risk to the landscape while maintaining food security.

Significant differences in spatiotemporal patterns, landscape characteristics, and land-use changes between China's paddy fields and drylands have been found from 1990 to 2020, using land-use raster data. The results suggest the protection of arable land on sunny slopes and in plain areas and, meanwhile, the strengthened sustainable utilization of water resources in the provinces of Xinjiang and Gansu (Appendix A, 13). The multiple functions and the green transition of cultivated land utilization are important ways to implement ecological progress and food security strategies. In the major grain-producing areas of Northeast China, the level of agricultural development determined the spatiotemporal evolution of the multifunctional coupling coordination degree of cultivated land (Appendix A, 14). Spatiotemporal coincidences were found with great consistency in changes in the "water-land-food-carbon" system and their coupling coordination degrees under the green transition of cultivated land utilization (Appendix A, 15).

Chen et al. (Appendix A, 16) indicated that the spatial patterns in China's soybean planting had significantly changed from 1949 to 2019; however, a fluctuating upward trend of soybean production and an unchanged area of soybeans sown were found. Different policies were proposed to alleviate the national soybean shortage problem in Southern China, the Huang–Huai–Hai Plain, and the Northeast China Plain. Li et al. (Appendix A, 17) used remote-sensing interpretation data to reveal the spatiotemporal evolution of the crop-planting structure in Hailun County of Northeast China. This study suggested that adjustments to the crop-planting structure should be conducted via the optimization of the crop area proportion and the spatial distribution of crops at the county level.

Five papers focused on the issue of land transfer. Gao et al. (Appendix A, 18) conducted a questionnaire-based survey to verify the function of the herd effect in farmers' land transfer behavior. The results demonstrated the herd effects of government on promoting land transfer by constructing farmland infrastructure and developing the land transfer market. The other four papers concerned the interaction mechanisms between land transfer and family structure, livelihood, household consumption, and labor migration. Zhang et al. (Appendix A, 19) studied the effects of family structure on the area of land transferred out. Elite families with party members had more individual land area in paid subcontracting than households with a grassroots cadre. Liu et al. (Appendix A, 20) revealed that the leaseback and re-contracting model of land transfer is the best way to increase farmers' livelihood capital, while Hong and Lou (Appendix A, 21) indicated that rural households involved with the transfer-in and transfer-out of land can promote non-food and food consumption expenditure, respectively. Wang et al. (Appendix A, 22) measured the coupling coordination degree between farmland transfer and labor migration in China using socioeconomic data. The primary coupling coordination stage was found to have large differences in the degree between regions in the coordinated development of farmland transfer and labor migration. In addition, Feng et al. (Appendix A, 23) examined the effects of China's high-standard farmland construction policy on the agricultural total factor productivity. Their results suggest that the high-standard farmland construction policy has significantly promoted the agricultural total factor productivity through the enhancement of agricultural technology change and technical efficiency.

Rural land use can be divided into agricultural land and rural constructed land [6]. Rural land use in China is a hot topic concerning the government, scholars, and rural residents. This Special Issue organized 23 papers to discuss it from different scales and perspectives, using different methods. Some interesting and important conceptual–theoretical and empirical contributions were made to progress the research on rural land use in China. However, there are still some themes that need to be noted in future studies of rural land use in China.

Firstly, the integrity and stability of rural ecological function are the basis of agricultural production and rural living. Previous studies have noted the coordinated development among rural production–living–ecological functions and their optimization strategies. In the context of dramatic human activities, the evolution of rural ecological space has brought out serious resource and environmental problems. The synergy and tradeoff of ecosystem services, the nexus of land–water–food–energy, and the pollution of water, soil, and gas causing changes in the rural production–living–ecological space still require more attention. In addition, China's central government has issued guidelines for setting up and improving a mechanism to realize the value of ecological products amid green development efforts. Rural areas have abundant ecological resources and traditional culture resources which can be measured, mortgaged, and transacted through the integration of policy, technology, industry, and markets. Potential rural land use transitions and land management should be noted.

Secondly, the number and structure of the rural permanent population have significantly changed. The reduction in and aging of the rural labor force pose challenges to agricultural production. In addition, climate change brings both challenges and opportunities to agricultural production. Who will tend the cultivated land and operate the agricultural machinery? How can climate-smart agriculture be implemented? These issues need to be addressed using top-down guidance and bottom-up engagement. Extensive research should be conducted to provide suitable polices and empirical modes for government and local farmers. Furthermore, the continuous expansion of the number of the people who have returned or moved to the countryside to start a business or innovate will result in changes in rural land use.

Lastly, China's rural areas have diverse types and distinct development levels. The regional coordination of human–land relationships and land use optimization are essential for rural revitalization. The challenges arising from continuous urbanization and extreme climate change threaten sustainable land use and rural development. It is urgent to learn from other countries' rural transformation experiences and modes, especially with respect to land use policies and planning, land system reform, and the comprehensive consolidation of land.

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Appendix A

1. Qu, Y.; Zhao, W.; Zhao, L.; Zheng, Y.; Xu, Z.; Jiang, H. Research on Hollow Village Governance Based on Action Network: Mode, Mechanism and Countermeasures-Comparison of Different Patterns in Plain Agricultural Areas of China. *Land* **2022**, *11*, 792. https://doi.org/10.3390/land11060792.
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Article

Research on Hollow Village Governance Based on Action Network: Mode, Mechanism and Countermeasures—Comparison of Different Patterns in Plain Agricultural Areas of China

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Abstract: With the large-scale development of urbanization in the world, phenomena such as the unbalanced allocation of various elements of the rural regional system, as well as the decline of the economic and social structure and functions in the process of urban and rural economic and social transformation and development in China, have endangered the healthy development of rural areas. The "hollowing" of rural areas is becoming more and more intense, and the governance of hollow villages has become a key link to stimulating the vitality of rural development and realizing the coordinated development of urban and rural areas. Taking a typical hollow village in Fangsi Town, Yucheng City, Shandong Province, China as an example, through the recognition method of hollow villages mode, the study adopted the in-depth interviews and questionnaires to obtain governance of hollow villages. Moreover, this study uses the actor–network theory to discuss the governance model mechanism and policy response of hollow villages, extract the applicable conditions of different hollow village governance modes, and provide the promotion of the hollow village governance mechanism. Our findings show that: (1) the governance modes of hollow villages are diverse. Under certain geographical conditions, the governance of hollow villages shows the relocation and merger–urban–rural integration mode, village integration-scale operation mode, village intensive-idle land revitalization mode, and original site optimization–sightseeing tourism development mode, along with other types. In the process of promotion and use, appropriate adjustments should be made in combination with differences and changes in system conditions, and the accurate governance of villages should be carried out. (2) The governance process of hollow villages is dynamic. The governance of hollow villages represents a heterogeneous network of actors led by key actors, which mainly realizes changes in the rural material space. With the change of development goals of the hollow village, the network of actors has been readjusted around the new OPP, and the role of the actors has changed, correspondingly showing a transition from the governance of the hollow village to the optimized development, thus further realizing the transformation of the hollow village.

Keywords: hollow village; actor–network; governance mode; operation process

1. Introduction

With the development of large-scale urbanization on a global scale, related opportunities and challenges also arise, such as the widening gap between urban and rural areas, excessive rural population loss, inefficient rural land use and continuous rural industrial outflow, etc. [1]. In the process of urbanization and industrialization, the decline of rural areas is a global problem, and developed countries have taken many measures to address this problem. For example, Germany implemented equal treatment of urban and rural elements based on the "equivalence" theory [2]; the United Kingdom implemented a large-scale agricultural intensification reform [3]; Japan implemented the nationwide "one village, one product" campaign, etc. [4,5]. Since the reform and opening, rapid urbanization, as a new engine to create China's economic growth, has also profoundly affected vast rural areas [6,7]. Problems such as the continuous outflow of the labor force [8,9], idle and abandoned land resources [10], weak cultural inheritance, and governance capabilities have emerged one after another [11], and the problem of "hollowing out" in rural areas has become increasingly serious.

In order to solve the increasingly hollowing out phenomenon in rural areas and seek the governance path of rural recession, the study of hollow villages has received significant attention from academic circles. The special governance stage and national conditions of development, the implementation of the "balanced occupation and compensation" of cultivated land [12], and the reconstruction of rural space and the overall development of urban and rural areas have all necessitated urgent requirements for in-depth village hollowing out renovations. In this regard, scholars in the field of rural governance have explored the concept definition, governance mode, and performance evaluation of hollow villages, which provide effective guidance and reference for this study. In terms of connotation definition, most scholars explain hollow villages from the perspectives of urban and rural element flow, land use, and village spatial planning, focusing on the spatial form of hollow villages [6,13–15]; some scholars focus on the loss of labor [16], age structure imbalance, industrial lag, etc., to determine the definition of hollow villages [17,18] and pay attention to their population distribution characteristics and economic development status [19]. In terms of governance mode, some scholars analyze it from the perspective of rural settlement planning and industrial cultivation, paying more attention to the path of village governance and carrying out multi-dimensional morphological identification and classification of governance for hollow villages [20–22]. Some scholars take the allocation of land resources as the key to governance and explore the relationship between hollow village governance and land resource utilization [23,24]. In terms of the construction of the governance evaluation index system, most scholars have constructed a macro evaluation index system of hollow village governance based on the formation mechanism and morphological characteristics of hollow villages, and on the basis of analyzing their spatial distribution and evolution process [11,25–27]. In addition, some scholars take the governance subject as the research entry point to analyzing the satisfaction of villagers [28–30] in order to reflect the governance performance level of hollow villages in the selected area or take the participation of farmers as the evaluation standard to evaluate typical hollow village governance [31].

In general, current research on the governance of hollow villages is mostly on a macro level, encompassing a static description of a single subject relationship and the intuitive evaluation of the governance effect; meanwhile, research on the dynamic process of hollow villages involves the development from governance to transformation and the relationship between participants; the governance effect of the multidimensional perspective is relatively weak. In view of this, this study utilizes the actor–network as theoretical support and Fangsi Town, Yucheng City, Shandong Province, China as the research area. Four governance cases, Fangsijie village, Xingdian village, Zhengniu village, and Weizhuang village, were selected to analyze the behavior and role orientation of human and non-human actors in the governance of hollow villages; comprehensively analyze the operation law of hollow village governance; and compare different governance modes, providing the basis for model optimization and the formulation of differentiated hollow village governance countermeasures, so as to enrich the systematic research and application practice of the hollow village governance mode, which is oriented to national strategic needs and regional development.

2. Theory and Methods

2.1. Research Ideas

Hollow village governance is a systematic process, which is an important aspect of improving the living environment, adjusting the rural spatial structure, and realizing the rural revitalization strategy. Hollow villages show different degrees of imbalance within the main structure, an idle abandonment of homesteads, a backwards industrial economy, a weak governance capacity, and a poor cultural life [32]. Essentially, there is an imbalance of population, land, industry, organization, and culture in the operation of the rural system. The interaction of various factors leads to the decline of rural life, production, ecology, organization, and culture. The governance process is also a dynamic one of mutual reorganization and connection between the governance subject and the governance object [33] and promotes the reconstruction of rural space and social relations. The actor–network theory takes each human actor and non-human actor as the research node, emphasizing that society should not be regarded as a screen that projects all actors and entities, but should be understood based on the complex and dynamic connection between them [34]. Hollow village governance refers to the interaction of a governance subject (human actor) and governance object (non-human actor), and the process is full of interaction, flow, and change. Therefore, this study intends to use the actor–network theory, focusing on process and relationship thinking as the analysis framework, to identify the composition of the actor–network of hollow village governance, analyze the interaction and connection of each actor in the process, analyze the hollow village governance process based on the actor–network theory, and deconstruct the hollow village governance model system [35]. On this basis, this study selects "two styles and four types" of typical governance models in China's plain agricultural areas, namely, "relocation and merger" and "retention of the original site", to explore the construction of actor–networks in different governance models and compare the different models to propose specific strategies for them (Figure 1).

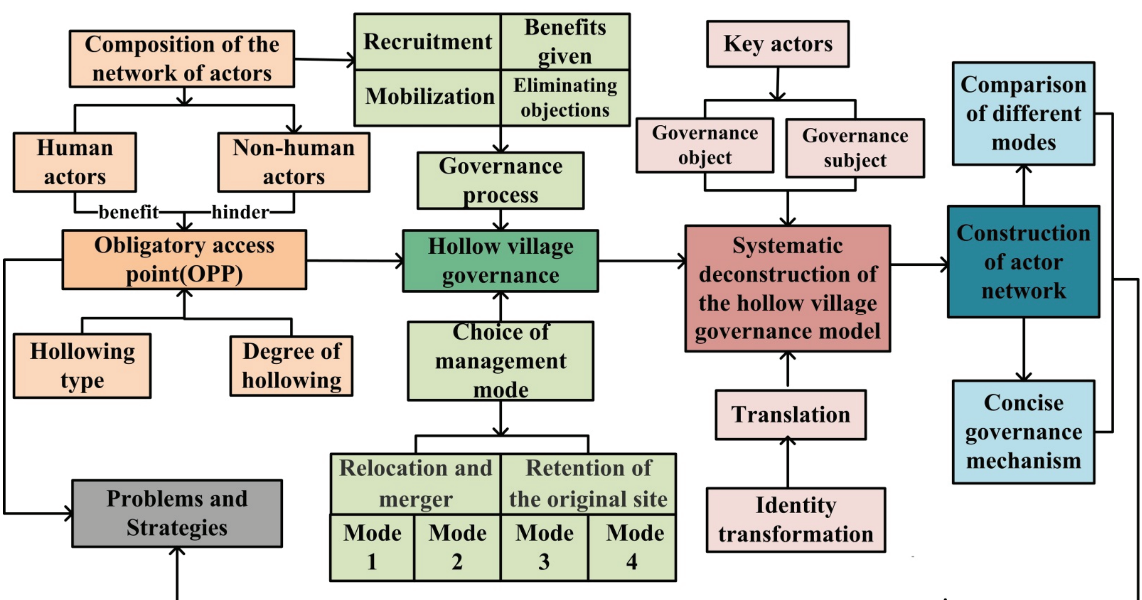

Figure 1. Research ideas of hollow village governance based on actor–network theory.

2.2. *Actor-Network Theory*

2.2.1. The Composition of the Actor–Network of Hollow Village Governance

The actor–network of hollow village governance is composed of governance subjects and governance objects, including municipal governments, local township governments, village collectives, villagers, outsiders, developers, land use enterprises, and other governance subjects, as well as population, land, industry, organization, culture, and other governance objects. Before translation, actors gathered their different interest goals and problems at the obligatory pass point (OPP) [36] and tried to obtain the expected relevant interests by solving problems. To solve the problems of each subject and achieve their aims, addressing the issue of village hollowing out and promoting the construction of a new countryside were finally implemented as core goals (Figure 2).

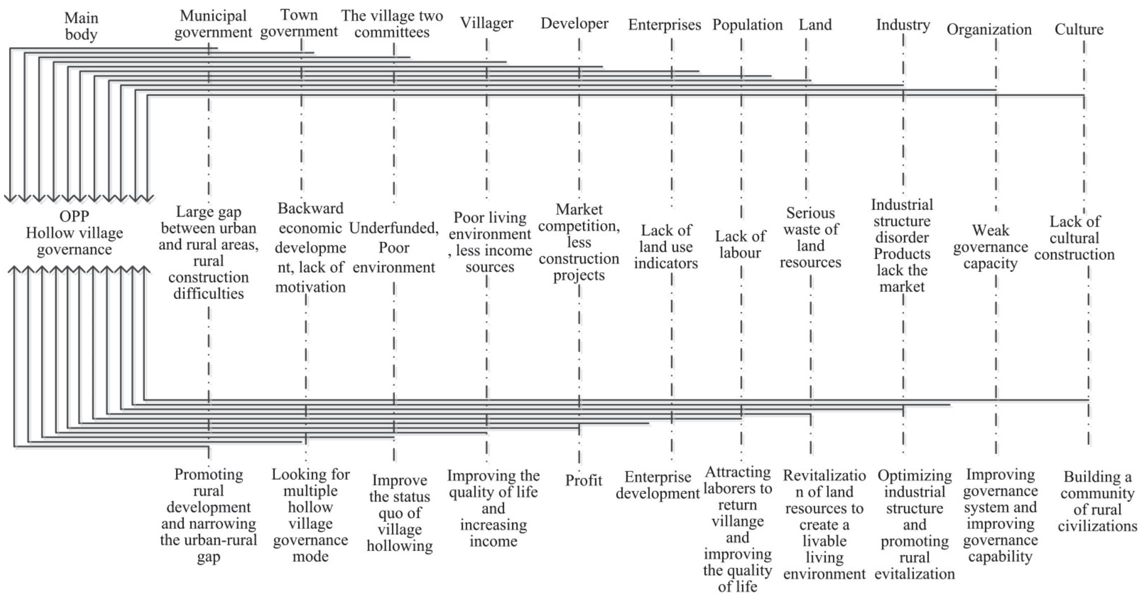

Figure 2. Actors of hollow village governance and their obligatory pass point (OPP).

2.2.2. Hollow Village Governance Process based on Actor-Network

From the perspective of the actor–network, the governance of hollow villages is a multi-level and complex process. Each actor is recruited to identify key issues, establish interest relationships, and form a translation process in a specific stage where multiple actors influence each other. Under the action of the system, a systematic governance model and an operable operating mechanism are formed [14]. The realization process of hollow village governance is reflected in several ways, as shown in Figure 3.

In terms of actor–network construction, in order to meet the goals and interests of each actor, it is necessary to implement translation in the network to eliminate action obstacles. The key actors in each mode recruit other heterogeneous actors, resulting in different modes [37]. This process predominantly includes two characteristics: organization mode and action mechanism. Organizational methods include the executive role of the two committees of the village, the leading role of the local government, the coordinating role of villagers in decision-making, the participation of social forces, the driving role of consumer consumption, etc., and different actors are interrelated and play their respective roles in the governance of hollow villages' actions. The mechanism operates to propose an integrated governance method for hollow village resources for different governance cores.

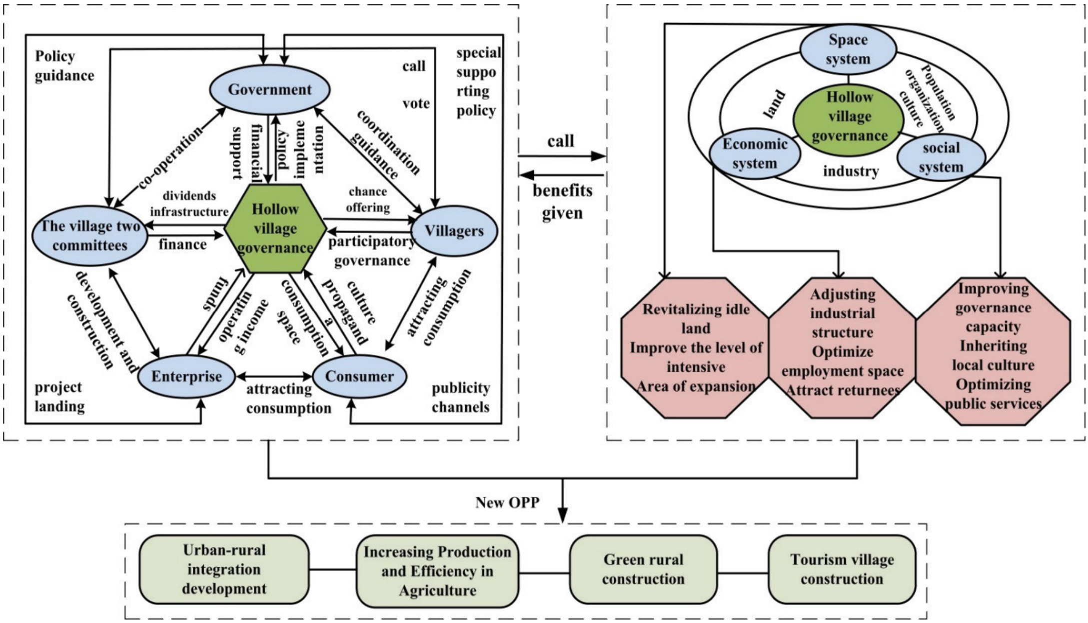

Figure 3. Hollow village governance process based on actor–network theory.

In terms of the role change of actors, with the evolution of policies and hollow villages, the actor–network will undergo dynamic adjustment, which is reflected in the impact of the entry, exit, and role change of heterogeneous actors on the network's relationship [38]. Guided by the current national strategy, the coordinated development of urban and rural areas, increased production and efficiency of agriculture, green rural construction, and tourism village construction are taken as new OPP goals for different actors to realize the transformation from hollow village governance to optimized development.

2.3. The Recognition Method of Hollow Villages Mode

The hollow village governance model based on the actor–network theory includes five characteristics: key actors, governance subjects, governance objects, transfer, and identity conversion [39]. In different villages, according to the characteristics of rural endowments between the governance object and the governance subject, as well as a specific compulsory passage point, translation and identity conversion are carried out under the leadership of key actors; thus, different hollow village governance models are formed.

Based on the actor–network theory, the identification of the governance model of hollow villages in a typical sample area involves a complex system comprised of multiple features (Figure 4), as well as a synthesis process consisting of rural endowment characteristics, governance objects, and governance subjects and their mutual influences and interactions. Among them, the resource endowment of hollow villages is a prerequisite for the selection of the hollow village governance model [40]. The village resource endowment clarifies the external environmental characteristics of the hollow village, including the location, type, socio-economic conditions, degree of hollowing, and current policies in the region. The absence or insufficiency of resource endowment has induced the hollowing out of one or more villages. Therefore, resource endowment essentially supports the choice of the governance model. On the contrary, the choice of the hollow village governance mode must adapt to the current situation of the village [41]. The governance object reflects the problems and obstacles existing in the current hollow village, including the hollowing of the population, land, industry, organization, and culture. Based on the problems and obstacles existing in the governance object, the hollow village is divided into a single-dimensional form and a multi-dimensional form. In the face of different types of hollow villages, the choice of the governance mode is diversified and targeted, which provides direction for the choice of hollow village mode. The main body of governance is the key to guiding the implementation of the hollow village governance model, which usually includes the government, villagers, village collectives, enterprises, and consumers. Choosing the main body of governance and determining the key actors is at the core of hollow village governance. The main body of governance plays its own role in the existing resources and problems of the hollow village, forming a regulatory force to ensure the orderly conduct of hollow village governance and promote the implementation of the hollow village governance model. The continuous coordination between the governance object and the governance subject forms the basis for translation and identity transformation in the governance mode, which promotes the continuous optimization and upgrading of the internal system of the hollow village and improves the degree of hollowing. Consequently, by understanding the resource endowments of different hollow villages, as well as the problems existing in the governance object and through the active role of the governance subject, all actors involved in the governance of hollow villages are translated. Through the interaction and mutual influence between each other, the identity transformation of participants is promoted, and different types of hollow village governance modes are formed.

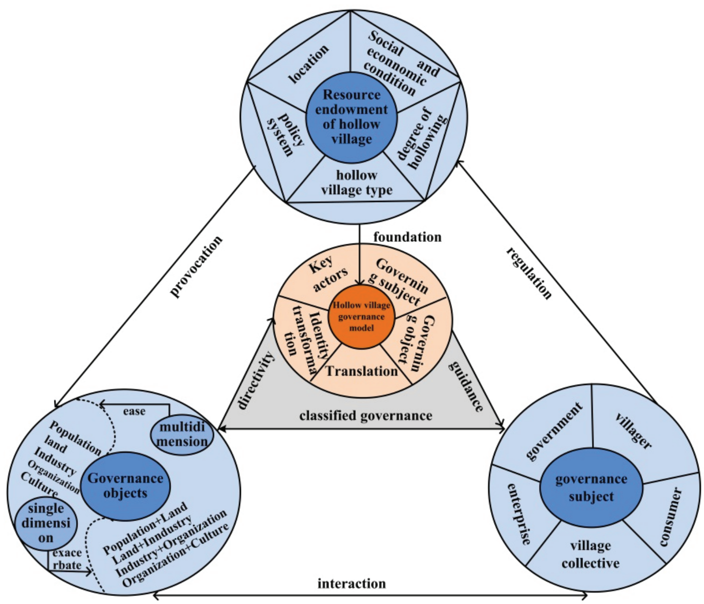

Figure 4. Deconstruction of hollow village governance mode.

3. Research Area and Data Source

3.1. Overview of the Research Area

Fangsijie Town is located in the west of Yucheng City, Shandong Province (Figure 5). It is a key township in China's "Hundred Small Towns and Demonstration Pilot Towns" and enjoys many titles such as "National Development and Reform Pilot Town" and "Provincial Rural Civilization Demonstration Town". The experience of urban brands in the implementation of hollow village governance can provide a reference for homestead management in different regions. According to the third land survey database of Fangsi Town in 2019, the total area of Fangsi Town is 14,593.96 square kilometers. Compared with the land survey data in 2006, the area of cultivated land in Fangsi Town increased by 218.08 hectares in the past 14 years; 12.65 hectares of cultivated land was occupied for construction and 219.16 hectares of cultivated land was added to land reclamation.

In general, work continues to improve but there is still a large area of idle land in the village to be reclaimed and developed. The per capita rural construction land is as high as 296 m^2, and the homestead is seriously empty, which has become the main restricting factor for rural revitalization and new rural construction. There are 62 administrative villages in Fangsi Town. In 2019, the total population was 74,330, the household registration population was 69,283 and the urban population was 24,000. The urbanization rate is low and migrant workers account for more than 70% of the rural population. Among the four villages studied, Fangsijie village has a registered population of 2276, and the proportion of migrant workers is as high as 50%; Xingdian village has a registered population of 2748, and the migrant worker ratio is 23.3%; Zhengniu village has a registered population of 516. The elderly, women, and children in the village account for more than 30% of the permanent resident population. The registered population of Weizhuang village is 896, and the labor force accounts for more than 60%. On the whole, there are many migrant workers in Fangsi Town, and the labor force in the village is scarce. The "369" left-behind population is the main factor affecting the sustainable development of the village.

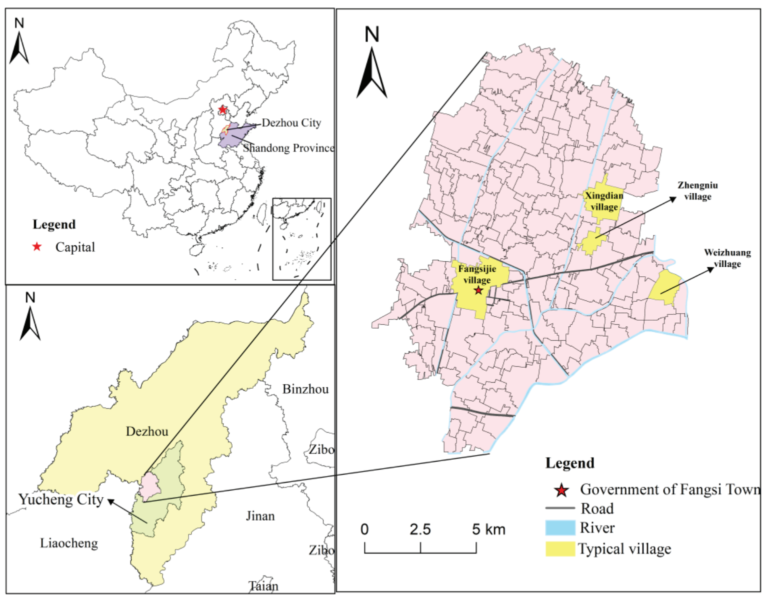

Figure 5. Research area.

According to the actor–network theory, in line with the principle of difference and comparability, the two hollow village governance categories are 'relocation and merger' and 'original site retention'; the different governance subject, governance object, and translation process occur in the process of hollow village governance. This study selected four typical villages—Fangsijie village, Xingdian village, Zhengniu village, and Weizhuang village—in the town to conduct in-depth research and discuss the operation mechanism and governance effect of four hollow village governance modes.

3.2. Data Source

This study adopted the research methods of on-the-spot investigation, in-depth interview and questionnaire survey to obtain the role orientation, role change, and village governance mode operation mechanism of each actor in the governance process of the case village. Before the investigation and study, we contacted the local town government and obtained research support. On the basis of the voluntary principle of respondents, we talked with the town government personnel, the two committees of the case village, villagers, business managers, tourists, and other actors, and filled out the questionnaire so as to obtain a series of actions, policies, and changes in the role of actors in the governance of hollow villages. The survey was conducted twice. From the first one, the general situation of village A and the basic situation of governance mode were obtained. From the second one, the operation mechanism of village hollow village governance mode was obtained, such as the process before and after governance, changes, and changes in the role of actors.

The research data mainly came from two sources: first, through an on-the-spot investigation, in-depth interviews were conducted with the local government, village committees, villagers, and other actors, with a total of 51 interviewees (Table 1). Through investigation and interviews, we sought to obtain the operation mechanism and governance of each mode in the process of transformation and understand the governance status and transformation effect of the four villages. The second source was the industrial survey report and meeting records of local government agencies or village committees on village development.

Table 1. Research objects and interview focuses.

Research Time	Interviewer	Quantity	Interview Focus
August 2020	Town government	2	1. Situation of hollow villages in towns
	Case village two committees	4	2. Hollow village governance process
	Case village villagers	16	3. Expected development direction of hollow villages
	Enterprise manager	6	4. The relationship between the actors
	tourist	5	5. The role of actors in the process of hollow village governance
November 2021	Town government	1	
	Case village two committees	4	1. Status and trends in village development
	Case village villagers	6	2. Evolution of the relationship between actors
	Enterprise manager	4	3. Satisfaction with village governance
	Tourist	3	

The data in the table are from interviews.

4. Results and Analysis

4.1. Mode Performance

Through interviews and on-the-spot investigations, it was found that there are human actors (governance subjects) of the municipal government, town government, village committees, villagers, developers, enterprises, and tourists in the governance process of Fangsi Town hollow village, including key actors and non-human actors (governance objects) of population, land, industry, organization, and culture. The actors and social factors involved in the process of local practice are all natural. Instead of a simple combination, actors redefine their identities and action logic through the translation process. Based on our understanding of the law of the formation and development of the hollow village, and taking full account of the morphological characteristics of the hollow village in the selected cases, we divided the data into four modes, namely, the relocation and merger–urban–rural integration mode, the village integration–scale operation mode, the village intensive–idle land revitalization mode, and the original site optimization–sightseeing tourism development mode. Different governance modes meet the goals and interests of actors in the actor–network according to local conditions and achieve translation in the network to eliminate obstacles to action. Key actors in each model summon other heterogeneous actors to generate network relations under different models. With the evolution of policies and hollow villages, the network of actors is dynamically adjusted, which shows the impact of entry, exit, and role change on the network relations of heterogeneous actors. At present, the governance of hollow villages in Fangsi Town has achieved remarkable results, and Table 2 summarizes the various typical villages and models for the governance of hollow villages in plain agricultural areas.

Table 2. Case village governance.

Mode	Case Villages	Basic Situation of Villages	Governance Content	Comparison before and after Governance
1	Fangsijie village	Located around the town, the degree of hollowing is low, as a single form of leading hollow village, farmers on agricultural income dependence are not strong, more migrant workers, the village guards weakened seriously, the villagers have a strong desire for village governance and urbanization.	The key actors of village governance are the hollow village governance group composed of the government and the village collective. The core of governance is to centralize the relocation to urban communities, transfer the village land after integration, innovate the urban–rural overall allocation and the flow mechanism of production factors, and realize the urbanization of housing and employment.	 Before  After
2	Xingdian village	Far from the urban center, the village has a high degree of aggregation and a low degree of hollowing out, which is a dual-form compound. The village land idle area is large, the village infrastructure is not perfect, farmers use farming as the main source of income, can accept a larger farming radius and intentionally improve the current living environment.	The key actor of village governance is the town government. The core of governance is to realize the scale of the operation, the centralization of living, the modernization of agriculture, and the intensification of land. The nearby villages are moved to the community, the original village land is reclaimed, and the large-scale community agricultural park is constructed.	 Before  After
3	Zhengniu village	Stay away from the central town and plan to remain a governance village. The degree of hollowing out is on the verge of moderate, belonging to the dual form compound hollow village. The village has extensive land use, poor infrastructure conditions, and farmers' migrant work and farming are the main sources of income. The seasonal idle homestead is obvious.	Villagers are the key actors in village governance. The core of governance is the intensive use of idle land such as rural corners and ponds, the planning of village boundaries, the restriction of disorderly expansion, the encouragement of villagers to withdraw more homesteads, and the use of corners to supplement village greening, infrastructure, and the development of the planting industry.	 Before  After
4	Weizhuang village	The south is adjacent to Tuhai River and the west is adjacent to Ruyi Lake Reservoir. The degree of hollowing is low, and it is a double-form compound hollow village. Villagers work outside and perform traditional agriculture for a living—there is extensive land use and the supporting facilities are not perfect.	The key actor of village governance is the government. The core is to use irrigation and transportation advantages to develop planting industry, establish cooperatives and planting bases and focus on all aspects of the village, tap the landscape potential, and develop ecological tourism.	 Before  After

Mode 1: Relocation and merger–urban–rural integration mode. Mode 2: Village integration–scale operation mode. Mode 3: Village intensive–idle land revitalization mode. Mode 4: Original site optimization–sightseeing tourism development mode. The data in the table are from interviews, questionnaires, and remote-sensing images.

4.2. Mechanism of Modes

The relocation and merger–urban–rural integration mode is one of the development modes of relocation and merger villages. This mode is people-oriented, uses policy support and village collective funds to relocate the village as a whole, re-plans the original site, and transfers rural surplus labor to the community. Through demolition compensation and housing subsidies, the government encourages villagers to voluntarily withdraw from the homestead, move into the new community with perfect supporting facilities, and reclaim and develop the homestead and the village leisure. The model is applicable to villages around the town, which are close to the town, have good transportation and an industrial base, have great governance potential and low governance cost, and can easily achieve urbanization.

4.2.1. Operating Mechanism of Relocation and Merger–Urban–Rural Integration Mode

(1) Construction of the actor–network: Fangsijie village is located around the town, with policy support to carry out new community construction. The operation mechanism of the actor–network construction process is as follows: taking the hollow village governance group composed of the Fangsi Town government and the village committees as the key actors, through top-down solicitation, the stakeholders are empowered to remove obstacles in action. ① Administrative recruitment. The government of Fangsi Town, together with surrounding villages, established a hollow village governance group, integrated multi-sectoral administrative resources, and joined the network of actors in the hollow village governance. ② Recruitment of housing and land. Set up a settlement area near the town center through the demolition compensation subsidies or housing subsidies to encourage the surrounding village's villagers to withdraw from the homestead voluntarily. This involves the homestead and village idle land's reclamation, taking land shares, joint development and the renovation of a joint stock system and other multiple utilization modes. ③ Recruitment of production and employment opportunities. Based on fine management, the main town is constantly building functional facilities to improve its carrying capacity and matching degree. Through the establishment of industrial zones and commercial logistics zones, the urban economy prospers, the commercial circulation and modern service industry are vigorously developed, the financing channels are innovated, the competition mechanism is properly introduced, and the investment of enterprises attracts a large number of employment opportunities for urban residents. ④ Recruitment of living environment renovation. Fangsi Town adheres to the core of "people's urbanization" and aims to build a new livable house temple. Fangsijie village has been successfully included in the central budget investment plan to support the infrastructure construction of affordable housing projects, and CNY 17 million has been invested in the central budget. A total of CNY 26.854 million has been invested to support infrastructure projects for community reconstruction, which meets the basic demolition and resettlement support needs of 1251 residents. At the same time, it improves public services such as medicine, health, and education in the community, expands public spaces such as squares, parks, and libraries, and improves residents' living suitability (Figure 6).

(2) The change of actors' role: with the further integration of urban and rural factors, the OPP of the actor–network has shifted from hollow village governance to accelerating the construction of new urbanization and promoting the development of suburban integration. In the network of hollow village governance actors in Fangsijie village, the hollow village governance group plays a leading role among key actors, placing the village collective as the main body in a passive position. After the gradual relocation of villagers to urban communities, the government delegates most of its leadership to village-level actors. In the new network of actors, the government's decision-making power gradually weakens instead of giving it the role of regulator and supervisor; the village's two committees together constitute the community property office and gradually grasp the decision-making power of space development, supporting facilities, etc., which has become a trend among key actors. For non-human actors, the implementation of this model interconnects the

original elements of each village with cities and towns, forming a long-term urban–rural coordination mechanism. ① Urban and rural spatial coordination. After the completion of the Fangsijie community, farmers can not only obtain employment in the city but also enjoy the living environment of urbanization. The operation and management of the community are integrated with the city to build a harmonious space for urban and rural integration. ② Urban and rural economic co-ordination. Relying on industrial and commercial logistics zones to promote the free and efficient flow of land, capital, talent, technology, management, information, and other production factors between urban and rural areas, forms a standardized circulation order and creates an environment for all kinds of economic subjects to obtain equal opportunities and have equal rights. ③ Urban and rural social pooling. The combination of urban employment and residence can increase employment opportunities for villagers, attract the transfer of the surrounding agricultural population, speed up the integration of urban and rural areas, and achieve equalization from social management and public service supply.

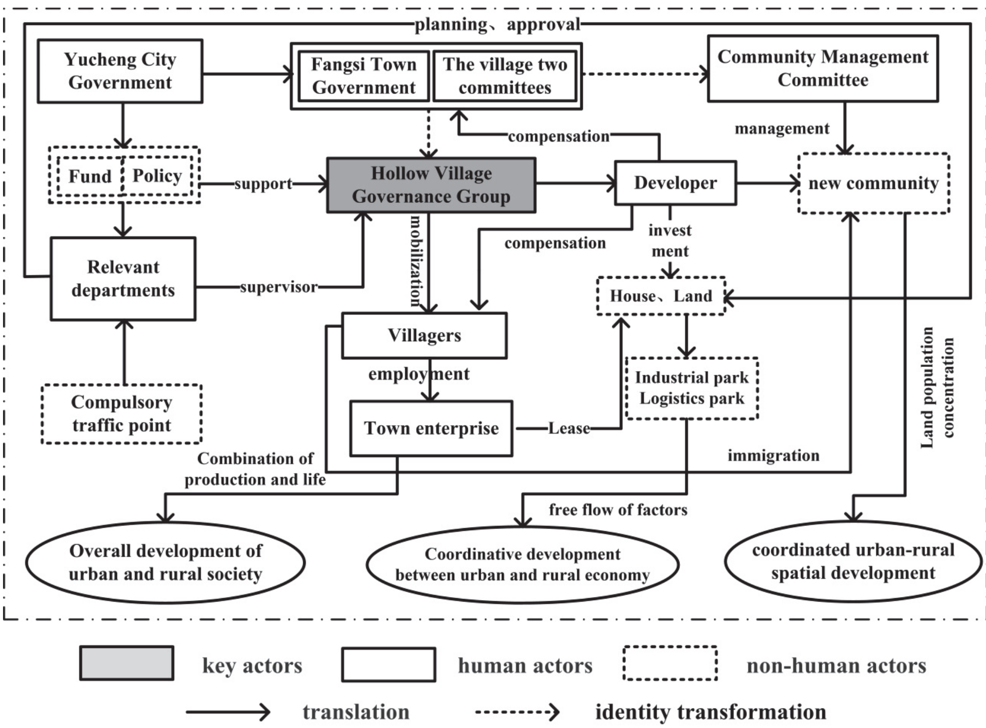

Figure 6. Action network of relocation and merger–urban–rural integration mode.

Under the top-down governance of the hollow village governance group, which is composed of the Fangsi Town government and the two committees of each village, the government formulates the governance scheme; the two committees of the village are then responsible for coordinating with farmers so that the various governance measures are carried out in a close and orderly manner. The village is based on the integration of urban and rural areas. The rural population is moved to the community near the center of the town, which promotes the integration of urban and rural populations. The population hollowing rate is reduced, the main structure of the village is improved, and the population density is increased. Moreover, under the radiation of urban enterprises, villagers have obtained a large number of jobs. While changing the traditional economic and occupational structure of the village, they also provide rich labor resources for urban enterprises. However, due to the lack of timely reclamation and utilization of abandoned homesteads and idle land in the process of village governance, and villagers moving into urban communities and staying away from cultivated land, village land resources are extensive. In addition, it is difficult for villagers to adapt to urban life in the short term after moving into urban buildings. In the process of governance, villagers have always played the role of executors, and it is difficult to effectively participate in the process of village governance. Although the public service of the new community is constantly upgrading and the entertainment life is constantly enriched, the sense of belonging and identity is still low.

4.2.2. Operating Mechanism of Village Integration–Scale Operation Mode

The village integration–scale management model is a hollow village governance model, which aims to promote agricultural production efficiency, gather adjacent villages, plan a collective community residence, and revitalize idle land, so as to integrate the village population and land and promote agricultural modernization and land intensification. Taking Xingdian village as the center and Fangsi Town government as the key actors, the governance and rural development transformation of hollow villages is carried out. The actor–network construction and role transformation of its operation mechanism are as follows:

(1) Construction of actor–network: taking Xingdian village as the center and gathering surrounding villages, the activist network appoints the Fangsi Town government as the key actor and relies on the existing administrative network to recruit other actors. ① Administrative recruitment. The town government grasps the key links, such as policy implementation and fundraising, and supervises village collectives to lead the villagers to relocate as a whole or in stages according to the situation in the village. ② Recruitment of house and land. In order to avoid the unfair evaluation of the rural vacated homestead, the village committee should hire a third-party company to evaluate the house price and formulate reasonable compensation and resettlement standards. Agricultural land consolidation companies and village collectives will comprehensively renovate vacated and abandoned homesteads, inefficient use of land, and idle land, and establish a mechanism for balancing the interests of arable land in the east and west of the province at a price of 170,000/mu. The city supplements the corresponding cultivated land quota for the southeast coastal cities. ③ Recruitment of agricultural transformation. With financial support from the government and the financial transfer of arable land reclamation provided by the eastern coastal cities to Yucheng, about 60 mu of land has been transferred to build community industrial parks and ecological experience parks, promote the transformation of traditional agriculture to modern agriculture, make full use of the village's labor force, and provide employment opportunities and increase residents' income (Figure 7).

(2) The change of actors' roles: after the initial completion of the Xingdian community, its development is facing a new transformation. The OPP of the actor–network has turned to promote agricultural production and efficiency, which has led to a change in the role of actors and the addition of new actors. For human actors, through village integration, originally scattered villages are gathered into resettlement areas. Under the guidance and supervision of the government, the "two committees" of the village assume the main responsibility for the transformation and development of the village. By coordinating the interest relationship between the investing enterprises, the villagers, and the village collective, the original independent economic status of each village will be broken, and a new community of interests will be formed. To a certain extent, this gives new actors an incentive to enter the network. For non-human actors, on the basis of large-scale operations, the goal of increasing agricultural production and farmers' incomes is to build a modern agricultural industry complex linked by factors, industries, and interests. ① Industrial chain. Xingdian community village collectively led the villagers to develop live pig breeding and greenhouse planting, dairy cattle and beef cattle breeding, and build a community industrial park and ecological experience through land transfer. The village

collective exerts its own functions, organizes and guides villagers to find employment in the park, actively cooperates with enterprises and attracts investment from them, expands publicity to attract consumers, builds the village brand, achieves an effective connection between agriculture and the secondary and tertiary industries, and forms a modernized agricultural industry chain. ② Element chain. Each business entity in the community industrial park establishes the buying and selling relationship of agricultural production materials and services by signing contracts, urges the close binding of business activities and continuously explores the establishment of a traceability system for the whole process of agricultural product origin, growth, production, and processing, forming a modern agricultural element chain. ③ Interest chain. Investing enterprises provide agricultural production materials to the industrial park and purchase agricultural products to solve the problem of shortage of funds. Villagers invest in labor to solve the problem of the labor shortage. The village collective coordinates agricultural professional enterprises to solve the problem of backward technology. Each subject exerts its respective advantages to ensure the rational operation of the industrial park, so as to obtain stable profits and form a chain of interests.

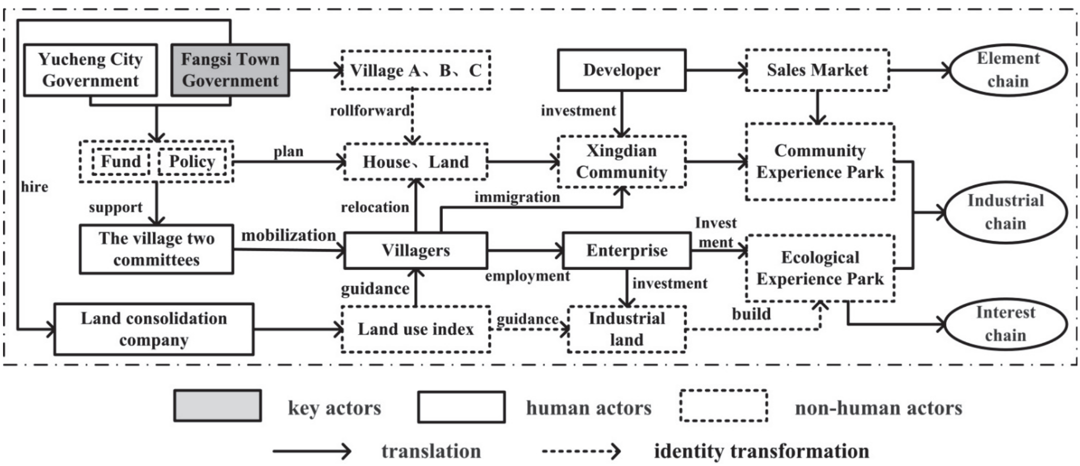

Figure 7. Action network of village integration–scale operation mode.

As a result of the translation of the network of actors, various actors promote the organic integration of new subjects, new industries, and new layouts in Xingdian village. With the support of policies, engineering construction and the participation of villagers, Xingdian village, based on village integration, gathers the originally scattered villages into the central village and conducts professional and comprehensive renovations of vacated land, homesteads, and idle land. Using the policy of linking increase and decrease to obtain financial funds, the village has realized the large-scale operation of the community, which not only effectively reduces the rate of homesteads, construction land, and abandoned cultivated land, but also builds an agricultural industry complex, changes the economic structure, and provides local employment for villagers. Large-scale management not only improves the efficiency of land use but also forms the industrial chain to enhance the collective economic benefits of the village. The increase in income is conducive to attracting the local population to return home for employment and the foreign population and enterprises to invest in suitable industries. Economic construction has also led to positive spiritual civilization and construction. Population, land, industry, organization, and culture form a positive interaction. The degree of hollowing out of the village is reduced and the transformation from a hollow village to a solid village is gradually realized. However, in village governance, it is difficult for farmers and village collectives to play a dominant role. On the one hand, in the early stages of village governance, village collectives and farmers are passive recipients of various measures. On the other hand, after the merger of villages, due to the increased community population, follow-up management and supporting facilities are not timely in place, the grassroots management is unstable, and the satisfaction of the masses is reduced to a certain extent.

4.2.3. Operating Mechanism of Village Intensive–Idle Land Revitalization Mode

The intensive and idle land revitalization mode in the village is a hollow village governance model that retains governance. That is, based on the original village site, through the repair of the original houses and infrastructure, the idle land is sorted out, and the integrated land is transferred to improve land-use efficiency and develop the collective economy. It applies to villages far from towns. With the support of the two committees and policies of the village, Zhengniu village carries out the hollow village governance action of idle land revitalization in the village intensive mode. The actor–network construction and role transformation are as follows:

(1) Construction of the network of actors: the network of actors under this mode recruits other actors with the two committees of Zhengniu village as key actors. ① Administrative recruitment. According to the various standards specified by the Yucheng City government and the Fangsi Town government, villagers are encouraged to participate in the integration of existing resources of the village and attract enterprises to join the actor–network by attracting investment. ② Recruitment of housing and land. Zhengniu village introduced construction companies through bidding to repair the houses in the village. The compensation standard of CNY 200 per house encourages villagers to withdraw from more homesteads and arrange 100 mu of idle land and formulate reasonable land transfer and reuse schemes. The land was registered for confirmation and contracted to villagers through cooperatives, and the villagers were encouraged to work independently. ③ Recruitment of industrial development. Zhengniu village, around the town's construction of the economic forest belt and high-quality line work deployment, made full use of the reclaimed land by planting 5000 persimmon and peach trees to create the 'Wanshiruyi Zhengniu village' brand. ④ Recruitment of environmental remediation. The village uses the special governance funds allocated to harden village roads, construct basic societal needs such as domestic garbage and sewage treatment equipment, configure public service facilities such as health and entertainment, and plant 3000 green seedlings such as cherry trees, crabapples, and holly to improve the natural environment and living environment of the village (Figure 8).

(2) The change of actors' roles: with the implementation and preliminary completion of the mode, the OPP of the actor–network turned to the development of farming and the construction of green villages. In the actor–network, the village collective, as the leader, cultivates the characteristic planting industry through the transformation of the old village. After the economic trees show benefits, the village collective and the villagers are distributed in proportion. For non-human actors, tomato planting is used as a means to establish an industrialization development model to build a green countryside. ① Product ecosphere. With villagers as the main body, the village takes the development of green agricultural product brands as the center, actively explores the management mode of 'village collective + farmers + market', gives full play to the role of village collective bridges, and links and vigorously promotes the unified purchase, planting, management, sales, and other 'four unified' planting modes to realize standardized planting. ② Village ecosphere. Through animal and plant production and microbial transformation, the balanced ecosystem can be restored, the small ecological cycle within the village area can be realized, the carrying capacity of the rural ecological environment can be improved, and the foundation for building ecological sightseeing agriculture in the future can be laid.

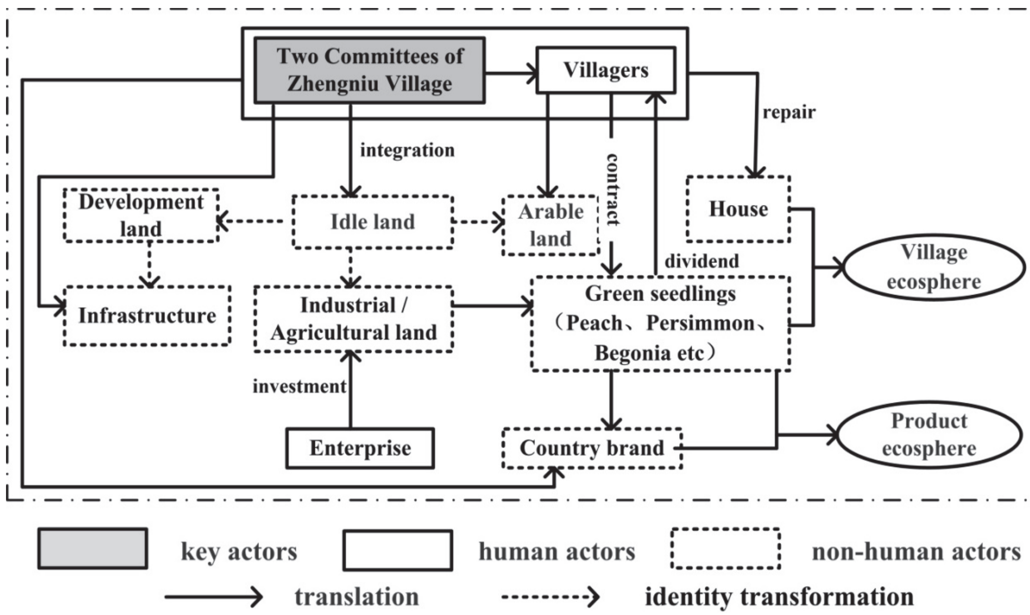

Figure 8. Action network of village intensive–idle land revitalization mode.

In order to retain governance within the village as the foundation, after finishing the homestead and village idle land, Zhengniu village was contracted to the villagers. Through the joint participation of the villagers, the abandoned homestead, idle construction land, and cultivated land in the village are effectively utilized; the main role of the village collective and the villagers' rural construction is also fully exerted and the endogenous power is actively exerted to promote the structural balance and quality improvement of the village population. At the same time, revitalizing idle land has improved land use efficiency, developed characteristic agriculture, and cultivated economic trees to improve industrial efficiency. This model also continues the village culture, repaired houses, and construction of an ecological livable governance system and cultural environment. The quality improvement and efficient utilization of land resources affect the scale of agricultural farming and the ecological environment, providing conditions for agricultural production and creating a livable living environment for villagers. The increase in production and efficiency, the improvement of the chain, and the optimization of the industrial structure have improved the level of collective economy and land value, attracting the return of the migrant population and external capital investment and helping to achieve rural revitalization. However, due to the village supporting infrastructure and public services still having room for improvement, the effect of attracting migrant workers to return home is general. At the same time, the lack of young talent in the construction of grassroots organizations also makes grassroots governance lax with a lack of innovation, and it is difficult to support the follow-up optimization operation of the industry, which severely strains the overall development of the village in the future.

4.2.4. Operating Mechanism of Original Site Optimization–Sightseeing Tourism Development Mode

The original site optimization–sightseeing tourism development mode seeks to fully tap the village landscape resources, carry out rural tourism, improve supporting facilities, support agriculture by tourism, optimize the income structure of villagers, attract the return of migrant workers, introduce enterprises and excellent talents, and inject new vitality into rural development. Relying on tourism endowments, Weizhuang village develops landscape resources and tourism villages. The network construction and role transformation of its operational mechanism actors are as follows:

(1) Construction of the actor–network: the network of actors under this mode takes local governments as key actors and recruits other actors from bottom to top. ① Administrative recruitment. Based on the preferential policies and financial support designated by Yucheng City, the Fangsi Town government actively joins relevant departments, including tourism departments and village collectives, as well as the network of actors, and undertakes corresponding responsibilities. ② Recruitment of housing and land. Integration of the construction land in the village; the villagers, according to their own wishes to repair the house, run the farmhouse, homestay and conduct other tourism services, and improve the beauty of the village while increasing income sources; there is also the large-scale management of land in the village, the introduction of high-yield varieties of pears, and the establishment of a planting base. ③ Recruitment of environmental remediation. Through discussion with the Weizhuang tourism management office, a comprehensive environmental improvement scheme was determined and the water quality, roads, and public places in the village were comprehensively developed. Roads were hardened, sewage treatment stations and squares were established, and public space was increased. ④ Recruitment of landscape resources. The environmental planning company is invited to redesign landscape resources such as village buildings, optimize the landscape layout, and develop the value of the human landscape. Through offline activities such as pear garden sketching, the media of the Yucheng newspaper, and the enthusiastic attention of the Yucheng Photographers Association, there is attraction in promoting the construction of rural brands. At the same time, entertainment, accommodation, catering, and other services are gradually improved to provide employment opportunities for returning people and villagers (Figure 9).

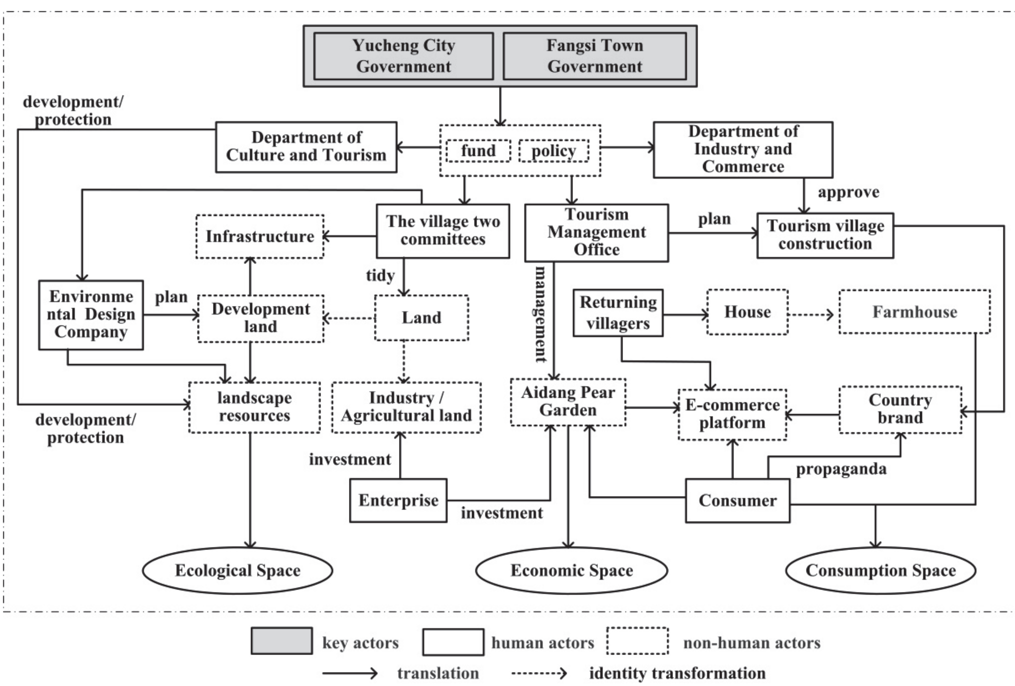

Figure 9. Action network of the original site optimization–sightseeing tourism development mode.

(2) The change of actors' roles: with the implementation and preliminary completion of this model, the actor–network OPP has transformed into the construction of tourism villages, and new actors have entered the actor–network of tourism village construction

under the influence of rural governance and operation concept renewal. For human actors, the government has become the supporter, followed by the original leader, giving preferential policies and publicity channels to rural areas. Low-level subjects such as tourism management offices and villagers, which were originally in a passive position, have gradually mastered the decision-making power of rural operations. The trend of rural development has attracted heterogeneous actors such as returnees and consumers to join the network. At the same time, due to the exclusion of the network itself, the old actors may withdraw from the network because of objections, such as some enterprises withdrawing from investment and a commodity exit from operations. For non-human actors, through the repair of the original houses in the village and the brand promotion of the Aidan pear garden, a cluster of ornamental consumer goods is formed. With the construction of tourism villages, the consumption space, which includes picking gardens, pear gardens, catering, and accommodation, is integrated into the characteristics of rural customs, which is endowed with more consumption characteristics.

Under the guidance of the key actors of the Yucheng City government and Fangsi Town government, the governance of the Weizhuang hollow village is based on the development of tourism, making full use of the internal landscape resources and cultural resources of the village, giving full play to the charm of rural traditional culture in order to attract tourists and enterprises, and making comprehensive use of the village land to take large-scale operations, so as to improve the efficiency of village land use, adjust the economic structure of the village, and greatly promote the diversified development of the village industry. Enterprises, as the main force in the construction of tourism villages, run through the investment, construction, and operation of villages, while villagers have the dual identity of participants and operators. They have more discourse power in the process of village governance and provide suggestions for the development of villages according to their own business conditions. Participation is high, which greatly increases the recognition and satisfaction of the masses with village governance, so as to extend the improvement of villagers' identity, sense of belonging, and satisfaction with rural culture. However, the development of tourism in the village lacks innovation and the lack of talent and villagers' professional knowledge makes it difficult to participate in the decision-making of village development. Farmers' self-management makes the role of village collectives in the distribution of decision-making interests weak; grass-roots organizations copy the experience of the construction of tourism villages with a lack of characteristics, coupled with the complex elements involved in tourism villages; it is difficult to achieve the expectations of village collective governance capacity in a short time, resulting in defects in the village tourism environment and services.

4.3. Policy Implications

Through the above analysis of the construction process and operation mechanism of the network of actors in different governance modes of hollow villages, we find that the governance of hollow villages does not refer to single governance on a certain aspect, but a comprehensive project with a comprehensive nature, which is continuously promoted in the interaction between the governance subject and the governance object. The supply of natural resources and village location conditions are important factors affecting the development direction of the village. The diversity and complexity of governance make it necessary to consume more material resources and time, which requires policymakers and key actors to comprehensively consider the existing resources and conditions of the village and the problems faced in the process of village governance when making governance decisions.

(1) In terms of governance objects, governments should first improve the financial system of village governance to meet their long-term capital needs. On the one hand, villages should be clear about the use of special funds approved by the state finance for the governance of hollow villages, establish a strong supervision mechanism for the use of the funds and record and disclose the funds needed by all parties involved in the

governance of hollow villages, so as to fundamentally eliminate their misuse. At the same time, the governance subjects should actively carry out market-oriented operations, encourage multi-party forces to participate in investment, continuously strengthen the construction of the village's collective economy, expand the rural business market, fully tap the rural resources and potential resources, and accumulate, restructure, and operate the assets of hollow villages, so as to obtain benefits, realize the self-accumulation and self-development of villages, and provide strong support for the development of hollow villages. Secondly, it is necessary to establish a long-term security and management mechanism, carry out long-term management and protection for the development of hollow villages, and formulate rules, regulations, and supervision systems for environmental protection and public facilities maintenance so as to protect the improvement of the production and living environment of the village and strengthen the operation mechanism of labor security, especially the problem of land loss and unemployment of some villagers in the relocation and merger management mode. The government should strengthen employment training for villagers so that they can find their own employment. Finally, it is important to pay attention to the construction of the rural public cultural service system. In the process of hollow village governance, it is necessary to clarify whether the improvement of material life or the enrichment of spiritual life is an indispensable part of hollow village governance. It is necessary to pay attention to the development of the economy and not neglect the construction of culture. The main body involved in the governance of hollow villages should clarify the rich connotation of rural culture. On the one hand, it includes landscape resources, spatial texture, village buildings, production tools, and other material aspects of culture, but also includes folk customs, traditional crafts and arts, and village regulations and conventions, especially values, moral values, and simple rural customs. On the other hand, it is necessary to innovate new ideas of cultural construction and reshape rural public cultural service projects and public cultural service spaces by means of digitalization and networking, especially for the relocation of merged villages. It is necessary to enrich the cultural atmosphere of villages through cloud libraries, online cultural lectures, and other information technologies, and improve villagers' sense of belonging and identity.

(2) In terms of governance subjects, first of all, villagers are the owners and participants of the governance results of the hollow village. Therefore, in the governance of the hollow village, governments should adhere to a people-oriented principle. Whether it is the village merger or village planning, it should respect the wishes of farmers, effectively protect their vital interests, and give them enough time to understand the relevant policies and regulations and respect their choices in line with their own interests. In addition, encouraging migrant farmers to return home and start a business is an important way to give full play to the dominant position of villagers in the governance of hollow villages. Encouraging them to participate in the governance of hollow villages can enhance villagers' recognition. In terms of governance methods, the government should choose the way that is suitable for the current situation of the village, try to achieve democratization and diversification, highlight the main feelings of the masses in participating in the governance of hollow villages, and expand the main force of rural governance. Secondly, governments should improve the governance level of village cadres, strengthen the construction of the talent team in rural grassroots organizations, broaden the way of selecting village officials, and encourage college students and migrant workers with abilities and good management to join the village cadres. Innovation of grassroots governance, through the Internet and other technical means to open rural affairs, takes initiative to accept the supervision of villagers and large numbers of migrant workers; it is difficult to participate in village-level activities and villagers' meetings in a timely manner so that villagers have a convenient understanding of grassroots governance and their sense of identity and trust in grassroots organizations is enhanced. Finally, according to the actor–network theory, the government, villagers, enterprises, and other social forces should play their own advantages in accordance with the law and communicate, coordinate, and cooperate with each other in order to achieve the goal of hollow village governance, which requires a

variety of ways to stimulate the initiative of the governance subject and give full play to the resultant force between the various subjects. In the process of governance, governments should pay full attention to the interests of all parties, minimize the damage to interests as much as possible, and fully mobilize the initiative of multiple governance subjects. In particular, villages should use multiple methods, such as introducing preferential policies and reducing loan interest rates, to encourage enterprises to play an economic leading role in rural construction. Governments should use enterprise projects to expand industries and improve villagers' incomes by providing jobs, village-enterprise cooperation, and land transfer. At the same time, governments can learn from the combination of urban management and methods with the development path of hollow villages, so that enterprises can promote their governance while simultaneously ensuring their economic benefits and enhancing the motivation of enterprises to participate in investment and governance.

5. Discussion

5.1. Hollow Village Governance Mechanism

Hollow villages exist in the complex rural internal and external environment and socio-economic network. The governance of hollow villages is rooted in the constraint framework of behavioral objects such as rural internal space, economy, and society, and embodies the game, competition, and cooperation relations among stakeholders such as the government, enterprises, and village collectives.

In terms of governance object, the economic, spatial, and social subsystems in the village's internal system constitute the behavior object of hollow village governance. The interaction of each subsystem and its elements shapes the single-dimensional and multi-dimensional appearance and morphological characteristics of the hollow village and exerts an important influence on the governance mode, operation mode, and actor input of hollow village governance. The formation process of hollow villages is a phased process in which low-quality solid villages finally form hollow villages. The formation of hollow villages can be seen as the current conditions and development level of villages that find it difficult to meet the needs of farmers for living conditions and quality. Farmers leave the village to seek a better life, or the material and spiritual needs that can be provided within the village continue to decrease, leading to the decline of the village. According to the influencing factors on the formation of hollow village force direction, it is divided into a core driving force and a foreign aid pulling force. On the one hand, in the core system of rural areas, the changes in agricultural production development, social and cultural changes, public service facilities, road construction, and the diversified transformation of farmers' livelihoods affect the adjustment and change of the rural economy, space, and ecology, and play a fundamental and endogenous role in promoting the evolution and development of rural hollowing. In particular, due to factors such as regional position and the natural conditions of some rural areas, the poor conditions and economic benefits are low. Under the influence of factors such as the lack of employment opportunities, low income levels, and low quality of education, farmers will have the psychological orientation of separating from rural areas and integrating into urban and non-agricultural industries. On the other hand, during the accelerated development of industrialization and urbanization, the pulling force of the rural foreign aid system is the dominant driving force for the formation of hollow villages. The main performance is industrialization, and the urbanization process of the modern agricultural industry is to replace agricultural labor and land investment; the attraction of urban rich jobs provides a driving force for the transfer of the rural population, as well as to meet the farmers' access to quality education, public service resources, and improve the quality of life needs, fundamentally making the rural population hollow. The reform and innovation of the land-use system have brought about a change in land management mode and an increase in farmers' income, and the lag of land management policy, social and cultural changes, and inheritance have jointly promoted the hollowization of rural land. In addition, the urban bias of the national policy system and the allocation of funds have long ignored the development of rural areas, blocked the flow of urban and rural factors and the lack of physical, human, and technical capital to promote rural development, resulting in insufficient internal development momentum in rural areas, weak governance capacity, backward cultural technology, a short industrial chain, and low added value; as a consequence, rural industry, organization, and culture hollow out. At the same time, in the process of the evolution of the rural regional system, the whole rural system will deviate from the evolution track if it encounters unexpected or unpredictable events or phenomena, such as floods, geological and other natural disasters, or major project construction, major pollution, and other human events, which is manifested as the rapid development of village hollowing or from hollowing to solidifying.

In terms of the main body of village governance, areas with a high level of non-agriculturalization or rich resource endowments have strong demand for construction land, relatively open ideas of farmers and a strong driving force for the implementation of hollow village governance. In regions with a low level of non-agriculturalization, there is a single industrial type; the income source of farmers is mainly agriculture, farmers are highly dependent on land and the driving force of hollow village governance is insufficient. In addition, the comprehensive effects of village location conditions, development orientation, information level, and other factors also affect the choice of the hollow village governance mode, such as convenient transportation, small and agglomeration villages, large idle land areas, and agriculture-based industrial structure villages. It is suitable to adopt an integrated village model to realize the integration of the population and residents through the relocation of scattered villages and the construction of new communities. Located in the urban fringe area or around the central town, the livelihood of farmers is mainly reliant on the villages that work outside. It is suitable to adopt the urbanization-led model, and the focus of governance is to solve the matching problem between employment and housing in rural towns. At the same time, the internal and external environments of the village have a great influence on the operation mode of the governance organization of the hollow village. For example, the villages around the town or with a high non-agricultural output value will obtain higher economic benefits through rural governance. The enthusiasm of enterprises to participate in governance is high, and multiple financing mechanisms and organizational operation modes are formed. The hollow villages with a single industry, which are far away from the central town, are dominated by the government and the village committees. Hollow village governance involves local government and relevant departments, developers, construction or investment enterprises, villagers' committees, farmers, and other stakeholders. Each group has different goals and interests and forms a hollow village governance action subject system through communication and coordination. The power operation of the government, the capital operation and development behavior of enterprises, the coordination behavior of the two committees of the village, the individual willingness of farmers, and the game and cooperation among various stakeholders jointly affect the governance mode of hollow villages and promote the change of land and space of hollow villages.

To sum up, the external environment derived from urban and rural development in the process of urbanization, such as technological progress, policy change systems, and development planning and positioning, provides the necessity and possibility for the governance of hollow villages. At the same time, the internal population–land–industry–organization–culture and other morphological representations of hollow villages provide the basis for their classified governance. Hollow village governance refers to the process of intervention and adjustment of the behavior object based on the planning and design, financing, organization, and implementation of the governance model after the comprehensive evaluation of the internal and external environment of the village by the behavior subject, so as to achieve the goal of rural industry prosperity, affluent life, ecological livability, rural civilization, and effective governance (Figure 10).

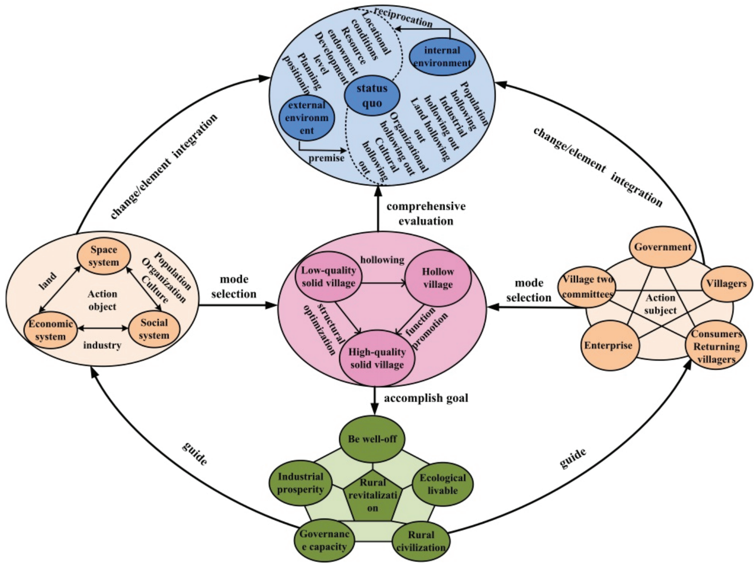

Figure 10. Governance mechanism of a hollow village based on action network.

5.2. Different Hollow Village Governance Mode Applicable Conditions

According to 'relocation and merger' and 'retention of the original site', which are two categories of hollow village governance based on the four types of suburban integration, relocation and merger, agglomeration promotion, and characteristic protection village classification and development, we selected Fangsi Town village (suburban integration type), Xingdian village (relocation and merger type), Zhengniu village (agglomeration promotion type) and Weizhuang village (characteristic protection type) as typical hollow village governance cases in plain agricultural areas, and explored the governance mechanisms of different modes on the basis of the actor–network theory. We found that, due to the different supply conditions and economic development needs of villages, there are differences in the spatial characteristics, driving mechanisms, development goals, and suitable locations of different governance categories and different development types of hollow villages under the same category, which have certain applicable conditions (Table 3).

Table 3. Applicable conditions of different hollow village governance modes.

Mode	Spatial Features	Drive Mechanism	Target	Key Actors	Operating Features	Appropriate Types
1	Relocation and withdrawal	Foreign aid	Suburban integration and overall development	Town Government and Village Committees	Interest coordination among multiple subjects	Villagers are less dependent on agricultural income in suburban towns
2	Relocation and withdrawal	Foreign aid	Residential concentration, land concentration, large-scale operation	Town government	High administrative dependence and industrial chain construction mechanism	Far from town, village gathering high, production and living layout chaos
3	Original site reservation	Inside core	Improving land use efficiency and developing collective economy	The village two committees	Flexible forms, strong participation of villagers	Production and living function foundation is good, villagers to agricultural income dependence degree is high
4	Original site reservation	Inside core	Building rural brand by traveling agriculture	Local and town governments	High dependence on enterprises and strong consumption characteristics	Good tourism resources and convenient transportation

Mode 1: Relocation and merger–urban–rural integration mode. Mode 2: Village integration–scale operation mode. Mode 3: Village intensive–idle land revitalization model. Mode 4: Original site optimization–sightseeing tourism development mode.

Specifically, in different types of modes, in terms of spatial characteristics, the 'relocation and merger' type of hollow village governance mode is usually intended to renovate several adjacent hollow villages; the key actors mobilize and recruit the villagers, and the villagers exit the homestead in an orderly way and move into the centralized resettlement area. Human actors reclaim the homestead and idle land in the village and adopt a variety of methods, such as land equity or farmland balance, to centralize the planning and utilization of reclaimed land, so as to achieve population and land centralization. However, the "retention of the original site" model in relation to hollow villages refers to managing the village on its original site. Through housing, environmental remediation, and other projects, the living environment of the village is improved. Relying on the natural endowment of the village, the idle land is revitalized and landscape resources are developed to realize the characteristic agricultural production or ecological sightseeing agriculture. In the driving mechanism, under the 'relocation and merger' type of hollow village governance mode, villagers are mainly guided by the policy; they are moved to the centralized resettlement area under the government policy, the land is transferred, and the former detainees and some migrant workers become employees of the enterprises and the social security and infrastructure construction rely on the government policy, which is the hollow village governance mode under the influence of foreign aid. However, under the 'retention of the original site' mode, the improvement of farmers' living standards is in great contrast with the current living conditions and living environment expectations, and the inherent willingness of farmers to renovate is strong, but it is difficult to rely solely on the strength of farmers themselves. Support from government policies and funds is needed to improve village conditions or develop village-specific resources, so 'address retention' is a 'village self-renewal' method driven by the internal core.

In the same category as the hollow village governance mode, other mode types are also different. In the governance model of "relocation and merger," the key actors of the relocation and merger–urban and rural integration model are the Fangsi Town government and the two committees of each village. Each village organizes housing and land, and the villagers move into the community, supporting a series of housing security policies, establishing industrial zones and commercial and trade logistics zones, providing jobs, and promoting suburban integration. Its goal is to achieve urban and rural spatial integration, social integration and economic integration, realize the construction of new urbanization, and promote the development of suburban integration. This is suitable for villages close to cities and less dependent on agricultural income. The key actor of the village integration–scale operation model is the Fangsi Town government. Xingdian village merges and integrates with the nearby villages, takes off homesteads, reclaims land, comprehensively renovates inefficient land use and idle land, and builds modern community industrial parks and ecological experience parks. Its goal is to achieve residential centralization and land centralization, realize scale operations, and promote agricultural production efficiency. It is suitable for villages far away from towns with a high village aggregation, high rate of idle land, and a chaotic layout of village construction and agricultural production. In the 'retention governance' mode, the key actors of the intensive and idle land revitalization mode in the village are the two 'village committees' of Zhengniu village. Through housing and environmental renovation projects, Zhengniu village withdraws from multiple homesteads, carries out land circulation and idle land revitalization, and develops characteristic agricultural planting. Its goal is to improve land-use efficiency, develop the collective economy and improve villagers' income. This is suitable for villages with good production and living functions and a high farmers' dependence on agricultural income. The governance mode can be replicated. The key actors of the site optimization–sightseeing tourism development model are the Yucheng City government and the Fangsi Town government. Relying on tourism resources endowment, Weizhuang simultaneously develops and protects, builds tourism villages, landscape construction, agritainment business management, and characteristic fruit tree planting. Its goal is to support agriculture through tourism, so as to attract the return of the village population and foreign population, manifest ecological value, and build characteristic rural brands. It is suitable for villages with distinctive landscape tourism resources or rich historical and cultural resources.

5.3. Insufficient Research and Prospects

To study the governance mode of hollow villages from the perspective of the actor–network, the subject and the object are actors with the same status. They form a close interactive network and jointly deduce the governance mode of hollow villages. However, due to the limitation of research scale and information availability, this study only analyzes the governance mode of typical hollow villages in China’s plain agricultural areas, and the understanding of the complex morphology of hollow villages needs to be deepened. Moreover, the governance mode of typical hollow villages may not be applicable to villages that are biased towards mountains or with complex topography and geology. In addition, in the context of rural revitalization, the governance of hollow villages should follow the path of development according to local conditions. Therefore, the governance mode of hollow villages such as Taobao Village, Logistics Village, and Industrial Village should be further studied.

In future research, we will describe the spatial pattern of rural hollowing according to the manifestations and types of hollow villages in different geographical environments, and systematically analyze the governance mode of typical hollow villages in the region from the perspective of regional differences, revealing the integrated operation mechanism of hollow village governance and rural revitalization, and forming “appearance–form–type–pattern–mode–mechanism”, which is a complete research system of hollow village governance mechanism under the guidance of rural revitalization.

6. Conclusions

Based on differences in the natural environment, social and economic development, and village governance modes of administrative villages, this study selected four case villages in Yucheng City, Shandong Province, namely, Fangsijie village, Xingdian village, Zhengniu village, and Weizhuang village. Based on the actor–network theory, this study analyzes the operation process and effect of typical governance modes, compares different hollow village governance modes, reveals their mechanisms from the perspective of governance subject and governance object, and puts forward targeted suggestions for the problems existing in the process of hollow village governance from the perspective of governance subject and governance object. The main conclusions are as follows:

(1) In the case of the hollow village governance model, Fangsijie village adopts the relocation and merger–urban–rural integration mode with the hollow village governance group as the key actor, and the core is concentrated on relocation to urban communities to solve the matching problem of non-agricultural employment and living space of farmers, and to realize the urbanization of living and employment; Xingdian village takes the Fangsi Town government as the key actor of the village integration–scale operation mode and the core realization of large-scale management, centralized living, agricultural modernization and intensive land, and the centralized construction of a large-scale community agricultural park; Zhengniu village adopts the village intensive–idle land revitalization mode with the two committees of the village as the key actors, focusing on the intensive utilization of rural idle land and the development of the planting industry; Weizhuang village adopts the original site optimization–sightseeing tourism development mode with the Fangsi Town government as the key actor. The core aim is to use irrigation and transportation advantages to develop the planting industry, tap resource potential and landscape value and develop ecological tourism. Four cases of hollow village governance have achieved good results; the governance work carried out is orderly, but there are also some problems to be improved.

(2) The hollow village governance mode based on the actor–network theory includes five aspects: key actors, governance subject, governance object, transfer, and identity transformation. In essence, the process of hollow village governance can be regarded as an actor–network space, which is dominated by key actors and promoted by various networks. In the process of governance, the organization mode and action mechanism of the governance subject act on the governance object and the network of actors is dynamically adjusted, which is manifested as the influence of the entry, exit, and role change of heterogeneous actors on the network relationship; this leads to the transformation of rural production and living space and realizes the transformation from hollow village to solid village. At the same time, due to differences in natural resource endowment, development degree, and development goals, as well as the influencing factors and governance requirements of the formation process of hollow villages, there are differences in the governance mode and operation process of hollow villages with different governance types and different development types under the same category. Relocation and merger–urban–rural integration mode applies to suburban villages with low dependence on agricultural income; village integration–scale operation mode is applicable to villages far from town, high village aggregation, production, and living layout confusion; village intensive–idle land revitalization mode is suitable for villages with good production and living functions and high dependence on agricultural income; the original site optimization–sightseeing tourism development mode is suitable for the villages with excellent tourism resources and convenient transportation. Within the general scope of towns in plain agricultural areas of China, the natural and geographical conditions of the same type of villages are basically the same. The favorable conditions derived from urban and rural development in the process of urbanization provide the necessity and possibility for the governance of hollow villages. The morphological representation of the governance object of hollow villages provides the basis for their classified governance. The four governance models provide experience for the precise governance of similar hollow villages in plain agricultural areas of China and the governance mechanism of hollow villages revealed in this study can be used for reference. This provides practical governance ideas for policymakers and key actors when making governance decisions.

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Article

Discerning Spatiotemporal Patterns and Policy Drivers of Rural Settlement Changes from 1962 to 2020

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Abstract: Despite two centuries of urbanisation worldwide, 45% of the world's people still live in rural areas. Driven by urban development, the form and structure of rural settlements have undergone drastic changes. Reasonable planning according to the scale of the land and spatial layout of rural settlements is particularly important for the development of rural areas. The continuous development of the economy means that the housing needs of farmers and the macro policy background will inevitably change. We create a relationship curve for the "policy-scale of rural settlements" in different periods according to the laws of Maslow's psychological demand theory and game theory and conduct an empirical study on Dingzhou City, China. The limited availability of remote sensing data means it is difficult to map the evolution patterns of rural settlements on medium and long time scales, and therefore, this paper explores and decrypts military satellite images, reveals the spatial evolution characteristics of rural settlements in Dingzhou, China from 1962 to 2020, and discusses the impact of policy factors on changes to rural settlements in different periods. The study found that from 1962 to 2020, the total area of rural settlements in Dingzhou showed a trend of continual increase, with a total increase of 8354.97 ha (73%). The average annual growth rates in 1962–1972, 1972–1990, 1990–2000, 2000–2010, and 2010–2020 were 0.29%, 1.17%, 1.81%, 1.26%, and 0.05%, respectively. The growth rate of rural settlements was relatively slow from 1962 to 1972. The policy was mainly because rural homesteads (land for building rural residences) were transformed from private ownership to "one homestead, two systems", and the expansion of rural settlements was inhibited. From 1972 to 1990, with the deepening of reform and opening up, there was a boom in building houses in rural areas, and the growth rate of rural settlements increased. From 1990 to 2000, although the state strengthened the management of rural settlement use, there was still an increasing trend in the area of rural settlements; from 2000 to 2020 the implementation of policies such as "one house for one household" and "connecting increase and decrease" meant that the growth rate of rural settlements slowed.

Keywords: land use change; rural settlements; spatial pattern evolution; land policy; China

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1. Introduction

Despite a prolonged period of urbanisation and industrialisation globally, 45% of the world's people still live in rural areas [1,2]. In order to promote the reasonable development of rural areas, countries around the world try to take different measures to guide the spatial layout of rural settlements [3]. Some European countries have introduced policies such as "multi-functional agriculture" to adjust the rural layout structure so as to achieve balanced development between urban and rural areas; some Asian countries have implemented the "New Village Movement" to alleviate social conflicts and promote the development of rural areas [4–6]; However, whether in a developed or developing country, policy implementation may not necessarily achieve the expected goals [7], and the loopholes in the policy may also lead to unbalanced development in rural areas [8,9]. For instance, some countries in South America have experienced "false urbanisation" (referring to the phenomenon of the rural population's excessive migration to cities, urbanisation that exceeds the national economic development capacity), resulting in an excessive influx of the rural population into cities, and a large number of rural settlements have been abandoned. The formation of huge "slums" has caused a series of social problems [10]. This experience shows that grasping the changing laws of rural settlements is not only conducive to the rational use of rural land in a region, but also helps to promote the coordinated development of urban and rural areas [11].

How do we correctly grasp the law of changes in rural settlements and guide their rational layout and development? First, we use remote sensing images to understand the distribution of rural settlements. For example, we found through imagery that rural settlements in the Mayo region of Yukon, Canada, are distributed along the river; the farmland in the Wilson area of Kansas in the western United States is distributed in rectangular blocks, and rural settlements are scattered around the farmland; the farmland in China's Guanzhong region surrounds rural settlements. Secondly, governments should formulate corresponding policies on rural settlements according to their own national conditions and regulate the layout of rural settlements with policies. Belgium realizes rural revitalization through organic integration of land planning and rural improvement; and the British government has focused on building central villages, thereby promoting the agglomeration of rural population to central villages. Israel has explored the hierarchical service centre model, which allows the size of rural settlements to adjust to changes in agricultural production methods. In China, there is an urgent need to adjust the layout of rural settlements.

In 2020, there were still 510 million people living in rural areas in China, accounting for 36.11% of the country's total population [12]. According to China's third land survey, the rural residential land area was 21.9356 million hectares, accounting for 62.13% of urban villages and industrial and mining land [13]. China's rural population accounts for 36.11% of the country's total population, but it occupies 62.13% of the country's construction land. In the context of new urbanisation, adjusting the layout of rural settlements is therefore still the top priority. In recent years, with the rapid development of the social economy and the promotion of related policies, the barriers to mobility among the rural population have been gradually broken down, leading to major changes in the pattern of rural settlements [14,15]. In order to cope with these changes, it is necessary to analyse the historical evolution law of rural settlements in depth and then guide their rational layout and development according to the law [16].

Accurate spatial data is the basis for studying the evolution of patterns in rural settlements. Compared with urban land use, rural settlements are smaller and relatively scattered. They are therefore less described in most existing land use maps, and there is no rural settlement type [17] in many global land use maps. For example, the land use survey classification system proposed by the US Geological Survey is divided into nine categories: urban or construction land, agricultural land, grazing land, woodland, waters, wetlands, wasteland, permafrost, and tundra. Some early studies used Landsat to extract rural settlements. The researchers combined terrestrial satellite data with public auxiliary geospatial data and used geospatial data fusion to map rural residential sites in remote areas [18]. Some researchers also used the global urban footprint (GUF) to obtain the rural training samples and used the spectral–texture–time information from the Landsat and Sentinel time series to map the rural residential population [17]. In recent years, many scholars have used SPOT, QuickBird, and other high-resolution images to extract clearer rural settlement data [3,19,20]. In order to extend the time scale of rural residential data acquisition, some scholars have used topographic maps to obtain long-term rural settlement data, but these maps provide less rural settlement information, and the shooting range is limited, so it is difficult to achieve full regional coverage [21]. There are thus still great challenges facing research into the pattern evolution of rural settlements on the medium and long time scales.

The spatial evolution pattern of rural settlements in different areas often suggests different laws. In short time scales, the size of a rural residential area usually shows a linear trend. For example, from 2009 to 2014, the area of rural settlements in Changchun City showed a decreasing trend [11]; from 2006 to 2015, the Kangbashi New Area in Inner Mongolia had significant spatial expansion characteristics [22]; from 2000 to 2018, the scale of residential settlements in Pudong, Shanghai decreased significantly, showing a decreasing trend from the urban-rural fringe to the outer suburbs [3]; and from 1990 to 2015, the kernel density of rural settlements in Hubei Province decreased, and there were obvious regional differences [13]. The evolution of rural settlement size is also different in the medium and long time scales due to differences in the development scenarios in different regions. For example, some scholars have used historical data left by social anthropologists to analyse the evolution of rural settlements in Xin He Village, China, from 1949 to the present and found that their changes involved a process from stagnation to disorderly expansion to orderly construction [23]. Some scholars have studied the changes in rural settlements in Belarus from 1959 to 2009. Their analysis found that changes in population during different periods affected changes in the number of rural settlements. For example, intensive migration outflow was accompanied by the disappearance of a large number of rural settlements. Some scholars have studied changes to rural settlements in different areas at the same time node. Their results showed that the number of rural settlements in some areas has declined continuously in the past 50 years, while the trend of change in rural settlements in other areas is to decrease first and then increase [24,25]. The above studies show that changes in the spatial pattern of rural settlements are usually relatively simple on short time scales, while the change trends on medium- and long-term scales are often diverse. It is therefore of profound significance to study the evolution of spatial patterns in rural settlements on a long time scale to grasp the rural development in this area.

There is a close connection between the evolution pattern of rural settlements and policy reform [26], and rural policy profoundly affects changes to rural settlements [27,28]. In the second half of the 20th century, with the acceleration of globalisation and urbanisation, many countries issued policies to plan the development of rural settlements [7]. The policies of developed countries mainly focused on the centralised layout of rural settlements, the construction of infrastructure, and other aspects of the rationalisation arrangement [29]. For example, the Japanese village-building movement is characterised by excavating local resources, respecting local characteristics, and using rural resources to develop and promote rural construction. In view of the lack of rural infrastructure and other problems, the UK proposed a village revitalisation pattern focusing on the construction of central villages, and the government formulated a series of policies to promote the concentration of rural settlements in the key development areas designated by the government. In rural France and rural Brazil, agricultural modernisation policies have also caused changes in the local settlement pattern [10]. In the 1980s, residential concentration policies were implemented almost throughout Central and Eastern Europe (such as Hungary and Poland) to promote the centralised development of rural settlements [30]. Developing countries have also promulgated various policies to guide the development of rural settlements. For example, Egypt has issued policies since 1996 to encourage people to settle in the arid regions of the eastern and western desert plateaus and to avoid building new buildings in the floodplain of the Nile River [31]; China implements macropolicies such as "new rural construction" and "new urbanisation" to coordinate urban and rural development and solve problems caused by the layout of some rural settlements [32,33].

In our research, we found that some scholars used topographic maps, text data, and so on to study the changes in the scale of early rural settlements, and the scale of rural settlements showed two trends: expansion and shrinkage. For example, from the 1960s to the 1980s, the number of rural settlements in the Tongzhou District of Beijing decreased from 417 to 365, and the number of rural settlements in the Jizhou District decreased from 660 to 497 [24,25]. Ownership has greatly hindered the production of farmers, and the construction of rural settlements in Xinhe Village has stalled [23]. Rural settlements in the Jinzhong Plain of Shanxi Province have been expanding since 1979 [34].

We found that land institutional change will affect land use change. Identifying policy as one of the main drivers of land-use change and agricultural development, Teka et al. assessed land-use change in northern Ethiopia since the 1960s and found that the land policies of imperial and communist regimes largely promoted arable land. The increase in vegetative land decreases, while in the EPRDF regime, the situation is reversed [35]. Spalding et al. describe the evolution of land tenure in Panama in terms of development process and land policy in Latin America, arguing that land use policy affects land use change at the local level [36]. Munteanu et al. integrated historical maps and satellite imagery of the Carpathians region to assess the impact of nineteenth century agricultural land choices on agricultural development today. They concluded that changes in political systems can affect future land use choices [37]. Wang Juan et al. analysed the dynamics of land policy and land use change in China based on land use data. They found that land use change in China is closely related to changes in government land policy and socioeconomic development [38].

From the current point of view, China's successively implemented rural settlement policies have changed significantly over the past 60 years, and homesteads have undergone a transition from private ownership to public ownership. This paper aims to solve the following two questions: (1) Changes in the scale of rural settlements are not clear in the period before remote sensing data, so is the scale of rural settlements expanding or shrinking? (2) The homestead has undergone a transition from private ownership to public ownership, and this change is decisive, so when did changes in the scale of rural settlements become more drastic?

Changes in the pattern of rural settlements have obvious period characteristics. The analysis and study of the evolutionary characteristics of rural settlements on a medium and long time scales can provide an effective basis for the scientific and reasonable planning of rural settlements. Previous researchers have mostly analysed changes in rural settlement patterns under the influence of driving factors such as terrain, water sources, traffic, altitude, and human activities [39]. There is currently less work on systematically assessing the impact of rural settlement policies in the medium and long-term scales. We have studied changes to rural settlements in some developed and developing countries and found that there is indeed a close connection between the evolutionary pattern of rural settlements and policy reform. Based on the decryption of military satellite images, this study reveals the spatial evolution characteristics of rural settlements in Dingzhou, China from 1962 to 2020 and explores the impact of policies on rural settlements and changes in different periods. The specific purpose of this study was as follows: (1) obtain medium- and long-term historical data for rural settlements in Dingzhou City, China by decrypting military satellite remote sensing images; (2) uncover the spatial evolution characteristics of rural settlements in Dingzhou City from 1962 to 2020; (3) analyse the effect of rural settlement policies on changes in rural settlements patterns in different periods and summarise the evolutionary characteristics of the different stages of rural settlement spatial patterns.

2. Overview of Study Area and Data Sources

2.1. Overview of Study Area

Dingzhou is a county-level city (A county-level city is one of the administrative divisions in China, with the same administrative status as municipal districts, counties, and autonomous counties.) directly under the Central Government of Hebei Province, China. It is located between 38°14′ N–38°40′ N and 114°48′ E–115°15′ E (Figure 1). In 2018, Dingzhou City had jurisdiction over 25 towns (streets) and 542 villages (communities), covering an area of 1283 square kilometres. The terrain of Dingzhou is flat and slightly inclined from northwest to southeast. It has a temperate–warm temperate, semi-humid, and semi-arid continental monsoon climate. The average annual temperature is 12.4 °C, and the interannual temperature difference is not large.

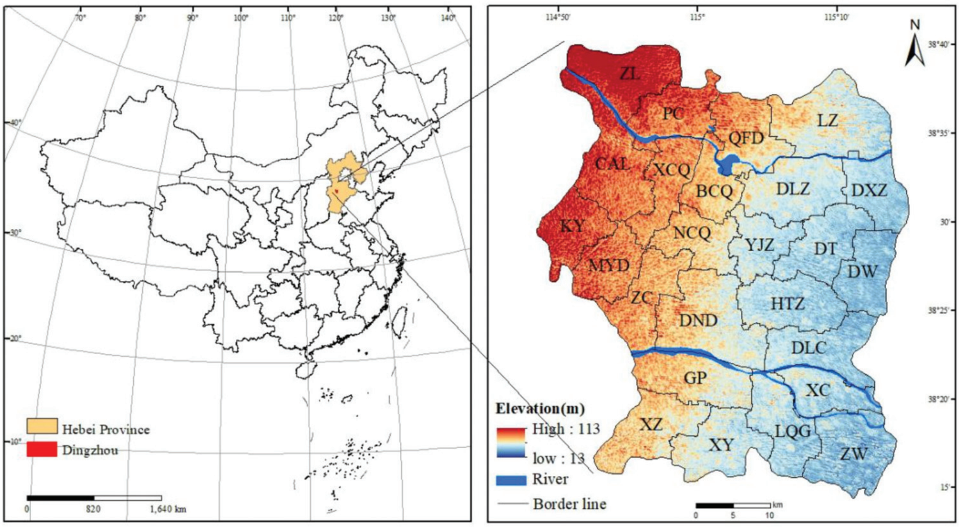

Figure 1. Location of Dingzhou City. Note: NCQ: Nancheng Qu Street, BCQ: Beicheng Qu Street, XCQ: Xicheng Qu Street, CAL: Chang'an Lu Street, LZ: Liuzao Town, QFD: Qingfeng Dian Town, PC: Pangcun Town, ZL:Zhuan Lu Town, MYD: Mingyue Dian Town, DND: Dingning Dian Town, DT: Dongting Town, DXZ: Daxin Zhuang Town, DW: Dongwang Town, GP: Gaopeng Town, XY: Xingyi Town, LQG: Liqin Gu Town, ZW: Ziwei Town, KY: Kaiyuan Town, DLC: Dongliu Chun Town, HTZ: Haotou Zhuang Hui Township, DLZ: Dalu Zhuang Town, XC: Xicheng Town, XZ: Xizhong Town, ZC: Zhou Cun Town, YJZ: Yangjia Zhuang Town. (Figure created in Arc GIS 10.5 ESRI, https://www.esri.com (accessed on 11 December 2021)).

Dingzhou City is an important node city in the Beijing–Tianjin–Hebei Economic Zone in Hebei Province. In 2020, the GDP of Dingzhou reached RMB 3.419 billion, an increase of 3.4% over the previous year. As of 2020, the resident population of Dingzhou is 1,095,900. Its urban population is 577,400, accounting for 52.69%, and the rural population is 518,500, accounting for 47.31%. According to the sixth national census in 2010, the urban population has increased by 102,800, and the rural population has decreased by 171,500, meaning that the proportion of urban population increased by 11.96%.

2.2. Data Sources

The data used in this study are mainly remote sensing image data, land use maps, and social and economic data for Dingzhou city. The rural settlements in 1962 and 1972 were identified from KeyHole remote sensing images [24]. KeyHole is a series of American reconnaissance satellites. They are military reconnaissance satellites with a spatial resolution of 1.5–3 m. Most of the KeyHole satellite images are concentrated between 1960 and 1980. So far, the first-generation images captured by KeyHole have been decrypted. We use the decrypted images of Dingzhou City in 1962 and 1972 to extract rural settlements. The spatial resolution of this image is 2 m. The data for rural settlements in 1990, 2000, 2010 and 2020 came from the Data Centre for Resources and Environmental Sciences, Chinese Academy of Sciences. These data are based on Landsat TM/ETM remote sensing images and the China–Brazil Earth Resources Satellite (CBERS-1), which are 30 m spatial resolution images generated by human–computer interaction [40]. The social and economic data for the per capita net income of farmers, per capita housing area of farmers, and the population of Dingzhou City were obtained from "*New Hebei 60 Years of 1949–2009*" [41].

3. Research Methods

3.1. Theoretical Framework

Maslow divided human needs from low to high into five levels: physiological needs, safety needs, social needs, esteem needs, and self-actualisation [42]. Maslow's theory of psychological needs is also applicable to a farmer's need for housing, which drives farmers to make decisions corresponding to the level of housing demand based on maximising their own interests. This kind of housing demand shows the characteristics of stages: in the first stage, farmers are at the lowest level of survival needs, and housing is needed only to meet the simplest living functions such as rest. In the second stage, with the deepening of reforms and opening up and the growth of the rural economy in China, farmers began to pursue luxurious and extravagant housing forms, far exceeding the needs and functions of normal housing. In the third stage, with the improvement of the education levels among farmers, they gave up houses that reflected a certain status and began to pursue rural houses that were comfortable. In the fourth stage, with the further improvement of educational levels, they began to demand a better quality of life. In the fifth stage, farmers change from rational needs to ideological needs, pursuing an ideal state of housing and hoping to realise self-worth.

Game theory mainly studies the interaction between incentive structures. The changing demands for farmers' housing reflects the changes in rural settlements and is the result of farmers gaming based on their own needs and external conditions. Policy is an external condition that has a strong guiding and restricting effect on land management [43], which is an important factor in farmers' decision-making. We divided the rural homestead policy into five periods according to its characteristics and trends: ownership transition, "unified planning", "paid use", "connection between increase and decrease", and "separation of three rights". The housing needs of farmers are different at different times, and the degree of—and their sensitivity to—policy feedback also varies. The gaming between farmers' needs and policy implementation directly causes changes in rural settlements. The continual development of the economy means that changes in the housing needs of farmers and in macro policy are inevitable. This has become the basic driving force, following the laws of Maslow's psychological needs theory and game theory, thereby affecting the scale of rural settlements, and forming the relationship curve of the "policy-scale of rural settlements" in different periods (Figure 2).

(I) Changes in the scale of rural settlements were relatively stable during the period of ownership transition. In theory, ownership change is a strong policy stimulus for rural settlements. However, at this time, farmers at the level of subsistence needs had low living standards and poor economic conditions, and their requirements for living space were relatively simple. There were no significant changes in rural settlements. (II) During the period of "unified planning", the scale of rural settlements changed in an inverted "U" shape. The rural economy developed rapidly after the reforms and opening up, and the basic survival needs of farmers (food, clothing, housing, and transportation) were met. With the relaxation of policies on the management of rural settlements, farmers achieved the conditions necessary to pursue superior housing (luxurious and extravagant forms of housing), leading directly to the continual expansion of the scale of rural settlements. After the housing boom in rural areas, the state and local governments issued policies in a timely manner in order to control the scale of rural settlements and made strict regulations regarding the area of homesteads. Farmers changed the form of their housing according to the requirements of the policy, reducing the scale of their housing, and effectively restrained the disorderly expansion of rural settlements. (III) The scale of rural settlements shrank during the "paid use" period, and their spatial patterns were optimised. Decision-makers took into account the fact that over-occupancy and random construction by people building multiple houses seriously affected the appearance of villages, and the multiple houses owned by a single family meant that a large amount of rural land was concentrated in the hands of a few people, which damaged the interests of other farmers. In order to solve these problems, the "one household, one house" policy was implemented. During this period, the government also planned the layout of rural settlements and improved rural infrastructure construction. Village and town planning improved the living conditions of farmers, and the functional layout of rural areas became more reasonable. Farmers pursued a clean and comfortable living environment, tended to participate in the construction of village and town planning, and gave up scattered and complex residential forms, resulting in a reduction in the area of rural settlements. (IV) The scale of rural settlements reduced further during the period of "connecting increase and decrease". The government further explored the homestead system in order to optimise the economic and social development pattern of urban and rural areas and increased the consolidation of rural residential land through the implementation of policies. At this stage, the residential comfort needs of farmers were met, and their needs for residential scale tended to be rational as their education levels increased. The policy also incentivised the withdrawal of homesteads (the local government gave incentives or subsidies to villagers who voluntarily vacated their homesteads), which directly mobilised the enthusiasm of farmers and made them more willing to withdraw from unnecessary homesteads. (V) The scale of rural settlements gradually stabilised during the "separation of three rights" period. The government actively carried out pilot work for the reforms of the "separation of three rights" system to fully stimulate the power and vitality of the circulation of homesteads, thereby increasing the collective income from circulation, and the standard pay for withdrawing homesteads was also raised. Farmers changed from having rational needs to ideal needs at this time. They gave timely feedback regarding policy, actively cooperated with the pilot work of the reform of the homestead system, and hoped to realise their self-worth in the process of the reform of the homestead system. Due to the long-term policy regulation and the effective development of rural settlements, the scale and pattern of rural settlements was optimised to a considerable extent. At this time, the scale of rural settlements did not change much.

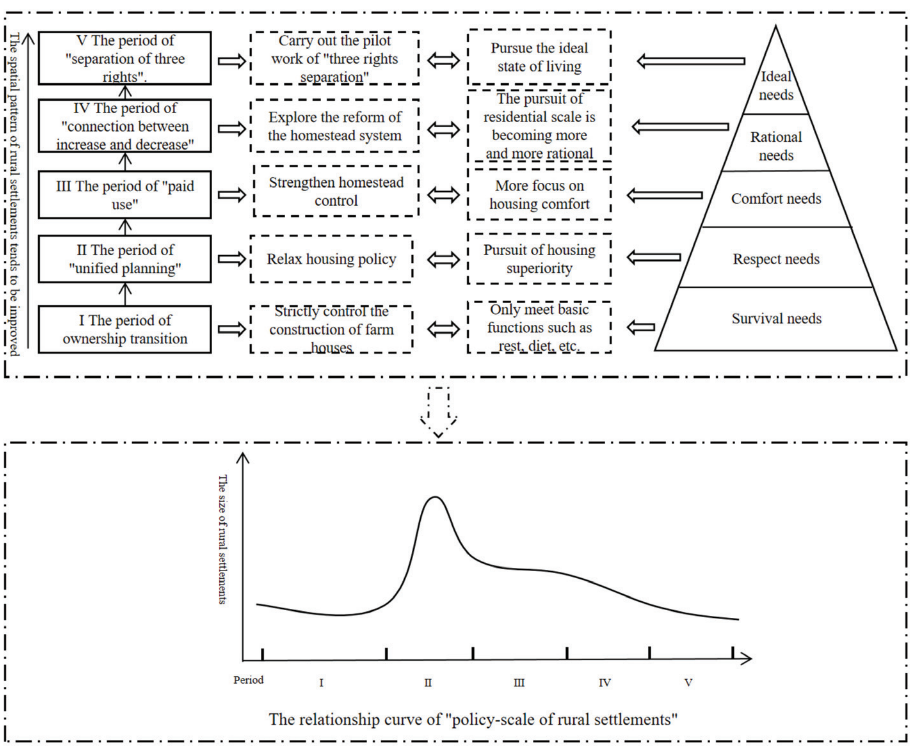

Figure 2. Theoretical framework.

3.2. Collection of Rural Settlements in the Historical Period

We deciphered the KeyHole remote sensing images from 1962 and 1972 and extracted the information about rural settlements (Figure 3). Before interpretation, an image needed to be preprocessed and compared to the land use map in 2000 for geometric correction [44,45]. The geographic coordinate system of the land use map for Dingzhou in 2000 was GCS_Krasovsky_1940, and coordinate correction was performed via the polynomial correction method. The specific interpretation process is shown in Figure 3, and these steps were all carried out in Arc GIS software. The spatial resolution of rural settlements was 2 m in 1962 and 1972 and 30 m in 1990, 2000, 2010, and 2020. We resampled the interpretation results so that the resolution of the data would be the same for all years, ensuring that the data processing and analysis of rural settlements were based on uniform spatial coordinates and uniform spatial resolution.

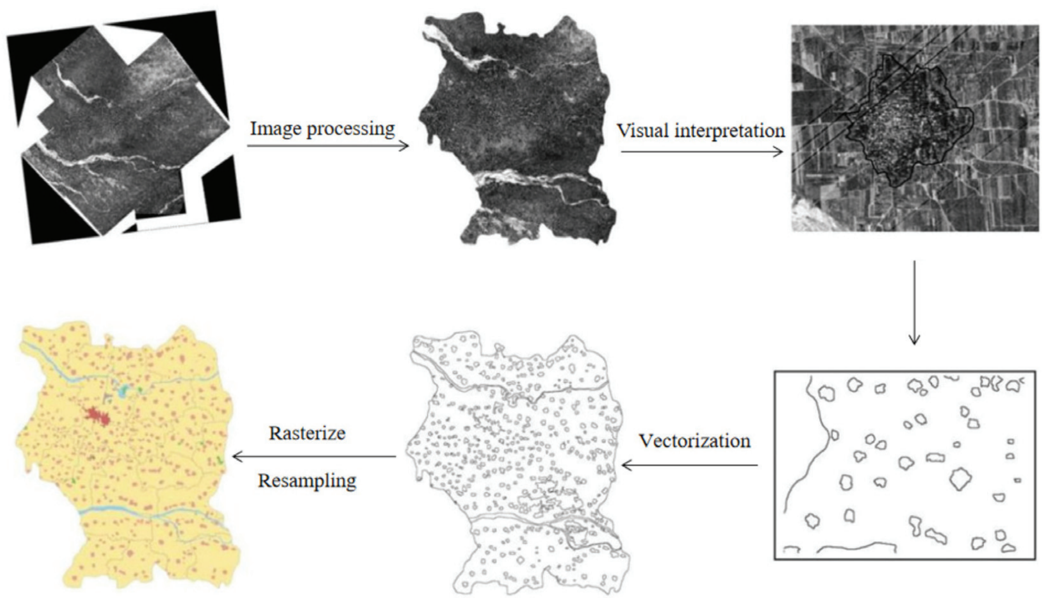

Figure 3. Visual interpretation process.

Since the year the images were interpreted cannot be checked in the field and there is no high-precision image data, accuracy was evaluated using expert interpretation and crowdsourcing tests [25]. We identified 300 random points corresponding to the ground class in remote sensing images in 1962 and 1972 (Figure 4) and identified random points as control points, and the final verification passed 287 (1962) and 279 (1972) random points; assessment accuracy was 95.7% and 93%, respectively.

3.3. Kernel Density Estimation

Kernel density estimation (KDE) can be used to study patch distribution density, spatial extent and intensity, and patch distribution density increases with increases in the kernel density value. This method is often used to detect spatial hotspots and identify location where high- or low-value elements cluster in space, which intuitively represents variability in the spatial density of rural settlements. The kernel density estimation is calculated using the following formula [46]:

$$f(x,y) = \frac{1}{nh^2}\sum_{i=1}^{n} K\left(\frac{d_i}{n}\right) \quad (1)$$

where f (x, y) represents the kernel density value of the point (x, y); h is the bandwidth or smoothing parameter; K represents the kernel function; and d_i represents the distance between the point (x, y) and the i-th observed position.

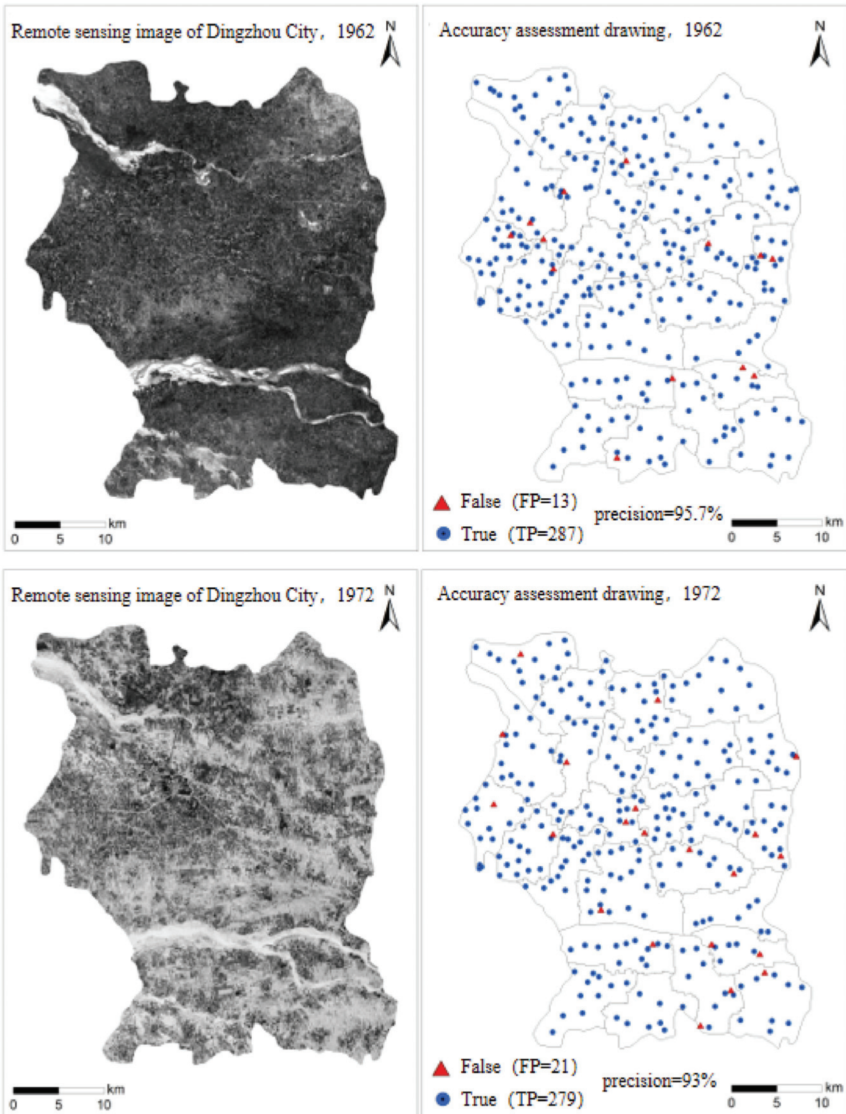

Figure 4. Assessment of rural residential accuracy in Dingzhou in 1962 and 1972 (Figure created in Arc GIS 10.5 ESRI, https://www.esri.com (accessed on 20 December 2021)).

3.4. Spatial Change Pattern of Rural Settlements

According to the changes of rural settlement characteristics in Dingzhou in the past 60 years and to related research, the change process of the spatial distribution of rural settlements in Dingzhou is divided into expansion pattern, merge pattern, retreated pattern, and urbanisation pattern (Figure 5) [25]. The diffusion pattern reflects the expansion of rural settlements on the original basis (Figure 5a); the merger pattern involves the merging of two or more rural settlements (Figure 5b); the evacuation pattern involves rural settlements being transformed into other land use types (Figure 5c); and the urbanisation pattern refers to the transformation of rural settlements into urban land (Figure 5d).

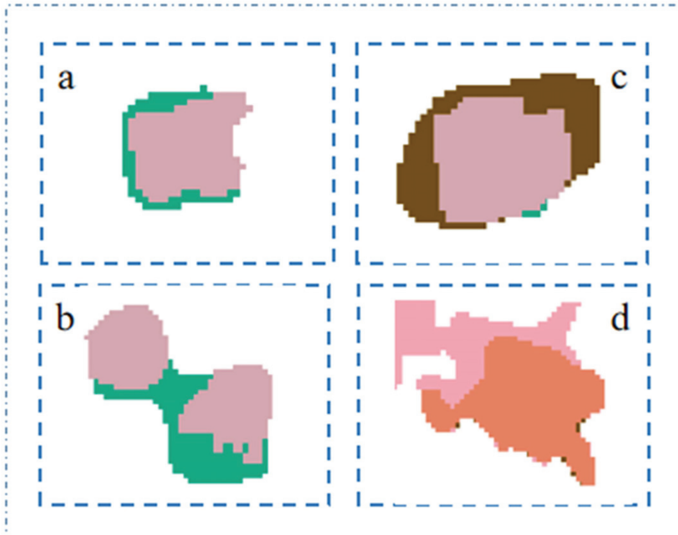

Figure 5. Change pattern of rural settlements. (Note: (**a**): expansion pattern; (**b**): merge pattern; (**c**): retreated pattern; (**d**): urbanization pattern).

4. Results

4.1. Changes in the Number of Rural Settlements in Dingzhou from 1962 to 2020

From 1962 to 2020, the total area of rural settlements in Dingzhou City showed an increasing trend (Table 1), and the area increased by 8354.97 ha. The average increases in 1962–1972, 1972–1990, 1990–2000, 2000–2010, and 2010–2020 were 0.29%, 1.17%, 1.81%, 1.26%, and 0.05%, respectively. The size of rural settlements in Dingzhou continues to expand, with the largest increase (1.81%) in 1990–2000 and the smallest increase in 2010–2020 (0.05%).

Table 1. Change index of rural settlements in Dingzhou, China.

Index	1962	1972	1990	2000	2010	2020
Area of rural settlements (ha)	11,415.33	11,747.25	14,491.17	17,343.9	19,664.46	19,770.3
Area change of rural settlements (ha)	-	331.92	2743.92	2852.73	2320.56	105.84
Annual average variation of rural settlements (%/Y)	-	0.29	1.17	1.81	1.26	0.05

There was clear expansion in Kaiyuan Town, Mingyue Dian Town, Xicheng Qu Street, Xizhong Town, Zhoucun Town, and Ziwei Town from 1962 to 2020. These townships have expanded greatly in the past 60 years (Table 2). The area of Zhoucun Town settlements increased from 530.33 hectares in 1962 to 1225.08 hectares, for an increase of 131%. Compared to the above towns, the area of Beicheng Qu Street and Dongwang Town expanded less, with growth rates of 48.67% and 45.72%, respectively.

Table 2. Changes in the area of rural settlements in various townships in Dingzhou, China from 1962 to 2020 (unit: ha).

Area	1962	2020	Proportion Increase (%)	Area	1962	2020	Proportion Increase (%)
Beicheng Qu Street	221.02	328.59	48.67	**Dalu Zhuang Town**	610.82	919.35	50.51
Daxin Zhuang Town	331.95	575.19	73.28	**Dingning Dian Town**	836.35	1488.96	78.03
Dongliu Chun Town	390.36	682.74	74.90	**Dongting Town**	457.49	882	92.79
Dongwang Town	449.26	654.66	45.72	**Gaopeng Town**	394.10	610.47	54.90
Haotou Zhuang Hui Township	570.23	926.91	62.55	**Kaiyuan Town**	413.50	943.47	128.17
Liqin Gu Town	382.23	680.76	78.10	**Liuzao Town**	724.20	1144.89	58.09
Mingyue Dian Town	438.33	1003.95	129.04	**Nancheng Qu Street**	544.84	825.21	51.46
Pangcun Town	498.25	973.98	95.48	**Qingfeng Dian Town**	614.34	1018.44	65.78
Xicheng Qu Street	338.29	700.56	107.09	**Xicheng Town**	309.09	567.99	83.76
Xizhong Town	348.03	759.33	118.18	**Xingyi Town**	356.22	668.25	87.59
Yangjia Zhuang Town	457.15	740.61	62.01	**Chang'an Lu Street**	456.32	833.67	82.69
Zhoucun Town	530.33	1225.08	131	**Zhuanlu Town**	535.92	1042.56	94.54
Ziwei Town	415.53	942.57	126.84				

4.2. Characteristics of the Spatial Changes of the Rural Settlements in Dingzhou City from 1962 to 2020

4.2.1. Spatial Changes of the Rural Settlements from 1962 to 1972

Although rural settlements in various towns and towns in Dingzhou expanded, the growth rate was slow from 1962 to 1972. This was mainly because the management of rural settlements in China was very strict during this period, and there was great pressure on rural housing. The spatial distribution of changes to the scale of rural settlements in Dingzhou mainly involved expansion during this period (Figures 5 and 6). Almost all towns in Dingzhou City have expanded. The average annual growth rate of rural settlement areas in Xizhong Town is the highest, at 0.71%; the highest average annual growth rates are for Xingyi Town, Gaopeng Town and Liqin Gu Town, at 0.69%, 0.61%, and 0.53%, respectively; and the average annual growth rate of the area of rural settlements in the rest of the townships remained around 0.2%. Residential expansion was scattered during this period, with some towns expanding southeast while others expanded to the northwest.

4.2.2. Spatial Change of the Rural Settlements from 1972 to 1990

After the first national work conference on rural housing construction, it was reiterated that rural housing involves a means of living, and the property rights of housing should be owned by individual members. China loosened its control over the construction of farmhouses during this period, and there was a boom in the construction of houses in the rural areas of Dingzhou City, resulting in dramatic changes in the area of rural settlements. From 1972 to 1990, the spatial distribution of rural settlement size changes in Dingzhou City mainly followed an expansion pattern and a merge pattern (Figures 5 and 6). Rural settlements in all towns in Dingzhou City experienced large-scale expansion. The area of rural settlements increased by 2743.92 ha during this period. Kaiyuan Town, Liqin Gu Town, Pangcun Town, and Xingyi Town had more obvious expansion. The average annual growth rates of the residential areas were 2.16%, 1.97%, 1.83%, and 1.84%, respectively. The expansion rate of Kaiyuan Town in this period was 5.14 times that of 1962–1972. Beicheng Qu Street, Chang'an Lu Street, Xicheng Qu Street, and Nancheng Qu Street also expanded significantly. The merger mode mainly occurred in the south of Zhuanlu Town, the north of Qingfeng Dian Town, the north of Xicheng Qu Street, and the middle of Gaopeng Town.

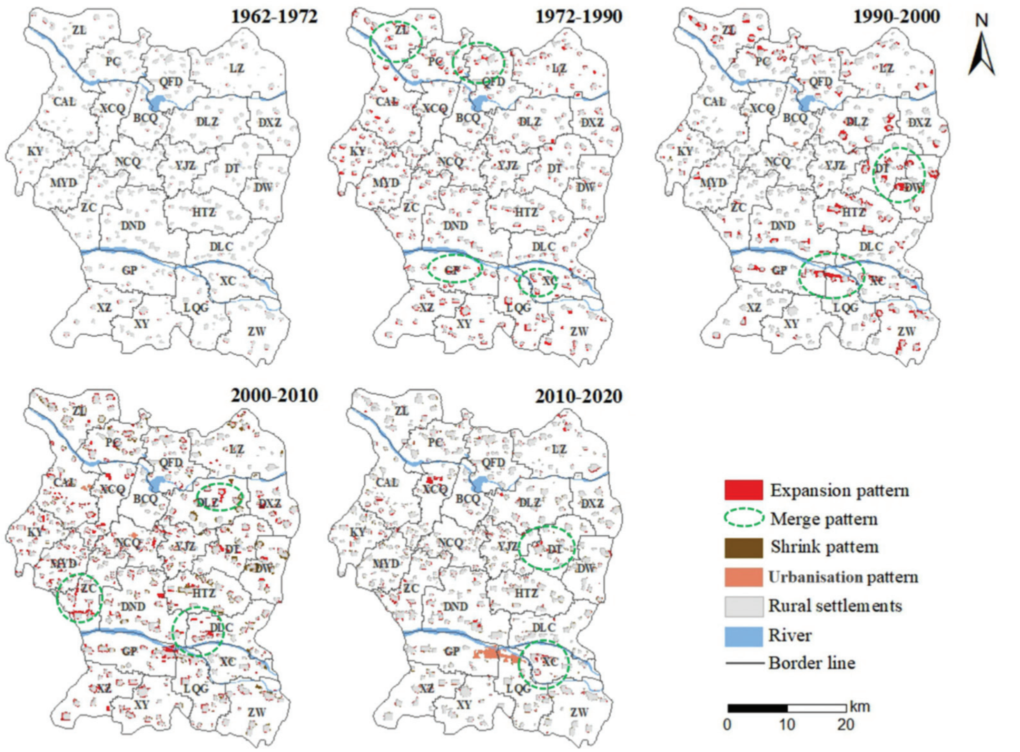

Figure 6. Change pattern of rural settlements in Dingzhou, China from 1962 to 2020. Note: NCQ: Nancheng Qu Street, BCQ: Beicheng Qu Street, XCQ: Xicheng Qu Street, CAL: Chang'an Lu Street, LZ: Liuzao Town, QFD: Qingfeng Dian Town, PC: Pangcun Town, ZL:Zhuanlu Town, MYD: Mingyue Dian Town, DND: Dingning Dian Town, DT: Dongting Town, DXZ: Daxin Zhuang Town, DW: Dongwang Town, GP: Gaopeng Town, XY: Xingyi Town, LQG: Liqin Gu Town, ZW: Ziwei Town, KY: Kaiyuan Town, DLC: Dongliu Chun Town, HTZ: Haotou Zhuang Hui Township, DLZ: Dalu Zhuang Town, XC: Xicheng Town, XZ: Xizhong Town, ZC: Zhoucun Town, YJZ: Yangjia Zhuang Town. (Figure created in Arc GIS 10.5 ESRI, https://www.esri.com (accessed on 25 December 2021)).

4.2.3. Spatial Change of the Rural Settlements from 1990 to 2000

The state managed the legal use of homesteads from 1990 to 2000 and regulated for the problem of excessive land occupation due to residents building houses. In 1992, the Hebei Provincial People's Government stipulated that if rural residential land exceeded the land area limit, it should be returned within a time limit. The state also required residential construction by rural residents to conform to the village and town construction plan, so the phenomenon of arable land occupation gradually decreased. The scale of changes in spatial distribution in rural settlements in Dingzhou City involved a new retreating pattern and urbanisation pattern during this period (Figures 5 and 6). For example, some rural settlements in Kaiyuan town were vacated as farmland. The urbanisation pattern is mostly seen in areas surrounding towns. For example, some rural settlements in Chang'an Lu and Beicheng Qu Street have been transformed into urban land. The average annual growth rates of the rural residential areas in Xicheng Qu and Chang'an Lu Street were negative, at −0.45% and −0.11%, respectively. The growth rates of Zhoucun Town, Yangjia Zhuang Town, Xingyi Town, Xizhong Town, and other towns have decreased compared to the previous period. The expansion of rural settlements in the western and southwest of Dingzhou slowed during this period, the rural settlements in the central and southwest of

Dingzhou did not expand significantly, and the expansion in the eastern and southeast of Dingzhou was more obvious.

4.2.4. Spatial Change of the Rural Settlements from 2000 to 2010

From 2000 to 2010, the state encouraged the consolidation of rural construction land and proposed that increases in urban construction land should be linked to the reduction of rural construction land. Dingzhou stepped up the consolidation of rural residential land, which was mainly characterised by exploring the withdrawal mechanism of homesteads and encouraging farmers to vacate excess homesteads. The changes to rural settlements in Dingzhou city mainly followed an expansion pattern, retreated pattern and urbanisation pattern during this period (Figures 5 and 6). There were large-scale reductions in rural settlements during this period, mainly in towns and towns in the east, northwest and southeast of Dingzhou, such as Dongting Town, Dongwang Town, Xicheng Town, Dalu Zhuang Town and Haotou Zhuang Hui Township. The average annual growth rates of the area of rural settlements were –2.93%, –1.67%, –0.57%, –0.53%, and –0.26%, respectively. Although rural settlements showed an expansion trend compared with 1990–2000, the expansion rate of urban land in Dingzhou slowed in the next 10 years, and the growth rate decreased from 1.81% to 1.26%.

4.2.5. Spatial Change of the Rural Settlements from 2000 to 2020

The effective implementation of measures, such as “one house for one family” and “connecting increase and decrease”, has curbed the expansion of rural settlements. The area of rural settlements in each township has shrunk significantly, and the spatial pattern of rural settlements has changed from disorder to order. The spatial distribution of changes in rural settlements in Dingzhou was mainly based on the retreated pattern, merge pattern and urbanisation pattern from 2010 to 2020 (Figures 5 and 6). From 2010 to 2020, the area of rural settlements increased by only 105.84 ha, and the proportion of land used remained at about 15%. The area of rural settlements in Dalu Zhuang Town and Dongwang Town decreased significantly, and the average annual growth rate of Daxin Zhuang Town, Gaopeng Town, Liqin Gu Town, Xizhong Town, and Xingyi Town dropped significantly, indicating that these towns have shrinking settlements. The growth rate of the other towns slowed from the previous period, with the highest growth rate in Zhoucun Town, at only 1.35%. The merger of rural settlements occurred mainly in Dongting Town, Xicheng Town and Liqin Gu Town. Gaopeng Town and Liqin Gu Town are on larger scales, have better economic conditions, and have begun to transform their rural settlements into urban land.

4.3. Analysis of the Variation Characteristics of Kernel Density in Dingzhou

A kernel density analysis of rural settlements in Dingzhou can be used to understand their agglomeration in space and time. We used the kernel density analysis tool in Arc GIS software to examine rural settlements in Dingzhou from 1962 to 2020.The results of the kernel density analysis show (Figure 7) that the maximum kernel densities of rural settlements in Dingzhou from 1962 to 2020 were 0.998 km^2, 0.996 km^2, 0.919 km^2, 0.983 km^2, 1.162 km^2, and 1.149 km^2. The scale and distribution density of rural settlements in Dingzhou are generally increasing overall. In 1962 and 1972, the high density values of rural settlements were concentrated in the areas surrounding towns and along rivers, such as Kaiyuan Town, Qingfeng Dian Town, and Gaopeng Town, and rural settlements far from urban areas and river areas were scattered. In the 1980s, the kernel density values in the surrounding areas of towns and along the river decreased, and high density values appeared in Zhuanlu Town. In 2000, compared to the original trend, the density values of rural settlements in Dongliu Chun Town and Xicheng Town increased. The spatial distribution of the kernel density values in 2010 and 2020 was basically the same, and the density values of rural settlements in the surrounding areas of cities and towns increased. Except for the high-value agglomeration in the surrounding areas of towns, areas demonstrated a new trend of multicore fragmentation based on the original trend.

From a local point of view, from 1962 to 2020, the high kernel density values were mainly distributed in parts of the central, western, and southeastern parts of Dingzhou City, and there were also cases where the kernel density values decreased in these areas. Based on an analysis of the number and spatial characteristics of rural settlements in the study area, we learned that the total area of rural settlements in the study area is increasing year by year, and there are merging rural settlements. Some rural settlements retreated to cultivated land, and existing settlements continued to expand, gradually connecting and merging with surrounding settlements. These changes resulted in a decrease in the kernel density value of some areas.

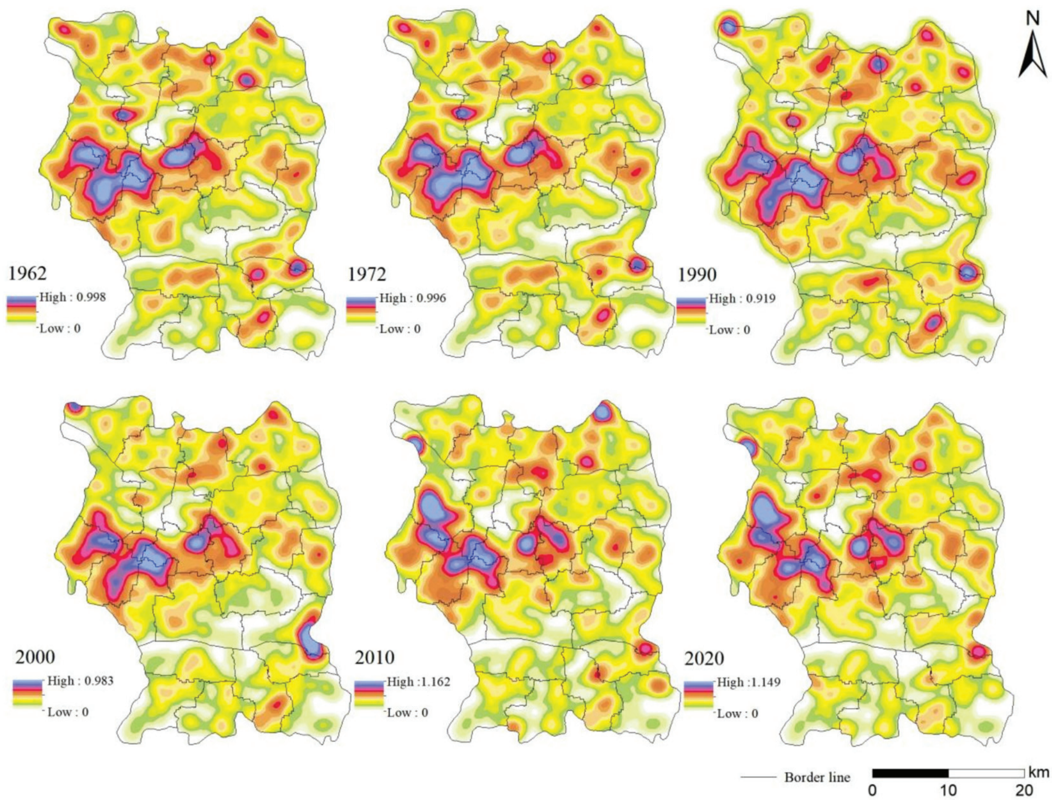

Figure 7. Changes in the kernel density of rural settlements in Dingzhou, China from 1962 to 2020 (Figure created in Arc GIS 10.5 ESRI, https://www.esri.com (accessed on 27 December 2021)).

5. Discussion

5.1. Main Policies Affecting the Changes of Rural Settlements and Stages

In rural areas of China, the policy for homesteads (land for building rural housing, the main component of rural settlements) profoundly affects rural settlements. The homestead system is an important part of China's land system. It began during the founding of the People's Republic of China. Continuous adjustment and improvement meant that it was relatively complete and gradually standardised in the late 1980s. We divided the policies causing changes in the spatial pattern of rural settlements in Dingzhou into five periods (Figure 8): the period of transition from "private ownership of farmers" to "one homestead, two systems", the period of the "unified planning" of homesteads, the period of the "paid use" of homesteads, the period of "connecting increase and decrease" in homesteads, and the period of "separation of three rights" of homesteads.

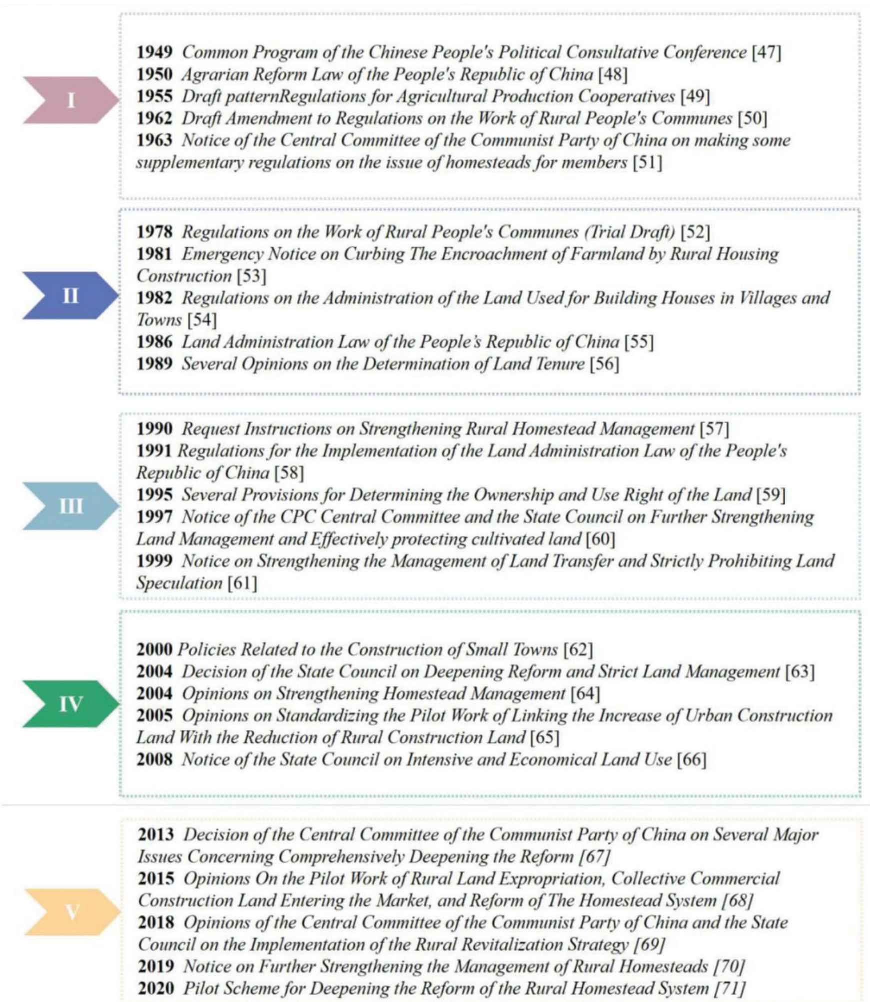

Figure 8. Partial Homestead Policy 1949–2020. Note: I: the period of transition from "private ownership of farmers" to "one homestead, two systems" (1949–1972) [47–51]; II: the period of "unified planning" of homesteads (1972–1990) [52–56]; III: the period of "paid use" of homesteads (1990–2000) [57–61]; IV: the period of "connecting increase and decrease" of homesteads (2000–2010) [62–66]; V: the period of "separation of three rights" of homesteads (2010–2020) [67–71].

5.1.1. 1949–1972: Period of Transition from "Private Ownership of Farmers" to "One Homestead, Two Systems"

The Common Program of the Chinese People's Political Consultative Conference adopted in 1949 [47] proposed that farmers' land ownership should be protected and that land (including homesteads) should be distributed to farmers free of charge. After the founding of the People's Republic of China, China reformed the rural land system. The Land Reform Law of the People's Republic of China [48] promulgated in 1950 proposed the establishment of a privately owned land system by farmers. In 1955, the Draft of the Pattern Constitution of Agricultural Production Cooperatives [49] stated that means of subsistence were privately owned and that means of production should be gradually nationalised. At this time, as a general rule, farmers were self-employed, and homesteads were distributed evenly and could be obtained free of charge. In 1962, the [46] established the principle of "one homestead, two systems" (that is, a homestead occupied by farmers for building houses are collectively owned, and the houses built on the homestead are owned by farmers individually) rural homestead pattern. Homesteads were transformed from peasant ownership to rural collective ownership. In 1963, the Circular of the Central Committee of the Communist Party of China on Making Some Supplementary Regulations on the Issue of Homesteads for Members [50] first proposed the concept of the right to use homesteads. During the period when the private ownership of peasants changed to "one homestead, two systems", the original ownership of homesteads was changed to a right to use the homestead, beginning the era of the "separation of two rights" of homesteads [51]. At this time, the framework of China's homestead system was preliminarily formed. As the concept of the right to use homesteads gradually became clear, the total number of homesteads remained stable.

5.1.2. 1972–1990: Period of "Unified Planning" of Homesteads

The Third Plenary Session of the Eleventh Central Committee was held in 1978, and the state established a policy of reform and opening up. With the deepening of reforms and opening up and the rapid advances in the marketisation of land, there has been a boom in housing construction in rural areas, and social problems such as speculation in homesteads and the erosion of cultivated land in rural areas have become increasingly serious. Against this background, the State Council promulgated the Regulations on the Administration of Land Use for Villages and Towns in 1982 [54], which for the first time stipulated a standard area for each household when applying for the right to use the homestead. On this basis, the 1986 Land Administration Law of the People's Republic of China [55] made more detailed regulations on the basis of the Regulations on the Administration of Land for Villages and Towns Construction, clearly restricting the occupation of farmland by homesteads. The main feature of this period was the disorderly expansion and controlled adjustment of the total number of homesteads. After the housing boom in rural China, the state intervened in the management of homesteads in a timely manner, and the homestead system was gradually standardised during this period.

5.1.3. 1990–2000: Period of "Paid Use" of Homesteads

In 1990, the Request for Instructions on Strengthening the Management of Homesteads in Rural Areas [57] first proposed a pilot program for the paid use of homesteads (that is, charging an appropriate amount of fees for homesteads). In 1991, the Regulations for the Implementation of the Land Administration Law of the People's Republic of China [58] pointed out that the state manages the legal use of homestead and punishes illegal acts. In 1995, Several Regulations on Determining Land Ownership and Use Rights [59], stipulations were made regarding the problem of exceeding the standard amount of land occupied by residents for building houses. Since then, the Central Committee of the Communist Party of China and the State Council have issued a notice that the residential construction of rural residents must conform to the village and town construction plan and implement the policy of one house for one household. The state strengthened the management of homesteads during this period, laying the foundation for the subsequent reform of the homestead system.

5.1.4. 2000–2010: Period of "Connecting Increase and Decrease" of Homesteads

After 2000, the central and local governments conducted a large-scale theoretical and practical exploration of the reforms of the homestead system. In 2004, the Decision of the State Council on Deepening Reform and Strict Land Management [63] encouraged the consolidation of rural construction land and suggested that an increase in urban construction land should be connected to a reduction in rural construction land. In 2008, the Notice of the State Council on Promoting Economised and Intensive Land Use [66] mentioned that the local government may give incentives or subsidies to villagers who voluntarily vacated their homesteads. Since then, China has stressed the formation of a new pattern of urban and rural economic and social development and integration for the future, and various localities have also intensified the consolidation of rural residential land. The main feature of the reform and exploration period is the reform of the homestead system and the exploration of the exit mechanism for homesteads. The state has also instituted many incentives to encourage farmers to vacate excess homesteads. In addition, the Fifth Plenary Session of the 16th CPC Central Committee proposed building a new socialist countryside, and the implementation of this major strategic measure also provided strong policy support for land use in rural settlements.

5.1.5. 2010–Present: Period of "Separation of Three Rights" of Homesteads

In 2013, the Decision of the Central Committee of the Communist Party of China on Several Major Issues Concerning Comprehensively Deepening the Reform [67] emphasised that it was necessary to improve the existing pilot projects connecting the increase and decrease of urban and rural construction land. In 2018, the No. 1 Central Document Opinions of the Central Committee of the Communist Party of China and the State Council on the Implementation of the Rural Revitalisation Strategy [69] proposed the "separation of three rights" of homestead ownership, contract rights, and management rights. In 2019, the Notice on Further Strengthening the Management of Rural Homesteads [70] noted that village collectives and farmers should be encouraged to use idle homesteads and houses. In recent years, China has further explored the pilot reform of the rural homestead system, focusing on exploring the "separation of three rights" of homesteads. In the future, under the guidance of the rural revitalisation strategy, the reform of the rural homestead system should make greater breakthroughs in controlling the scale of rural settlements and sorting out rural settlements.

5.2. Impact of Relevant Policies on Changes in Rural Settlements in Dingzhou

5.2.1. Period of Transition from "Private Ownership of Farmers" to "One Homestead, Two Systems"

During this period, the management of rural settlements in China was very strict, the living standards and economic conditions of farmers were relatively low, and farmers' housing could not be improved for an extended period. The growth of rural housing construction in China was thus very slow. From 1962 to 1972, the area of rural settlements in Dingzhou increased by only 331.92 ha. As the concept of the right to use homesteads was gradually clarified, the total number of homesteads then remained stable during this period.

5.2.2. Period of "Unified Planning" of Homesteads

In 1979, the first national work conference on rural housing construction was held, which reiterated that rural housing involved the means of living and that the property rights of housing should be owned by the members of the community. Since then, China has eased its long-standing controls on rural housing construction. In the 1980s, in order to activate the rural economy and strengthen rural construction, the government formulated some rural policies to relax the application targets for homesteads, resulting in problematic phenomena, such as the random occupation of cultivated land and disorderly expansion of rural housing construction [72]. During this period, the area of rural settlements in Dingzhou City changed drastically and the area of rural settlements increased by 2743.92 ha. Some settlements in Zhuanlu Town, Qingfeng Town, Gaopeng Town expanded and merged, and there were also new settlements near the cultivated land. Due to the lack of village and town planning, the idea of renovating old houses was relatively weak, and the construction of new houses resulted in the disorderly expansion of most rural housing sites and a general increase in the scale of villages, a relatively scattered layout, and the problematic occupation of cultivated land. After the housing boom in rural areas, the state and local governments intervened in the management of homesteads in a timely manner, and the homestead system was gradually standardised.

5.2.3. Period of "Paid Use" of Homesteads

In the past, the lack of regulations meant that the phenomenon of multiple dwellings per household was common in rural areas. Behaviours such as over-occupancy and random construction seriously affected the appearance of the villages. One family owning multiple houses meant that a large amount of rural land was concentrated in the hands of a few people, which damaged the interests of other farmers. In order to solve these problems, the state and local governments implemented the "one household, one house" policy. The state also issued documents such as the Request for Instructions on Strengthening the Management of Rural Homesteads and Several Regulations on Determining Land Ownership and Use Rights to intensify the control of rural homesteads. In 1992, the Hebei Provincial People's Government promulgated the Regulations on the Administration of Rural Homesteads in Hebei Province [73]. If rural residential areas in Hebei Province exceeded the land use limit, the land was retreated within a time limit and planned index management was implemented. During this period, some rural settlements in Kaiyuan Town were converted into cultivated land, some rural settlements in Chang'an Lu Street and Beicheng Qu were vacated into cultivated land, and some were converted into urban land. The growth rates of rural settlements in Zhoucun Town, Yangjia Zhuang Town, Xingyi Town, and Xizhong Town slowed compared to the previous period. Rural homesteads were allocated by households, and redundant homesteads were recovered. This measure strengthened the organisation of rural residential sites in Dingzhou. The government also indicated the direction of action for farmers through positive advocacy and incentives and gave rewards or subsidies to villagers who voluntarily vacated their homesteads. These policies directly aroused the enthusiasm of farmers and effectively controlled the number of rural settlements.

5.2.4. Period of "Connecting Increase and Decrease" of Homesteads

In 2002, the People's Government of Hebei Province issued the Measures for the Administration of Rural Homesteads in Hebei Province [74], which pointed out that, upon review by the county (city) land administration department, the county (city) people's government could take back one household from a rural villager after approval. Since then, Dingzhou has implemented the relevant regulations of the State Council on strict land management and encouraged the consolidation of rural construction land. The increase in urban construction land is linked to the reduction of rural construction land. The growth rate slowed down during this period, although the total area of rural settlements in Dingzhou increased. The average annual growth rate of rural settlements from 2000 to 2010 decreased from 1.81% in the previous period to 1.26%. Rural settlements have also retreated in most areas of Dingzhou, such as Kaiyuan Town, Dalu Zhuang Town, Dongwang Town, Zhuanlu Town, and Ziwei Town. The effective implementation of measures such as "one house for one household" and "connecting increase and decrease" has curbed the expansion of rural settlements and has prompted the spatial pattern of rural settlements in Dingzhou to change from disorder to order.

5.2.5. Period of "Separation of Three Rights" of Homesteads

With the orderly launch of the pilot work connecting the increase and decrease of urban and rural construction land, China's homestead system has gradually improved. The General Office of the Hebei Provincial Party Committee and the General Office of the Provincial Government jointly issued the Opinions on Accelerating the Promotion of Rural Reform to explore the "separation of three rights" system for rural homesteads [75]. In response to higher-level policies, Dingzhou also formulated institutional documents, such as the Dingzhou Homestead Management Method [76], and started preparing the city's village land use planning. In the Measures for the Use of Surplus Indicators for Homestead Retirement in Dingzhou City [77], the government proposed using the increase or decrease in bonus funds to support the pilot reform. The average annual growth rate of rural settlements in Dingzhou was only 0.05% during this period, which shows that the towns and villages in Dingzhou actively responded to national policies. In March 2015, Dingzhou City was identified as one of the 33 pilot projects for the reform of the rural land system in the country and has successively carried out three pilot reforms, including the rural land expropriation system, the entry of collectively owned construction land into the market, and the homestead system. Dingzhou actively explored ways to exit during this period, and due to the long-term policy regulation and effective implementation of rural settlements, the scale and pattern of rural settlements has been optimised to a certain extent. The scale of rural settlements has not currently changed much. As a result, the average annual change in the area of rural settlements in 2020 was low.

The orderly launch of the pilot work connecting the increase and decrease in urban and rural construction land means that China's homestead system has gradually improved. During the period of the "separation of three rights" housing estates, the average annual growth rate of rural settlements in Dingzhou was only 0.05%, which shows that all towns and villages in Dingzhou actively responded to national policies. In September 2020, 104 counties (cities, districts) and three prefecture-level cities launched a new round of pilot reforms for the rural homestead system. The core of this new round is exploring the form of separate ownership, contracts, and the management of homesteads. Dingzhou city is a pilot city in the new round of rural homestead system reform determined by the central government. In 2021, Dingzhou City promulgated the Dingzhou City Rural Homestead System Reform Pilot Implementation Plan, Guiding Opinions on the Revitalisation and Utilisation of Rural Idle Homesteads and Idle Houses in Dingzhou City (Trial) and Dingzhou Rural Homestead Circulation Management Interim Measures [77], focusing on exploring the "separation of three rights" of homesteads and promoting the management of rural settlements in Dingzhou.

5.3. Policy Suggestions for the Reform of the Rural Homestead System

Although the state requires residential construction by rural residents to comply with the village and town construction plan and has carried out the pilot work regarding the paid use of homesteads in an orderly manner, we found that some towns in Dingzhou City did not adequately control the expansion of rural residents during the period of "paid use" of homesteads. The above phenomenon mainly occurs in towns far from the city, such as Zhuanlu Town, Dalu Zhuang Town, Dongting Town, Dongwang Town, and Haotou Zhuang Hui Township, while the expansion of rural settlements in towns close to the city, such as Mingyue Dian Town and Zhoucun Town, has been effectively suppressed. This shows that there may be some deviations in policy implementation in remote areas of Dingzhou. It is therefore necessary to strengthen the management of homesteads in remote towns and towns. Increasing the publicity and guidance of homestead policies in remote towns and towns and improving the implementation of policies in these areas should be considered.

As a pilot city for the reform of the rural homestead system, Dingzhou should also strengthen its organisation of rural settlements. In recent years, the implementation of policies such as "one house for one household" and "connecting increase and decrease" means that the growth rate of rural settlements in Dingzhou has slowed down, and the disorderly expansion of rural settlements has been effectively controlled, however, our analysis of the spatial pattern of rural settlements suggested that rural settlements in some townships in Dingzhou are small in scale and scattered in layout, including the northern part of Mingyue Dian Town, the eastern part of Kaiyuan Town, the southern part of Chang'an Lu Street, the southeastern part of Liqin Gu Town, and Yangjia Zhuang Town. The government should therefore consider optimising and adjusting the land use scale and internal structure of rural residential areas. While organising rural residential areas, the spatial layouts of Mingyue Dian Town, Liqin Gu Town, Kaiyuan Town, and Yangjia Zhuang Town should be strengthened. This is more concentrated and intensive and promotes orderly and rational land use. Reforming the rural homestead system is also important for the future development of rural residential areas in Dingzhou City. Dingzhou

City could revitalise idle homesteads through the development of farmhouses, homestays, rural tourism, and so on and promote the construction and development of rural areas.

5.4. Limitations of This Study and Future Research Directions

The data for different years used in this article are slightly different, but we have adopted some methods to reduce errors caused by the data source. The data resolution (2 m) of 1962 and 1972 is different from that used in other years. The method we used was to firstly convert the spatial data for all years into unified geographic coordinates and define a unified projection; resample the data from 1962 and 1972, and change its spatial resolution to 30 m. Once the operation is complete, we unified the geographic coordinate system, projected coordinate system, and resolution of the data. Due to data transformation, however, there are still some foreseeable errors. When we converted the rural settlement data from 2 meters to 30 meters in 1962 and 1972, and the area increased by 0.087 hectares and 0.0109 hectares, respectively. The deviations were all less than 0.01%, and these deviations may cause slight changes in rural settlements at the pixel edge. In the process of analysing the changes to the spatial pattern of rural settlements, we analysed the effect of policy factors. In real society, there are many factors of the spatial pattern of rural settlements. Spatial elements such as roads, areas of water, and distances from cities and towns will also affect the distribution of rural settlements. In this study, however, these factors were assumed to be stable.

According to our understanding and analysis of the current research status and the thinking about the limitations of this paper, we believe that future research could involve the following: (1) analysing changes in the spatial pattern of rural settlements in other regions and examining whether the changes to rural settlements in each region conform to the relationship curve of the "policy-scale of rural settlements"; (2) considering the effect of other factors on the changes to the spatial pattern of rural settlements, such as population, roads, water areas, and so on. (3) Simulating and predicting the spatial pattern of rural settlements in the future according to the current trend in rural settlements policy.

6. Conclusions

This paper took rural settlement policy as its basis, analysed the scale and pattern changes of rural settlements according to Maslow's psychological needs theory and game theory, and identified the relationship curve of "policy-scale of rural settlements" in different periods using Dingzhou City, China as an example for empirical research. We analysed the evolution of the spatial scale of rural settlements in Dingzhou from 1962 to 2020 under the influence of this policy. In terms of data acquisition, decrypted military satellite images were used for visual interpretation so as to obtain long-term historical data and extract the historical spatial information of rural settlements in Dingzhou. We used Arc GIS software to perform spatial analysis on the data for rural settlements in Dingzhou City and used the medium- and long-term land use maps of Dingzhou City to explore the evolution law of rural settlements in Dingzhou City. According to the changing trend of rural settlements in Dingzhou over the past 60 years, this paper divided the changing processes of the spatial distribution of rural settlements in Dingzhou into an expansion pattern, merge pattern, retreated pattern and urbanisation pattern. The effect of policies in different periods on the evolution of the spatial pattern of rural settlements was thus analysed. From 1962 to 2020, the total area of rural settlements in Dingzhou showed an increasing trend, with a total increase of 8354.97 ha (73%). Kaiyuan Town, Mingyue Dian Town, Xicheng Qu Street, Xizhong Town, Zhoucun Town, and Ziwei Town have expanded significantly in the past 60 years. The area of rural settlements in Zhoucun Town changed from 530.33 hectares in 1962 to 1225.08 hectares, which is an increase of 131%. The average annual growth rates for 1962–1972, 1972–1990, 1990–2000, 2000–2010, and 2010–2020 were 0.29%, 1.17%, 1.81%, 1.26%, and 0.05%, respectively.

The relevant policies of rural settlements since the founding of the People's Republic of China have been divided into five periods according to the node events issued by the policy: the period of transition from “private ownership of farmers” to “one homestead, two systems”, the period of the “unified planning” of homesteads, the period of the “paid use” of homesteads, the period of “connecting increase and decrease" of homesteads, and the period of “separation of three rights” of homesteads. During these five periods, policy has played a role in regulating, guiding, and distributing the changes to rural settlements. The growth rate of rural settlements was relatively slow in the period of transition from “private ownership of farmers” to “one homestead, two systems”. The main policy reason for this was that rural homesteads changed from private ownership to “one homestead and two systems”, and the expansion of rural settlements was inhibited. During the period of “unified planning” for homesteads, with the deepening of reform and opening up, there was a boom in building houses in rural areas, and the growth rate of rural settlements increased. During the period of the “paid use” of homesteads, although the state had strengthened the management of rural settlements, they continued to increase in area. During the period of “connecting increase and decrease” of homesteads and the period of the “separation of three rights” of homesteads, some residential township areas began to be vacated due to the implementation of policies such as “one house for one household” and “connecting increase and decrease”, and the growth rate of rural residential areas slowed down. For example, the growth rates of Dongting Town, Dongwang Town, Gaopeng Town, Kaiyuan Town, Mingyu Dian Town, Nancheng Qu Street, and Xingyi Town were all lower compared to the previous period.

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Distribution Characteristics and Influencing Factors of Rural Settlements in Metropolitan Fringe Area: A Case Study of Nanjing, China

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Abstract: Rural settlement is the core content of rural geography research. Exploring the spatial distribution characteristics and influencing factors of rural settlements can provide reference for the optimization of rural settlements. This paper selected Nanjing as a typical case, based on remote sensing image, using R statistics, kernel density analysis, hot spot detection analysis and semi variogram function; the paper analyzed the spatial, scale and morphological distribution characteristics of rural settlements; and preliminarily analyzed the influencing factors of rural settlements distribution in the metropolitan fringe area. The results showed that: (1) The spatial distribution of rural settlements generally presented a "multi-core" center, and a spatial distribution trend of stepwise decline from the core to the periphery, showing a typical "core-edge" structure. (2) There was a significant spatial difference in the scale distribution of rural settlements, which was characterized by a gradual decrease in the scale of rural settlements with the increase in the distance from the central urban area. (3) The morphological distribution of rural settlements showed spatial differentiation, and the morphological types of settlements mainly included strip, arcbelt, cluster and scatter. (4) The distribution of rural settlements was affected by such factors as terrain, river system, traffic, economic and social development, cultural and policy. The distribution of rural settlements had the location orientation of "low altitude, water affinity and road affinity". The increase in agricultural population, rural economic development, cultural and policy factors played an important role in the distribution of rural settlements in the metropolitan fringe area.

Keywords: rural settlement; spatial distribution; scale distribution; morphological distribution; influencing factors; the metropolitan fringe area; Nanjing

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1. Introduction

Rural settlement is the key research field of rural geography. It is a complex system composed of social economy, natural ecology and other subsystems. It has a certain scale, structure, form and function, and has the main characteristics of complexity and dynamics [1,2]. Since the reform and opening up, with the rapid industrialization and urbanization process in China, the interactive flow of urban and rural resource factors has accelerated, the structure of production factors in rural areas is changing, and the development and evolution of rural settlements are undergoing rapid transformation. Rural settlements are also gradually shifting from "homogeneous" to "heterogeneous", and the transformation and development of rural settlements present a variety of scenarios [3,4]. To promote the implementation of the rural revitalization strategy and build a beautiful countryside suitable for living, working and visiting, the development of rural settlements is an important basis for rural revitalization [5]. Therefore, exploring the spatial characteristics, influence mechanism and reconstruction path of rural settlements in typical regions is a realistic proposition under the background of rural revitalization.

Rural settlement geography is the main branch of rural geography. With the development and transformation of rural geography, the focus of rural settlement geography research is also constantly changing [6]. In the 18th century, geographers began to explore the relationship between people and land in rural areas. In this process, they began to study rural settlements, mainly involving the origin, distribution, type, evolution of rural settlements and their relationship with the environment [7–9]. After the 1950s, research in developed countries began to focus on spatial classification and measurement, research on rural sustainable development and the impact of human decision-making behavior on rural settlements [10–13]; the research content was constantly enriched. By the 1990s, under the influence of many philosophical trends, especially postmodernism, existentialism, idealism, humanistic geography, structuralist geography and critical realism geography, the research paradigm of rural geography in western countries began to transform to the social human direction at this stage [14–16]. With the rapid development of rural industrialization and urbanization, the rural settlement system and spatial structure have been constantly changed. The research on rural transformation and reconstruction has attracted scholars' attention, involving rural economy, society, space and other aspects [17–20]. In terms of distribution characteristics, landscape index, spatial syntax, fractal theory and other research methods are used to study the distribution characteristics of rural settlements from different aspects. For example, Hudson [21] analyzed the distribution system of rural settlements in Iowa on the basis of central place theory and diffusion theory; Weisler [22] studied the settlement space structure of Polynesian bacteria states from the perspective of historical evolution; Conrad [23] used remote sensing technology to measure the expansion of the spatial scale of rural settlements in Uzbekistan; Gallarati [24] combed the context of landscape and environment at various scales and studied the space and type of rural settlements. The research focused on the spatial layout of settlements [25], rural land use [26], settlement scale and form [27], etc. In terms of influencing factors, scholars in western countries started to study the influencing factors of rural settlement layout early. As early as the 1940s, they carried out a discussion on the relationship between rural settlement distribution and geographical environment [28]. With the development of social economy, the focus of research has gradually shifted to the human, economic and social directions, paying more attention to the relationship between population density and rural settlement distribution [29], the relationship between economic transformation and rural settlement distribution [30], the relationship between policy system and rural settlement distribution [31], the relationship between farmers' behavior and rural settlement distribution [30]. The research on influencing factors of rural settlement has experienced a change from focusing on natural factors to comprehensively considering various factors, such as natural, social, economic and cultural factors, and the perspective of research tends to be comprehensive.

The study of rural settlements in China started relatively late. Influenced by the academic research trend of geography in western countries, Lin [32] and other geographers of the older generation began to study rural settlements in the 1930s. Summarizing the research results of rural settlements in China, the study can be roughly divided into four stages: embryonic start (before 1949), preliminary development (1949–1978), rapid development (1978–2000), transformation and reconstruction (2000-present) [33–35]. Taking a general view of the research achievements related to rural settlements in China, a summary was made from the three dimensions of research contents, methods and scales. (1) In terms of research contents, the research mainly focused on the spatial pattern [36,37], evolution characteristics [38], influencing factors [39] and optimal regulation [40] of rural settlements. (2) In terms of research methods, multiple methods such as GIS spatial analysis [41], econometric analysis model [42] and field investigation method [43] were applied to the spatial analysis of rural settlements, showing a trend of cross-integration of multidisciplinary research methods. (3) In terms of research area, the current research mainly focused on the Pearl River Delta [44], Yangtze River Delta [45], Beijing-Tianjin-Hebei [46], etc. The research area mainly focused on the developed coastal areas in the east, and the typical areas (hilly area [47], loess area [48]) were also involved. Some scholars have also paid attention to the spatial pattern of rural settlements in metropolitan areas [49,50]. Through the review, it can be found that the current research focused more on the description of the spatial pattern characteristics of rural settlements. The discussion on the spatial characteristics and formation mechanism of rural settlements in different typical regions was relatively weak.

As a transitional zone between urban and rural areas, the metropolitan fringe is faced with an overall transformation of economic, social and spatial structures. However, the spatial evolution of rural settlements located in the metropolitan fringe was influenced by rural urbanization. Compared with the traditional rural settlements, the rural settlements located in the metropolitan fringe were affected by the radiation and driving effect of the urban core area, and their spatial characteristics were characterized by complexity and diversity [51]. Nanjing is located in the Yangtze River Delta urban agglomeration, which is a metropolis in the coastal development area of eastern China. In the process of rapid urbanization, the rural settlements in the urban fringe are facing transformation and reconstruction, which can better reflect the characteristics of the rural settlements in the metropolitan fringe. In view of this, this paper chose Nanjing as a typical case, based on the interpretation of remote sensing image, using R statistics, kernel density analysis, hot spot detection analysis and semi variogram function, the paper analyzed the distribution characteristics and influencing factors of rural settlements in the metropolitan fringe area. The objective of these analyses is to address the following research goals: (1) What are the distribution characteristics of rural settlements in the metropolitan fringe? (2) What are the factors affecting the distribution of rural settlements in the metropolitan fringe? The research structure of this paper is as follows (Figure 1).

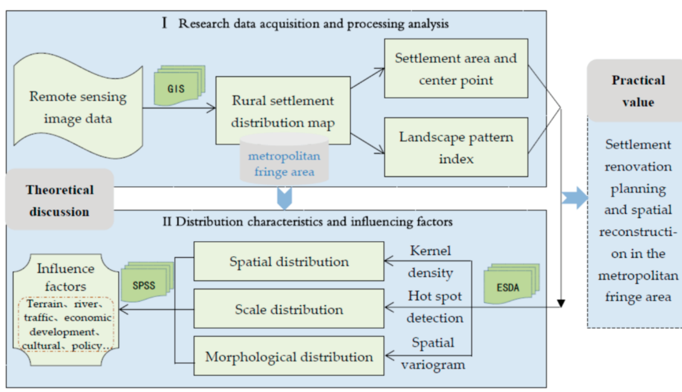

Figure 1. Theoretical analysis framework.

- What are the distribution characteristics of rural settlements in the metropolitan fringe area? Using R statistic, kernel density analysis, hotspot detection analysis and semi-variogram, from three different dimensions: scale distribution, space distribution and morphological distribution, this paper analyzed the spatial distribution characteristics of rural settlements in the metropolitan fringe area.
- What are the factors affecting the distribution of rural settlements in the metropolitan fringe area? On the basis of theoretical analysis of influencing factors, terrain, river system, traffic, economic, social development, cultural and policy factors were adopted to analyze the internal relationship between them and the distribution of rural settlements, and revealed the influencing mechanism of the distribution pattern of rural settlements in the metropolitan fringe area.

2. Materials and Methods

2.1. The Study Area

Nanjing is located in the eastern part of China, the lower reaches of the Yangtze River and the coastal areas near the Yangtze River. It is an important central city in the eastern part of China, an important gateway city for the development of the central and western regions driven by the Yangtze River Delta radiation, and an important node city for the strategic intersection of the eastern coastal economic belt and the Yangtze River Economic Belt. Nanjing covers an area of 6587.02 square kilometers, with a built-up area of 868.28 square kilometers. By 2021, the permanent resident population was 9.4234 million, and the urban population was 8.1889 million, with an urbanization rate of 86.9%. The GDP reached 1635.532 billion. Nanjing as one of the important cities in Yangtze River delta, with the rapid urbanization, rural industrialization, and promote the new rural construction, the dramatic changes in rural landscape, the region characteristics of traditional countryside gradually shift, a shift from rural to urban settlements, space from scattered to gather, lead to the new pattern of rural human settlements faces differentiation restructuring. In addition to its own development, rural settlements in the hinterland of the metropolis are also affected by the radiation of the central city, and their spatial characteristics are characterized by diversity and complexity. In view of this, this paper choosed Nanjing as a typical case to analyze the spatial distribution characteristics and influencing factors of rural settlements, which was typical for studying the development of rural settlements in the metropolitan fringe area (Figure 2).

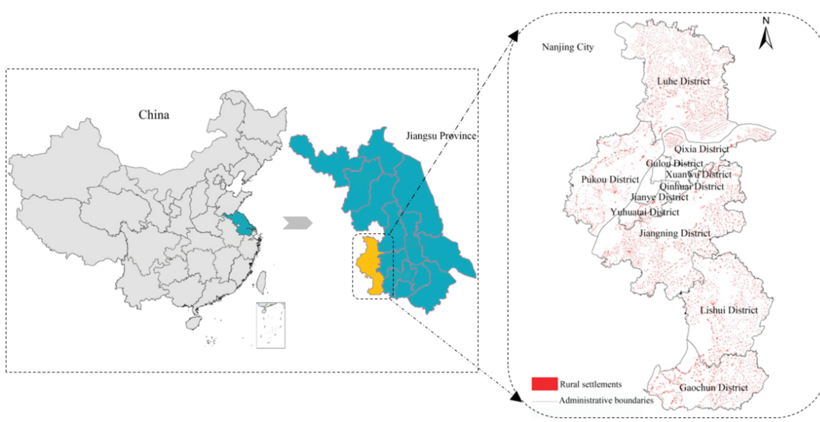

Figure 2. Location map of Nanjing.

2.2. Research Methods

2.2.1. R Statistics

The R statistic was first proposed by Clark and introduced into geographical research by Dacey in 1960 [52]. The core idea is to compare the minimum distance between each point and the distance between its nearest neighbors to obtain the spatial distribution characteristics of points, which can effectively reveal the basic characteristics of aggregation or dispersion of observation patterns and random patterns [53]. The theoretical formula is as follows:

$$R = \frac{r_{obs}}{r_{\exp}}; r_{obs} = \frac{\sum_{i=1}^{n} d_i}{n}; r_{\exp} = 0.5\sqrt{\frac{A}{n}}$$

where r_{obs} is the average distance observation value of the nearest neighbor; $r_{\exp}$ is the expected average distance of the nearest neighbor; d_i is the nearest neighbor distance of rural residential area i; n is the total number of rural residential areas; A is the area of the study area. If $R > 1$, it indicates that the observation mode is more dispersive than the random mode; If $R < 1$, it indicates that the observation mode is more concentrated than the random mode.

2.2.2. Kernel Density Analysis

Kernel Density Estimation (KDE) is a nonparametric method for estimating probability density function and a spatial analysis method for studying the distribution characteristics of certain elements in a region. The basic principle is to estimate the density function of the research object first, and then calculate the density value from the density function. In theory, the higher the density value is, the higher the distribution density of the geographic object is. The calculation formula is as follows [54,55]:

$$f(\mathrm{x},\mathrm{y}) = \frac{1}{\mathrm{nh}^2}\sum_{i=1}^{n} K(\mathrm{d}_{\mathrm{i}}/\mathrm{h})$$

where f(x,y) is the density estimation of (x,y) position; n is the observed value; h is the smoothing parameter; K is the kernel function; d_i is the distance between (x,y) position and the ith observed position. Kernel density estimation is calculated by running ArcGIS10.2 software.

2.2.3. Hot Spot Detection Analysis

The local spatial autocorrelation analysis method is used to identify the possible agglomeration pattern in the local space, judge the spatial correlation between the rural settlement density and the settlement density in the surrounding areas, so as to show its spatial agglomeration or discrete characteristics. The theoretical model of G_i^* index is as follows [56,57]:

$$G_i^*(d) = \sum_{j=1}^{n} W_{ij}(d) X_j / \sum_{j=1}^{n} X_j$$

where W_{ij} is the spatial weight matrix, spatial adjacency is 1, and non adjacency is 0. If G_i^* is positive and significant, it indicates that the rural settlement density around the location is concentrated in high value space. On the contrary, if G_i^* is negative and significant, it indicates that the rural settlement density around the location is low.

2.2.4. Semi Variant Function

The rural settlement forms are different with different location directions of villages, and show certain spatial differentiation rules, which belong to regionalized variables. Semi variogram is an effective tool to describe the spatial variation rules and spatial structure of regionalized variables. In this paper, semi variogram method based on landscape shape index (LSI) is used to explore the distribution characteristics of rural settlement morphology. The theoretical formula is as follows [58,59]:

$$\gamma(h) = \frac{1}{2N(h)}\sum_{i=1}^{n}[Z(x_i) - Z(x_i + h)]^2$$

The spatial variation function is generally represented by the variance graph (Figure 3), which is the corresponding graph between the variation function value γ(h) of a certain lag variable H and this H. It is defined under the condition that the regionalized variable satisfies the stationary and eigenassumptions. When the semi variogram increases, the spatial autocorrelation decreases. The distance h is the most important characteristic of variance graph. Another important characteristic quantity is the direction, that is, isotropy and anisotropy. Where, is called block gold value, which represents the discontinuous variation when the regionalization variable is smaller than the observation scale. C is the structural equation; C + C_0 is the base value, which represents the stationary value of semi-variogram variable as the spacing increases to a certain scale. a is the range, which represents the interval when the semi-variogram reaches the abutment value. The commonly used fitting models include spherical model, exponential model, Gaussian model, power exponential model, logarithmic model.

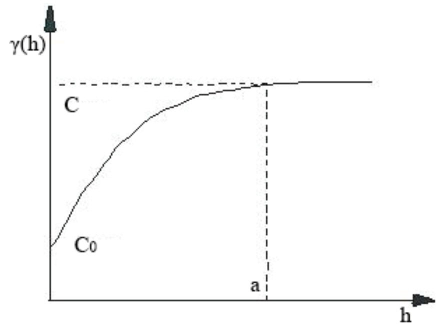

Figure 3. Model variogram.

2.3. Data Collection

The research data mainly included three parts: the remote sensing image data, the basic geographic data and the economic and social data.

(1) The remote sensing image data. Based on Google earth high-definition remote sensing image in 2022, the resolution was 30 m, and using Arcgis10.2 software, through geometric correction, coordinate registration, visual interpretation and vectorization, the rural settlement data in Nanjing were obtained (Figure 2). It was mainly used to analyze the distribution characteristics of rural settlements in Nanjing.

(2) The basic geographic data. DEM data were obtained from the geospatial data cloud platform (http://www.gscloud.cn, accessed on 2 September 2022), the resolution was 30 m; river and traffic data were obtained from the national geographic information resources directory service system. It was mainly used to analyze the influencing factors of rural settlement distribution in Nanjing.

(3) The economic and social data. The economic and social data were obtained from Jiangsu Statistical Yearbook, Nanjing Statistical Yearbook, Nanjing National Economic and Social Development Statistical Bulletin and other relevant materials. It was mainly used to analyze the influencing factors of rural settlement distribution in Nanjing.

3. Results

3.1. Distribution Characteristics

3.1.1. Spatial Distribution Characteristics of Rural Settlements

The spatial distribution of rural settlements presented a pattern of "agglomeration" in the metropolitan fringe area. Based on ArcGIS10.2 software, the centroid of patches of rural settlements was extracted and converted into point format. By using the Near tool in GIS software, the nearest spatial distance between rural settlements was calculated, and the R statistic and standardized Z value of rural settlements were calculated. The results showed that the R statistic of rural settlements in Nanjing was less than 1, and the standardized Z value was less than -1.96, which further indicated that the spatial distribution and aggregation trend of rural settlements were significant, showing the characteristics of "agglomeration type" spatial pattern in Nanjing.

The density distribution of rural settlements showed a "multi-core" center in the metropolitan fringe area, and the high-density were located in the agricultural county far from the built-up area. Based on ArcGIS10.2 analysis software, the vector data of rural settlements in Nanjing were converted into raster data, and the density distribution map of rural settlements in Nanjing was generated by Kernel density analysis method. The density of rural settlements in Nanjing was divided into five grade areas by Jenks natural fracture point method: low-density area (0–6.43 units/km^2), sub-low-density area (6.44–12.87 units/km^2), medium density area (12.88–19.29 units/km^2), sub-high-density area (19.30–25.73 units/km^2), high-density area (25.74–32.16 units/km^2), and output the spatial distribution Kernel nuclear density map of rural settlements in Nanjing (Figure 4). As shown in Figure 4: (1) The spatial distribution of rural settlements in Nanjing generally showed a "multi-core" center, and the spatial distribution showed a stepwise decreasing trend from the core to the periphery, showing a typical "core-edge" structure. (2) The areas with high-density of rural settlements were distributed in Luhe and Jiangning, with the density values above 20.08 units/km^2. These areas were located in plain and polder areas, with flat terrain and rich hydrothermal resources. At the same time, agricultural production and agricultural economy in these areas developed rapidly, which also had a certain impact on the expansion and development of rural settlements. Medium density areas were mainly distributed in Lishui, Gaochun and other areas. The low-density areas were mainly distributed around the urban core area and the periphery of the new urban area, the villages around the urban core area were radiated by the city, and the population was urbanized locally, rural settlements gradually evolved into urban settlements, resulting in a small distribution of rural settlements.

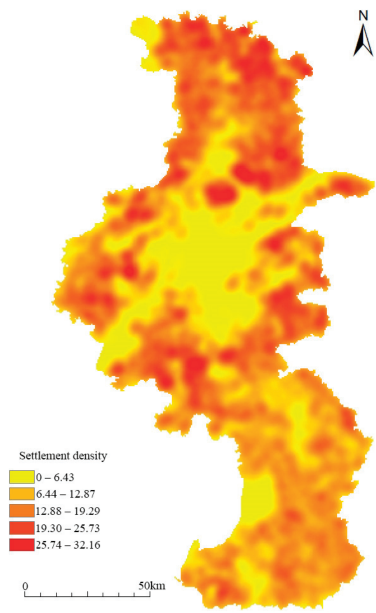

Figure 4. Density distribution of rural settlements in Nanjing.

3.1.2. Scale Distribution Characteristics of Rural Settlements

The scale distribution of rural settlements showed the autocorrelation of agglomeration in the metropolitan fringe area. Taking the rural settlement patch area as the analysis variable, the global G(d) index was used to detect the global agglomeration characteristics of the rural settlement land scale in Nanjing. According to the calculation, the G(d) index value of the rural settlement scale in Nanjing in 2022 was 0.582, and the distribution of rural settlement size in Nanjing showed positive spatial correlation. This indicated that the high value agglomeration characteristics of rural settlement scale distribution were significant in Nanjing.

The scale distribution of rural settlements showed a pattern of "hot spot clustering in the near suburbs and cold spot clustering in the far suburbs". The hot spot detection tool was used to analyze the characteristics of local scale differentiation of rural settlements, and the G_i^* statistical value of the rural settlement land scale in each administrative village in Nanjing was obtained. The G_i^* score value was divided into cold and hot spots, and the hot spot map of rural settlement scale distribution was produced (Figure 5). Figure 5 showed that: (1) There was a significant spatial difference in the size distribution of rural settlements in Nanjing, showing that the size of rural settlements gradually decreased with the increase in the distance from the central city. The overall distribution pattern was that the size of rural settlements in the near suburbs was large, the size of rural settlements in the outer suburbs was moderate, and the size of rural settlements in remote areas was small. (2) The large-scale rural settlements in Nanjing were concentrated in the suburban areas of the central urban area. The suburban areas mainly attract the rural population, capital, technology and other production factors to the city and the suburbs due to the strong pull of the urban economy, thus changing the location characteristics of rural settlements in the suburbs, and thus changing the scale of rural settlements. (3) The small rural settlements in Nanjing were mainly distributed in rural areas far from the built-up areas, which were limited by the radiation of the metropolis and were still dominated by traditional agriculture. The lack of external power and limited economic development were not conducive to the settlements agglomeration, which led to the small scale of rural settlements.

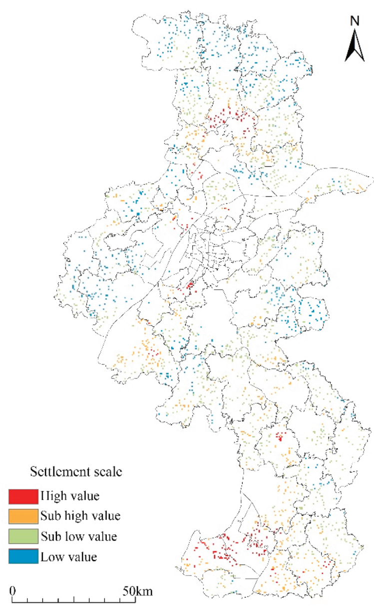

Figure 5. Hot spots pattern of rural settlements scale in Nanjing.

3.1.3. Morphological Distribution Characteristics of Rural Settlements

The morphological distribution of rural settlements had good stability, and the spatial self-organization of morphological distribution was strong in the metropolitan fringe area. The semi variation function was used to express the morphological distribution characteristics of rural settlements in Nanjing. Taking landscape shape index (LSI) of rural settlements as an indicator, it was given to the geometric center of each town as attribute data. The sampling step was set to 2000 m, and the experimental variation function was calculated, respectively. The best model was fitted and selected, and Kriging interpolation was carried out (Table 1, Figure 6). (1) From the perspective of the abutment value and nugget value indicators, the abutment value $C + C_0$ was 0.0402, while the nugget value C_0 was 0.0378, which had a medium degree of spatial autocorrelation. This indicated that structural factors (topography, geomorphology and other geographical and environmental factors) and random factors (economic development, policies and systems, etc.) jointly played a role in the differentiation of rural settlements. (2) From the model selected for fitting, the spatial fitting model selected by the least square method was Gaussian model, and the determination coefficient R^2 reached 0.895, indicating that the distribution of rural settlements had good stability, and the spatial self-organization of rural settlements was strong in Nanjing. (3) From Kriging interpolation fitting diagram, the γ(h) curve in each direction had a certain regularity, indicating that the distribution pattern of rural settlement morphology had the characteristic of autocorrelation. The spatial distribution morphology had a unique internal structure, showing a "bimodal" morphological distribution characteristic.

Table 1. Fitting parameters of variation of rural settlement morphology distribution.

Indicators	a	$C + C_0$	C_0	Fitting Model	R^2
Parameter value	797,024	0.0402	0.0378	Gaussian	0.895

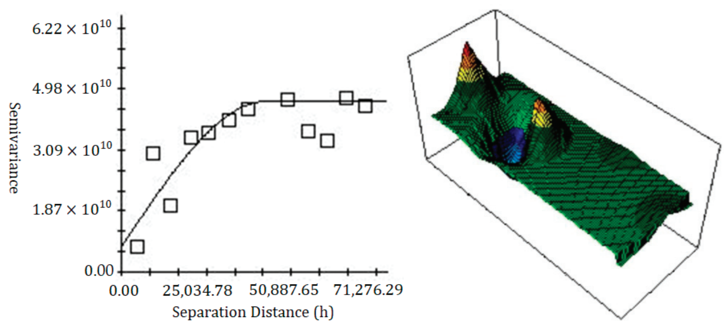

Figure 6. Variation function diagram of rural settlement morphology distribution in Nanjing.

The rural settlements morphology has significant spatial differentiation characteristics in the metropolitan fringe area. In order to more accurately consider the differences in rural settlement morphology in the metropolitan fringe, based on the interpretation and analysis of remote sensing images of Nanjing and the field visits and surveys of villages in different distribution locations such as Qixia District, Jiangning District, Luhe District, Pukou District, Lishui District, Gaochun District, it was found that the rural settlement morphology in the metropolitan fringe mainly existed four types (Table 2, Figure 7).

Table 2. The morphological types and basic characteristics of rural settlements in Nanjing.

Type	Distribution	Features
Strip type	It is mainly distributed in Qixia District, such as Liudong Village, Shuangqiao Village, Wangpeng Village.	The river network is dense, and the agricultural production mode is mainly traditional paddy field planting. The cultivation radius is small, and the distribution along the riverbank highland is in the form of strip extension.
Arcbelt type	It is mainly distributed in Gaochun District, such as Shangshang Village, Laozhuang Village, Xinyang Village.	The settlements are built along the river, affected by the trend of the river, the rural settlements are arc-shaped. The farming radius is large and the village scale is small, but tspatial layout is compact.
Cluster type	It is mainly distributed in Lishui District and Jiangning District, such as Qingwei Village, Jiufangdian Village.	The cultivated land is rich and has a large farming radius, which is easy to form large-scale settlements. The rural settlements have a regular shape, a large distribution density and a cluster distribution rural settlement pattern.
Scatter type	It is mainly distributed in Luhe District and Pukou District, such as Hewang Village, Xialiang Village.	The cultivated land resources are relatively rich, and the river system is relatively developed. However, affected by the hilly terrain, the distribution pattern of small and medium density scattered rural settlements has been formed.

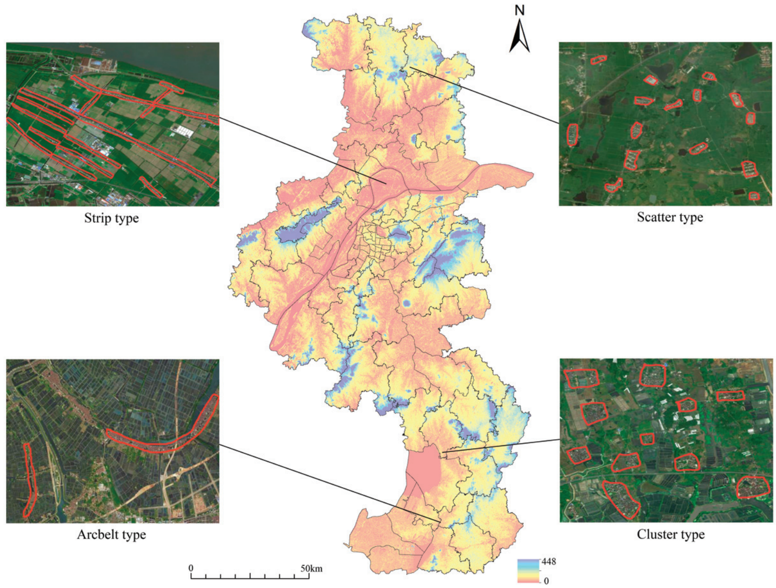

Figure 7. Distribution of rural settlement types in Nanjing.

3.2. *Analysis of Influencing Factors*

Theoretically, the distribution of rural settlements is closely related to natural, economic, social, cultural and policy [60,61]. From the terrain, river system, traffic, economic and social development and policy factors, this paper mainly discussed the influencing factors of rural settlement distribution in the metropolitan fringe area.

3.2.1. Rural Settlements Distribution and Terrain Factors

Terrain condition is an important factor affecting agricultural production and life, as well as the basic factor forming the spatial pattern of rural settlements. According to the topographic characteristics of the study area, the altitude was divided into five levels: ≤100 m, 100~200 m, 200~300 m, 300~400 m and ≥400 m. The DEM raster data was carried forward into vector data according to the classification and analyzed by stacking with the distribution map of rural settlements. It revealed the internal relationship between the spatial distribution of rural settlements and the topography in the metropolitan fringe (Table 3). According to Table 3, within the altitude of 200 m, the distribution of rural settlements was the largest, and the proportion of the distribution of rural settlements gradually decreased with the increase in elevation. The patch density of rural settlements also showed an obvious decreasing trend with the increase in elevation. At the same time, with the increase in altitude, the distance index also gradually increased, indicating that the spatial distribution of rural settlements was more dispersed, and the density was weakening. It showed that the spatial distribution of rural settlements had a significant "altitude location directivity" in the metropolitan fringe area.

Table 3. Landscape index of spatial distribution of rural settlements at different altitudes.

Altitude	Area (km^2)	Density (Units/km^2)	Distance Index (Units/km^2)
≤100 m	20,345	0.56	0.32
100~200 m	18,973	0.52	0.35
200~300 m	10,294	0.43	0.44
300~400 m	5903	0.33	0.47
≥400 m	1003	0.15	0.55

3.2.2. Rural Settlement Distribution and River System Factors

The distribution of river system is also an important factor affecting the spatial pattern of rural settlements in the metropolitan fringe area. This paper, based on the river system in Nanjing, calculated the shortest distance D from rural settlements (points) to rivers (lines), and divided the shortest distance D into six levels: $D \leq 500$ m, 500 m $< D \leq$ 1000 m, 1000 m $< D \leq$ 1500 m, 1500 m $< D \leq$ 2000 m, 2000 m $< D \leq$ 2500 m, 2500 m $< D \leq$ 3000 m. By counting the percentage of rural settlement patches within different distance levels between rivers and rural settlements, the relationship between the spatial pattern of rural settlements and the distribution of river system was analyzed (Table 4). Table 4 showed that when the shortest distance D from rural settlements to the river was less than 1000 m, the total number of patches in rural settlements was 14,679, accounting for 80%; while when D was more than 2000 m, the total number of patches in rural settlements was 325, accounting for only 1.8%. Therefore, with the increasing radius from the river, the number of rural settlement patches showed a decreasing trend. The farther the distance from the river system, the less the distribution of rural settlements, and the spatial distribution of rural settlements showed a significant "hydrophilic distribution location directiveness".

Table 4. Number of patches at different distances from rural settlements to rivers in Nanjing.

Minimum Distance	Number of Plaques (Units)	Proportion (%)
$\leq$500 m	8786	48.78
500 m $< D \leq$ 1000 m	5893	32.71
1000 m $< D \leq$ 1500 m	2134	11.84
1500 m $< D \leq$ 2000 m	876	4.86
2000 m $< D \leq$ 2500 m	239	1.32
2500 m $< D \leq$ 3000 m	86	0.48

3.2.3. Rural Settlement Distribution and Traffic Factors

Transportation is a prerequisite for commodity exchange, which has an important impact on the spatial distribution pattern of rural settlements in the metropolitan fringe area. The road is the axis connecting rural settlements, and the main channel for material flow and information flow transmission between settlements. With the increase in settlement scale, the demand for people flows and logistics between settlements will increase synchronously, and the density of road network between settlements will also increase rapidly. The convenience of transportation will also promote the expansion of settlement scale, and there is a certain mutual promotion between them [62].

In order to quantitatively reflect the relationship between traffic and rural settlements, based on ArcGIS10.2 analysis software, taking 500 m as the buffer radius, the road network was analyzed for buffer zone, and the 12 buffer zones obtained were superimposed, and analyzed with the layer of rural settlements in Nanjing to obtain the relationship between the distribution of rural settlements and the traffic network (Figure 8). Figure 8 showed that the first section (<1500 m) was a stable section, where rural settlements were mainly distributed. The second section (1500~4500 m) was a rapid reduction section, and the number and area of rural settlement patches were significantly reduced compared with the first section. The third section (>4500 m) was a slowly decreasing section, with a stable decline rate and a small number of rural settlements. Therefore, traffic factors played an important role in the distribution of rural settlements in the metropolitan fringe area, showing the characteristics of "road affinity" distribution.

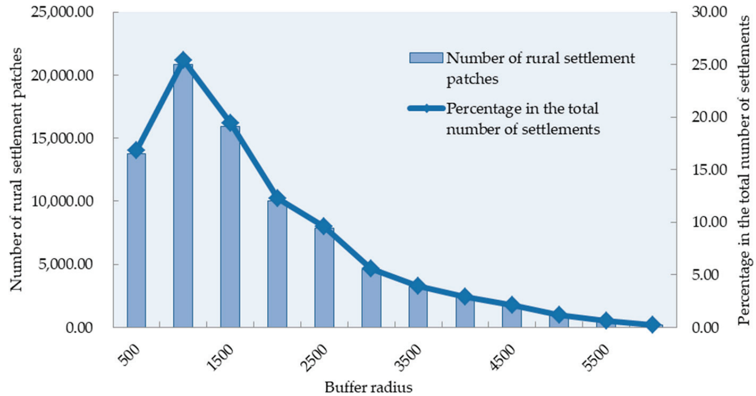

Figure 8. The rural settlements in different distance zones to roads in Nanjing.

3.2.4. Rural Settlement Distribution and Economic Social Development Factors

Economic social development factors are important factors affecting the spatial distribution of rural settlements, which are mainly reflected through agricultural population growth, industrial structure adjustment and urbaniztion [63,64]. In view of this, the paper selected 10 factors reflecting the economic social development and used factor analysis to reveal the economic social development factors that affect the spatial distribution of rural settlements in Nanjing. Firstly, SPSS18.0 software was used to conduct KMO and Bartlett tests. The results showed that KMO was 0.658, and Bartlett's p value was $0.0495 < 0.05$, indicating the feasibility of factor analysis. Secondly, according to the data calculation, the characteristic root was greater than 1, and there were two common factors that met the requirements. According to Table 5, the cumulative variance contribution rate was 86.69%, so two common factors could be extracted to replace the original data indicators.

Table 5. Factor analysis results.

Common Factor	Characteristic Value	Contribution Rate	Cumulative Contribution Rate
1	7.52	58.76	58.76
2	4.88	27.93	86.69

Table 6 showed that, the common factor 1 was mainly determined by indicators X_1, X_4, X_9 and X_{10}, which mainly reflected that agricultural population was the direct power to affect the distribution pattern of rural settlements. The premise of rural settlement construction was to meet the residential needs of farmers, so the increase in agricultural population and rural labor force was positively related to the size of rural settlement space. With the development of urbanization, the increase in the proportion of urban population was conducive to the regularization of the spatial distribution of rural settlements and promoted the development of rural settlements towards urban settlements. The common factor 2 was mainly determined by indicators X_3, X_5, X_6 and X_8, which mainly reflected the development status of rural economy. The level of rural economic development indirectly affects the spatial distribution pattern of rural settlements. With the development of rural economy, it provides economic guarantee for the development of rural settlements, the villages with the higher income of farmers have the larger area of rural settlements. Therefore, the distribution characteristics of rural settlements were mainly affected by agricultural population and rural economic development in the metropolitan fringe area.

Table 6. Selection of explanatory variables.

Variable	Amount of Load	
	The Common Factor 1	The Common Factor 2
Total agricultural population X_1	0.983	−0.343
Total grain output X_2	0.563	−0.422
Agricultural income X_3	0.523	0.936
Rural labor force X_4	0.974	0.378
Per capita net income of farmers and herdsmen X_5	0.632	0.902
Total output value of agriculture, forestry, animal husbandry and fishery X_6	−0.453	0.927
Primary industry income X_7	0.378	0.785
Secondary industry income X_8	0.403	0.893
Urbanization rate X_9	0.945	0.342
Population density X_{10}	0.967	−0.203

3.2.5. Rural Settlement Distribution and Cultural Policy Factors

Cultural and policy factors play an important role in regulating the distribution pattern of rural settlements. Cultural factors include cultural customs, religious beliefs, etc, these are important components of China's traditional culture, which have a profound impact on the ideology of farmers and have an important impact on the distribution and form of regional rural settlements, which is the main reason for the formation and morphological evolution of many famous villages in Nanjing [65]. Policy factors had an important impact on the distribution of rural settlements in the metropolitan fringe. On the one hand, policy factors affect the distribution pattern of rural settlements through direct administrative mechanisms; on the other hand, it affects the behavior of residential location by indirectly acting on the behavior subject of farmers [66]. Land use planning, industrial structure adjustment and administrative division adjustment have a profound impact on the development and layout of rural residential areas in Nanjing. In recent years, with the implementation of the national strategy of rural revitalization, the spatial renovation policies of Nanjing, such as comprehensive land consolidation, the removal of villages and towns, and the construction of central villages, have affected the form and scale of rural settlements in Nanjing, it has promoted the transformation of rural construction space into a spatial layout form of large dispersion and small concentration. In addition, the adjustment of administrative divisions in Nanjing has changed the infrastructure level of some rural settlements, which had also become an important factor affecting the distribution and spatial reconstruction of rural settlements.

To sum up, the physical geographical environment (terrain, river, etc.) provided the basic conditions for the distribution of rural settlements in the metropolitan fringe area. With the continuous development of urbanization, traffic accessibility, agricultural population growth, rural economic development, cultural and policy have become the dominant factors for the distribution of rural settlements in the metropolitan fringe. The interaction of these factors has an increasing impact on the evolution and reconstruction of rural settlements in the metropolitan fringe in the future (Figure 9).

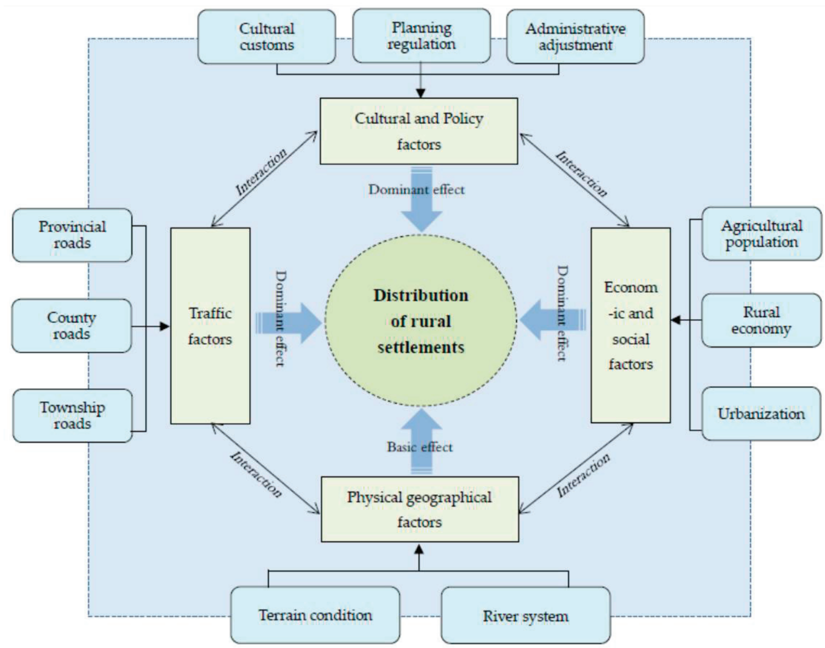

Figure 9. Impact mechanism of rural settlement distribution in the metropolitan fringe area.

4. Discussion

(1) Rural settlement is the evolution of the long-term integration of human and nature. Rural settlement is a complex system involving social, economic, ecological, resource and other factors. The distribution of rural settlements is characterized by regional differences. At present, the academic community has carried out research on the distribution law of rural settlements in different regions. Tang [67], Guo [68], Ma [69] and others have focused on the distribution law of rural settlements in northwest China. They have selected Yulin City in Shaanxi Province, Qin'an County in Gansu Province, Tongwei County in Gansu Province, such as case to carry out empirical research. They found that rural settlements in northwest China presented a small-scale decentralized distribution pattern; the natural geographical environment (elevation, slope, river, farmland, etc.) had a decisive impact on the distribution of rural settlements in northwest China, and the change of natural environment directly affected the distribution of rural settlements.

By comparison, this paper chose the rural settlements in the metropolitan fringe area as the research object. Through the empirical analysis of Nanjing, it was found that the distribution of rural settlements in the metropolitan fringe area presented a large-scale agglomeration distribution pattern, which was mainly affected by economic and social development factors, while the natural environment factors had less impact on the distribution of rural settlements. This conclusion was quite different from the distribution law of rural settlements in northwest China. This difference was mainly attributed to the fact that the metropolitan fringe area was a transitional zone between cities and villages. The rural settlements in the metropolitan fringe area were a concentrated reflection of the human-land relationship, with significant characteristics of rapid economic development and urbanization. Under this influence, the rural settlements in the metropolitan fringe area were facing or experiencing dramatic spatial evolution and modern transformation, and their spatial distribution and evolution patterns were different from those of the rural settlements in other regions.

(2) The spatial distribution of settlements can be used as a basis to show the comprehensive relationship between human activities and the natural environment in a region

and has reference value for the optimization of the spatial pattern of settlements. Based on the analysis of the distribution characteristics and influencing factors of rural settlements, combined with the field research in this typical region, the optimization of the layout of rural settlements in the metropolitan fringe area was attempted to be divided into four types: urban transformation type, key development type, limited development type, and relocation type [70–72].

- Urban transformation type. This type refers to the rural settlements distributed at the edge of the county seat and the central town and near the main traffic arteries. Suggestions for optimizing layout: bring rural residential areas close to built-up areas or central towns into the urban planning system, actively guide the transformation of rural residential areas into urban residential areas, increase the construction of transportation and other infrastructure, emphasize the functional zoning of internal land, and form an all-round and multi-level land use pattern.
- Key development type. This model mainly refers to the rural settlements which are far away from the urban center, large scale, transportation location and good level of economic development. Suggestions for optimizing layout: the rural residential areas with small scale and poor conditions in towns and townships should be relocated to the central village nearby, focusing on the construction of the central village within the city scope; and improve the basic and public service facilities of central village, based on the resource advantages of central village, develop and expand the characteristic industries, attract the surrounding small natural villages to gather in the central village.
- Limited development type. On the premise of the stability of the original spatial pattern of rural residential areas, this type of rural residential areas should be rebuilt and reasonably developed. Through promoting the renovation and construction of rural residential areas, the potential of the village's internal land use should be fully exploited, and the village, especially the hollow village, should effectively "lose weight" to improve the intensive use of rural residential land in hilly areas.
- Relocation type. This type of rural residential area is mostly located in areas with poor suitability level of urban residential areas, with shortage of cultivated land resources, inconvenient transportation and more villagers going out to work. Suggestions for optimizing layout: gradually move to another place by taking multiple approaches such as urban resettlement, central village resettlement, small villages merging into large villages and building independent new villages.

5. Conclusions

This paper took the rural settlements in the metropolitan fringe area as the research object, taking Nanjing as a typical case. From three aspects of spatial distribution, scale distribution and form distribution, this paper analyzed the distribution characteristics of rural settlements in the metropolitan fringe area. On this basis, this paper tried to reveal the influencing factors in the distribution of rural settlements in the metropolitan fringe area. The following conclusions were drawn:

(1) The spatial distribution of rural settlements was significant in the metropolitan fringe area, it showed the characteristics of "agglomeration" spatial pattern. The spatial distribution of rural settlements generally presented a "multi-core" center, and a spatial distribution trend of stepwise declined from the core to the periphery, showing a typical "core-edge" structure. The core of rural settlements in the metropolitan fringe was mainly distributed in the agricultural counties in the outer suburbs, while the surrounding villages in the main urban area were radiated by the city, and the population was urbanized locally. Rural settlements gradually evolved into urban settlements, resulting in less spatial distribution of rural settlements.

(2) There were significant differences in the scale distribution of rural settlements in the metropolitan fringe area, showing that the scale of rural settlements gradually decreased with the increase in the distance from the central city. The overall distribution pattern was that the scale of rural settlements in the near suburbs was large, the scale of rural

settlements in the outer suburbs was moderate, and the scale of rural settlements in remote areas was small. The closer the rural settlement was to the built-up area, the more affected by human activities and policy factors, the easier it was to form a large-scale rural settlement distribution.

(3) The morphological distribution of rural settlements had good stability in the metropolitan fringe area, and the spatial self-organization of the distribution of rural settlements was strong, which showed that structural factors (topography, geomorphology and other geographical environmental factors) and random factors (economic development, policy system, etc.) jointly played a role in the differentiation of rural settlements in the metropolitan fringe area. The morphology of rural settlements mainly included strip, arcbelt, cluster, scatter types, the formation of different settlement types was closely related to the natural geographical environment, historical and cultural factors.

(4) The distribution of rural settlements in the metropolitan fringe area was mainly affected by topography, river system, traffic, economic development, cultural and policy. Among them, the distribution of rural settlements had the location orientation of "low altitude, close to river and close to road", and the natural geographical environment has laid the foundation for the distribution pattern of rural settlements in the metropolitan fringe area. The increase in agricultural population and the development of rural economy played a leading role in the distribution of rural settlements in the metropolitan fringe area; the cultural and policy factors played an important guiding role in the distribution and reconstruction of rural settlements in the metropolitan fringe area.

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Article

Evaluation for Appropriate Tillage of Sandy Land in Arid Sandy Area Based on Limitation Factor Exclusion Method

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Abstract: Investigating and evaluating the quantity and spatial distribution of arable sandy land in arid and semiarid sandy areas is of great significance for the sustainable development and utilization of sandy land resources and the maintenance of the stability of the structure and function of regional ecosystems. Based on the characteristics of sandy soil, being without structure and susceptible to wind erosion, this study used the limiting factor exclusion method to investigate and evaluate arable sandy land in arid and semiarid areas. All sandy soils were taken as the evaluation objects of arable sandy land (including visible sandy land and invisible sandy land). On the basis of following the principle of ecological protection, the evaluation indicators and limiting factor exclusion evaluation methods of arable sandy land were determined. The results of Hangjin Banner are as follows: the total area of the visible sandy land and the recessive sandy land was 1.2 × 106 hm^2; the visible sandy land accounted for 42.6%, and the invisible sandy land accounted for 57.5%. However, only 7.7% of the sandy land was suitable for farming, which is the current cultivated land of bare sand and sandy soil, extremely-low-coverage grassland, inland tidal flats, and other saline-alkali land. Even if these arable sandy lands are to be used sustainably after reclamation, reasonable ecological protection, irrigation engineering measures, and field protective farming measures must be taken. It is hoped that this study can provide a valuable reference for the sustainable development and utilization of arable sandy land and desertification control in arid and semiarid areas.

Keywords: appropriate tillage sand land; land survey; limiting factor; land evaluation

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1. Introduction

Desertification is a common type of land degradation in ecologically fragile areas [1,2]. It can threaten regional environmental security and is becoming an important barrier that hinders the global economy and the transition to a sustainable society [3]. In general, desertification refers to land degradation that is dominated by sand or gravel due to natural and human factors under various climatic conditions [4]. Sandy land refers to the land formed by the process of desertification, and the surface is mainly sand (or gravel) material. Research shows that desertification may be caused by natural or human factors, among which human factors play an important role in the process of land desertification [5,6]. In arid and semiarid areas, unreasonable land use will lead to the decline of vegetation coverage and the destruction of soil structure, which will lead to desertification [7,8]. Excessive reclamation is an important inducer of land desertification [9]. The growing coverage of sandy land is becoming an important issue and poses a serious threat to the sustainability of human habitation, especially in China [10]. Therefore, the protection and management of desertification land and the sustainable utilization of desertification land resources have attracted extensive attention from government departments and researchers [11,12].

There are two different views on the utilization of sandy land in the existing research. One is to protect the sandy land and abandon it completely, so that some sandy land that can be improved by engineering, is suitable for farming, and that can produce food has not exerted its production potential [13,14]. Second, there is a lack of supervision to include sandy land in the reserve resource pool of cultivated land. The disorderly and excessive development of sandy land destroys the balance of regional water resources and accelerates the speed of land wind erosion and desertification [15–17]. The existing studies on land desertification mainly focus on the process and causes of desertification [18,19], the desertification degree evaluation method and evaluation index system [20,21], desertification risk analysis [22,23], dynamic monitoring of land desertification [24,25], and sand control [26]. In addition, under the climate conditions of arid and semiarid areas, sandy soil flows in the wind because its sand particles are non-cohesive and single granular, resulting in rapid changes in land cover and landform [27,28]. As a result, the evaluation objects of existing studies on sandy land are mostly aeolian sandy soil or sandy land, which cannot cover all sandy soils [29,30]. Obviously, the evaluation and explanation of suitable sandy land in the existing research is insufficient, and it is necessary to carry out more detailed and targeted research to scientifically and rationally promote the protection and sustainable use of sandy land.

Therefore, this study defined suitable arable sandy land as sandy land suitable for crop growth, depending on natural conditions or with certain artificial measures. Based on the above characteristics of unstructured and wind-eroded sandy soils in arid and semiarid areas, the evaluation object of arable sandy soil was determined as all sandy soils without considering surface cover (land use type), and the study area is Hangjin Banner, Inner Mongolia, which is an arid and semiarid area with an obvious current land use structure. Then, the limitation factor exclusion method was used to carry out the investigation and evaluation of arable sandy soil in arid and semiarid areas, determine the quantity and distribution of arable sandy soil in the region, treat the development and protection of sandy soil from the perspective of ecological security, and put forward the direction and measures of arable sandy land development. We hope that the research results can provide a valuable reference for the sustainable development and utilization of arable sandy land and desertification control in arid and semiarid areas.

2. Materials and Methods

2.1. Study Area

Hangjin Banner is located in southwestern Inner Mongolia, northwest Ordos city, with a total area of 1.89 × 104 km^2 (Figure 1). It is located in a mid-temperate monsoon continental climate with low annual rainfall and an uneven regional distribution of rainfall. The average annual rainfall is 281 mm, decreasing from southeast to northwest. The rainfall is concentrated from June to August, and the interannual variation is large. The annual evaporation is 2630 mm, which belongs to the arid and semiarid area. The topography of Hangjin Banner consists of alluvial plains of the Yellow River, sandy deserts, wavy high plains, and hills inlaid and arranged, with an obvious zonal distribution pattern (http://www.hjq.gov.cn/, 1 April 2022). The soil type is mainly aeolian sandy soil, which is distributed along the northern edge of the Kubuqi Desert and the Mu Us Sandy Land, accounting for 58.7% of the total area of Banner. Other soil types, such as fluvo-aquic soil, saline soil, brown calcium soil, chestnut soil, and grey desert soil, are sporadically distributed. Due to the large variability in annual precipitation and the loose sandy substances in sediments, Hangjin Banner will have a large risk of desertification with unreasonable development. In 2020, Hangjin Banner's Gross Domestic Product (GDP) was 12.8×10^9 Chinese Yuan (CNY), a 2.3% increase from 2019, and the per capita disposable income was 33,084 CNY, a 3.5% increase from 2019 (The Government of Hangjin Banner, 2021). In addition, because of the limitation of natural and socioeconomic conditions in Hangjin Banner, the current structure of land use is embodied in the high proportion of grassland and unused land (sand land), accounting for 50.0% and 28.8%, respectively, and the proportion of cultivated land and forestland is low, 3.5% and 9.2%, respectively (http://nmggky.cn/ 1 April 2022). Because Hangjin Banner has obvious regional differences in land use, with obvious differences between the planting areas along the Yellow River in the north and the high plains and sandy animal husbandry areas in the central and southern parts, it was selected as a typical case for empirical research.

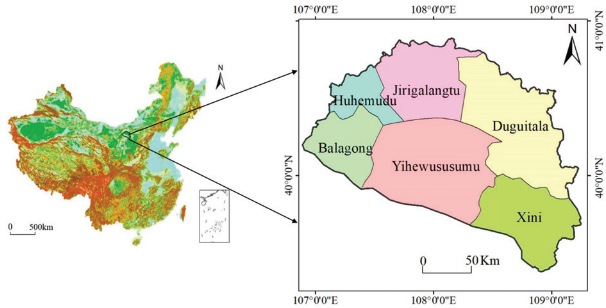

Figure 1. Location of the research area.

2.2. Data Source and Process

Hangjin Banner has a vast area and requires three remote sensing images to cover the entire administrative area. The strip numbers on the OLI-TIRS remote sensing images were 128/032, 129/032, and 128/033. Summer is the best time to extract information on sand, grassland, and other land types because vegetation grows luxuriantly. Therefore, the acquisition time of the Hangjin Banner Landsat 8 remote sensing images was from 1 August 2020 to 1 September 2020. At the same time, the cloud cover of the three remote sensing images was less than or equal to 4%. The pre-processing of remote sensing images includes radiometric correction, atmospheric correction, and image mosaicking and cropping. The data of soil, meteorological, socioeconomic, and land use came from the second soil census in Hangjin Banner, the daily value dataset of climate data in the past 30 years, "Hangjin Banner's National Economic Statistics (2004–2020)", and the land of Hangjin Banner in 2020 Utilize change investigation database (1:10,000), "Hangjinqi Salinization Grade Map" (1:250,000).

2.3. Evaluation Method

2.3.1. Clarity of Evaluation Object

The "Land Use Status Classification" (GB/T 21010-2007) defines sandy land as land with a surface covered by sand and basically without vegetation. Low vegetation coverage and bare sandy soil on the surface can be perceived through the surface morphology of the land, which is an intuitive and realistic reflection of land degradation. This study defined the existing sandy land as visible sandy land and defines other land use types except the existing sandy land, and its soil texture is sandy soil as invisible sandy land (Figure 2).

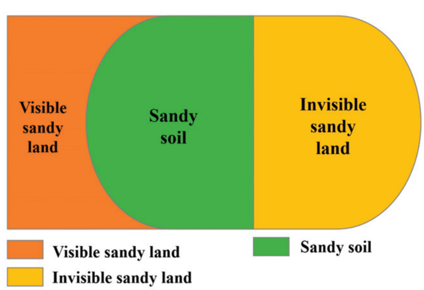

Figure 2. Relationship between sand land type and sandy soil.

All visible and invisible sandy land was considered as the object of investigation and evaluation of sandy land suitable for cultivation. According to the survey results of land use change in Hangjin Banner in 2013, the land use type of sandy land (land type code: 126) was extracted on the geographic information system (GIS) platform as the spatial range of dominant sandy land. The extraction process includes two aspects: one is the extraction of sandy soil. According to the analysis of soil types in Hangjin Banner, the sandy soil types in the soil map were extracted, including mobile aeolian soil, semifixed aeolian sand, fixed aeolian sand, sandy chestnut calcium soil, sandy fluvo-aquic soil, and sandy light brown calcium. There are 9 soil types in total: soil, sandy brown calcium soil, and sandy flood silt soil. The second is the extraction of invisible sandy land. With the help of the spatial superposition function of GIS, the superposition of the obtained sandy soil and the land use types outside the sandy land is the recessive sandy land. For the existing cultivated land, all are considered invisible sandy land (Figure 3).

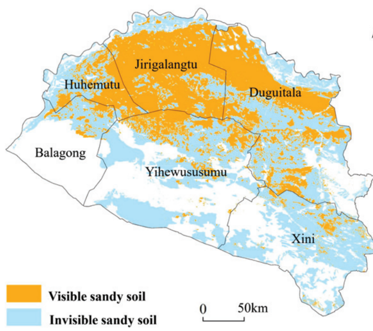

Figure 3. Type and spatial distribution of sandy land in Hangjin Banner.

2.3.2. Construction of the Evaluation Index System

Based on the natural and socioeconomic conditions of Hangjin Banner and combining existing research, this study constructed an evaluation index system for limiting factors of suitable arable sandy land in arid and semiarid regions. Evaluation indicators include land use type and vegetation coverage [31], irrigation conditions [32], ecological conditions [33], and soil properties [34,35] (Table 1).

Table 1. Limited evaluation index system of appropriate tillage sandy land.

Limited Evaluation Index	Inappropriate Tillage
Land use type	Other land use types except very-low-coverage grasslands (natural pastures and artificial pastures), other grasslands with very-low-coverage, saline-alkali land, inland tidal flats, semifixed dunes, and fixed dunes
Vegetation coverage	Degree of vegetation cover in land use type
Ecological conditions	In ecological reserves, or development may lead to land degradation
Irrigation conditions	The natural precipitation is less than or equal to 350 mm and there is no irrigation condition, which cannot meet the requirements of crop growth
Degree of salinization	The degree of soil salinization is more than severe

1. Land use types

The type of index of land use was based on the idea of protective development of sandy land suitable for cultivation and identifies the land use types suitable for cultivation in sandy land. For the purpose of ecological protection, forestland, grassland with high and medium coverage, swamp, and other lands should be regarded as ecological land and should not be reclaimed, while sandy land, saline-alkali land, tidal flats, and other grasslands with irrigation conditions and soil improvement conditions should be evaluated as suitable sandy land.

2. Vegetation coverage

In the "Classification of Land Use Status" (GB/T21010-2007) issued by the Ministry of Land and Resources, the vegetation coverage of sandy land and other grasslands in land use types has not been clearly quantified. Through field investigation and the superposition of land use status and vegetation coverage in the internal industry, it was found that there is very-low-coverage vegetation, low-coverage vegetation, and medium–high-coverage vegetation in the grassland and sandy land in the land use status map. For vegetation with different coverage degrees in sandy land, according to the classification of desertification degree in "Technical Regulations for Monitoring Desertification Land" (GBT24255-2009), vegetation coverage $\leq$ 10% is extremely low vegetation coverage, belonging to mobile sand dunes, and 10% $\leq$ vegetation coverage $\leq$ 30% is low-coverage grassland, belonging to semifixed dunes.

3. Ecological conditions

Ecological land plays an important role in ecological security, was used directly or indirectly by humans or other organisms, and mainly plays the role of maintaining biodiversity and the regional environment. The nature reserves, parks, water sources, and tidal flats with an area of more than 100 hm^2 designated by governments are ecological land. Scenic spots, revolutionary sites, cultural heritage reserves, and scenic tourist areas are special human and ecological lands that also need to be protected. Therefore, suitable arable sandy land in these protected areas should not be developed.

4. Irrigation conditions

Water is a necessary condition for plants to synthesize carbohydrates for photosynthesis. During the growing season of crops, the soil must have a certain amount of water supply before it can mature. Soil moisture comes either from natural precipitation or from irrigation. The annual precipitation in Hangjin Banner was between 140 and 340 mm, and the interannual variation is large, so it was impossible to meet the basic requirements of agricultural water demand through natural rainfall. Therefore, taking irrigation conditions as a restrictive index for the development and utilization of sandy land in Hangjin Banner, sandy land without irrigation conditions is not suitable for reclamation.

5. Degree of salinization

Saline-alkaline soil is a general term for soils that contain a certain number of soluble salts and make crops unable to grow and are divided into saline soils and alkaline soils. Among them, saline soil contains a large amount of soluble neutral salt, and the PH value is not very high; alkaline soil contains a large amount of alkaline soluble salt, and the PH value is very high, greater than 9.0. Hangjin Banner has no alkaline soil, only salt, which can be improved by leaching the salt with fresh water. This fresh water could be from water irrigation and precipitation, especially in areas with better drainage systems. However, severe salinization leaching salt improvement consumes more water and costs too much, which is not suitable for arid and semiarid regions. Therefore, severe salinization is classified as unsuitable sandy land.

2.3.3. Evaluate Appropriate Tillage Sandy

We divided the research ideas of this article into the following three parts (Figure 4).

First, this study used ENVI 5.0 and ArcGIS 10.8 as research platforms to extract the vegetation coverage of Hangjin Banner in 2013 by using the band calculation and raster classification functions of ENVI 5.0 and obtained the final range of extremely-low-coverage grassland combined with the spatial intersection function of ArcGIS. Based on the strong linear relationship between Normalized Difference Vegetation Index (NDVI) values and vegetation coverage, we employed a pixel-by-pixel bipartite model to estimate vegetation coverage (VFC). In practical applications, the NDVI of Vegetation (NDVIV) and NDVI of Soil (NDVIS) were not fixed, which makes the estimation of vegetation coverage more difficult. Therefore, we used the maximum and minimum NDVI values during the plant growth season in August to approximately replace NDVIV and NDVIS.

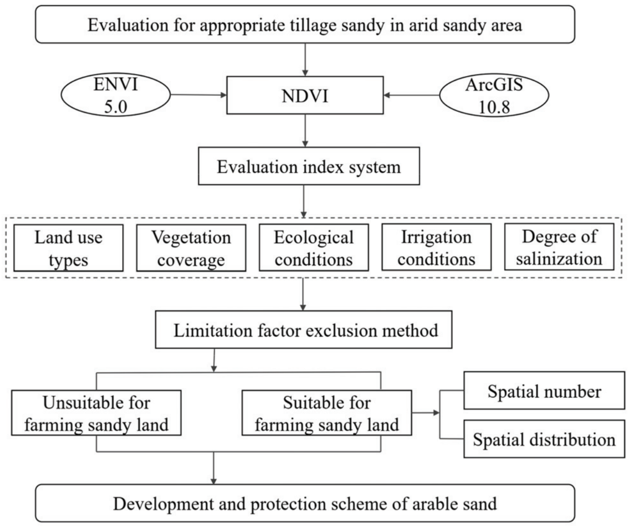

Figure 4. Research framework for the evaluation of appropriate tillage of sandy land in arid sandy area.

Second, this study used the restriction factor method to screen sandy land suitable for cultivation. We digitized the collected indicator (including land use type, vegetation cover, irrigation conditions, ecological conditions, and soil properties) data into various evaluation index factors, which were used as limiting factors to obtain the relevant evaluation index information of the evaluation object by using the spatial analysis function of GIS. In addition, we used the single factor restriction and exclusion method to evaluate the evaluation units. Among the evaluation indicators of the evaluation unit, if any index item is unsuitable for farming, it was classified as unsuitable for farming, and the rest were suitable for farming sandy land.

Finally, this study used the spatial analysis function of GIS to obtain the evaluation objects of suitable arable sandy land in the process of dividing the evaluation objects of suitable arable sandy land. Based on the analysis of the survey and evaluation results of suitable arable sandy land, we counted the number of different types of suitable arable sandy lands and analysed the spatial distribution of different types of suitable arable sandy lands.

3. Results

3.1. Analysis of the Results of Suitable Arable Sandy Land from an Overall Perspective

The area of sandy land of suitable arable sandy land in this survey was 1,274,935.9 hm^2, accounting for 67.5% of the total area of Hangjin Banner. After the screening of four limiting factors of land use or cover, ecological conditions, irrigation degree, and salinization, the sandy land area suitable for reclamation was 97,550.1 hm^2, accounting for only 7.7% of the sandy land area, and 92.3% of evaluation unit is not suitable for farming. According to the different types of sandy land, the suitable ploughing sandy land in Hangjin Banner can be divided into explicit suitable visible sandy land and suitable invisible sandy land. The dominant land type suitable for arable sandy land was sandy land, and the land use types of invisible sandy land are cultivated land, inland tidal flats, saline-alkali land, natural and artificial grasslands with very low coverage, and other grasslands with low coverage (Table 2).

Table 2. Result of survey evaluation for appropriate tillage sandy land.

Type of Sandy Land	Source of Land Type	Appropriate Sandy Land		Evaluation Object		Decrease Range (%)
		Area (hm^2)	Proportion (%)	Area (hm^2)	Proportion (%)	
Recessive suitable ploughing sandy land	Cultivated land	65,020.87	66.65	65,020.87	5.63	0.00
	Inland tidal flats	2010.90	2.06	3492.98	0.29	42.43
	Other grasslands	1291.96	1.32	31,087.27	2.55	95.84
	Saline-alkali land	214.03	0.22	314.54	0.03	31.95
	Natural grassland and artificial grassland	5668.12	5.81	513,457.85	42.05	98.90
Explicit suitable ploughing sandy land	Sandy land	23,344.2	23.93	542,514.34	44.42	95.70
Total		97,550.08	100.00	1,155,887.9	100.00	91.56

The area of visible sandy land suitable for cultivation was the largest at 23,344.2 hm^2, accounting for 23.9% of all sandy land suitable for cultivation. The invisible sandy land suitable for cultivation was 74,205.9 hm^2, accounting for 76.1% of the sandy land suitable for cultivation. Among the land use types of the invisible sandy land suitable for cultivation, the main land use types are the extremely-slow-coverage natural grassland and artificial grassland, accounting for 5668.1 hm^2, accounting for 5.8% of the sandy land suitable for cultivation. However, the decrease was also the largest. First, less than 3% of natural pastures and artificial pastures were reserved as sandy land suitable for cultivation. Second, the area of inland tidal flats suitable for cultivation was 2010.9 hm^2, accounting for 2.1% of all sandy land suitable for cultivation, and 57.6% of the inland tidal flats were suitable for development and utilization. Third, the area of other grassland suitable for cultivation was 1292.0 hm^2, accounting for 1.3% of the suitable arable sandy land. The decrease was very large, and only 4.2% of other grassland was suitable for development and utilization. Finally, although the suitable arable saline-alkali land only accounted for 0.2% of the suitable arable sandy land, the decrease was the smallest, and 68.1% of the saline-alkali land was suitable for development and utilization (Table 2).

3.2. Analysis of the Results of Suitable Arable Sandy Land from a Local Perspective

The cultivated land suitable for cultivation was mainly distributed in Jirigalangtu town (33.1%), Duguitala town (32.2%) and Huhemudu town (15.3%). There was a small amount of distribution in Balagong town and Yihewususumu, while there was no cultivated land distribution in Xini town. From the spatial distribution, the arable land is mainly concentrated along the Yellow River in the north, where the irrigation conditions are relatively favourable (Table 3; Figure 5).

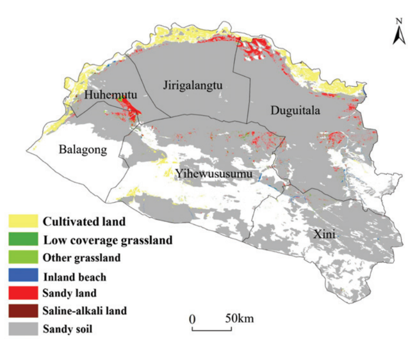

Figure 5. Type and spatial distribution of appropriate tillage sandy land.

Table 3. Statistics on spatial distribution of sandy soil suitable for ploughing in Hangjin Banner.

Source of Land Type		Balagong	Duguitala	Huhemudu	Jirigalangtu	Xini	Yihewusumu	Total
Cultivated land	Area (hm^2)	5035.82	20,924.19	9918.49	21,500.25	0.00	7642.12	65,020.87
	Proportion (%)	7.74	32.18	15.25	33.07	0.00	11.75	100.00
Low coverage grassland	Area (hm^2)	591.50	1612.45	536.39	11.85	625.6	2290.3	5668.12
	Proportion (%)	10.41	28.49	9.47	0.20	11.06	40.34	100.00
Inland beach	Area (hm^2)	97.65	871.08	177.96	37.15	350.42	476.62	2010.9
	Proportion (%)	4.85	43.31	8.84	1.84	17.42	23.7	100.00
Other grassland	Area (hm^2)	125.88	282.56	739.71	85.24	47.33	11.22	1291.96
	Proportion (%)	9.74	21.87	57.25	6.59	3.66	0.86	100.00
Sandy land	Area (hm^2)	2203.13	12,034.83	3305.64	2795.02	238.31	2767.24	23,344.20
	Proportion (%)	9.43	51.55	14.16	11.97	1.02	11.85	100.00
Saline-alkali land	Area (hm^2)	7.05	3.34	139.41	64.21	0.00	0.00	214.03
	Proportion (%)	3.29	1.56	65.13	30.00	0.00	0.00	100.00
Total	Area (hm^2)	8061.03	35,728.45	14,817.60	24,493.72	1261.66	13,187.50	97,550.08
	Proportion (%)	8.26	36.63	15.19	25.11	1.29	13.52	100.00

Natural grasslands and artificial grasslands suitable for cultivation were mainly distributed in Yihewususumu (40.3%) and Duguitala Town (28.5%). Except for Jirigalangtu town, where the distribution was only 11.06 hm^2, the distribution in other towns was between 590 and 2286 hm^2. From the spatial perspective, extremely-low-coverage grassland suitable for cultivating sandy land was intertwined with the dominant sandy land suitable for ploughing and sporadic inlaid in the dominant sandy land suitable for ploughing (Table 3; Figure 5).

The inland tidal flats suitable for farming are mainly distributed in Yihewususumu (23.7%), Xini town (17.4%), and Duguitala town (43.3%). In terms of spatial distribution, there was only a small area of Bayin Wendur Gacha in the Huhemudu Township in the northern Yellow Irrigation District. However, in the Liangwai District, it was distributed in strips along the inland rivers near Arishan Gacha and Baiyinbugacha (Table 3; Figure 5).

Other grasslands suitable for cultivation were mainly distributed in Huhemudu town (57.3%) and Duguitala town (21.9%), and the distribution in the other four towns was not large, ranging from 0.9% to 9.0%. This sandy land was mainly divided into two parts in space: one part was concentrated in Chagannur Gacha in Huhemudu town, and the other part was relatively concentrated in Sharizhao Gacha in Duguitala town. In general, other grassland pattern areas suitable for cultivation were small and fragmented (Table 3; Figure 5).

The saline-alkali land suitable for cultivation was distributed in the other four towns except Xini town and Yihe Wusumu town, and the most distributed was in Huhemudu town and Jirigalangtu town, accounting for 65.1% and 30% of the saline-alkali land suitable for cultivating sandy land, respectively. The sandy land suitable for cultivation in saline-alkali land was concentrated in Chagannur in Huhemudu town and along the river in Bayinwenduer in Jirigalangtu town, with an area of approximately 180.8 hm^2 (Table 3; Figure 5).

The visible sandy land suitable for cultivation was mainly distributed in Huhemudu town (14.2%) and Duguitala town (51.6%), and the distribution in other towns was relatively small. Among them, the dominant sandy land in Huhemudu town was relatively concentrated and contiguous, and mainly concentrated in Chagannur Gacha in Huhemudu town; the dominant sandy land in Jirigalangtu town and Duguitala town was in the shape of a concentrated and continuous strip in space, and the span extends from Gegenzhao Gacha in Jirigalangtu town to Huhemudu Shari Zhao Gacha; the visible sandy land in the other four towns was relatively small in number and small in size, but it was relatively concentrated in space (Table 3; Figure 5).

4. Discussion

In this paper, Hangjin Banner was taken as the research area, and the evaluation object of sandy land research was expanded from the traditional soil type of aeolian sandy soil or the land type of sandy land to all sandy land [36]. According to the different types of land use, specifically vegetation coverage, the sandy land with low vegetation coverage in the current land use survey was regarded as the visible sandy land, and other land types with sandy soil but land use types classified as cultivated land, forestland, grassland, garden land, swamp, water surface, etc., were regarded as invisible sandy land. Although these land types have various types of cover, they have the risk of desertification, and even desertification due to the characteristics of sandy soil, so they need to be taken as the evaluation object [37]. In another method, limiting factors such as land use type, irrigation conditions, and salinization degree are screened and eliminated one by one, and an evaluation system of limiting factors suitable for cultivated sandy land is constructed [38]. This method abandons the conventional comprehensive evaluation method of index factor scoring, avoids the superposition of factors, and ignores the influence of dominant control factors [39]. Our result also shows that 95.7% of the land units were screened by this method (compared with the sandy land units before screening), which means our research method is more effective.

Vegetation coverage can quantitatively characterize the degree of land desertification, but there are large differences in the thresholds of vegetation coverage set by different researchers for the degree of desertification [40,41]. According to the classification of vegetation coverage on desertification degree in "Technical Regulations for Monitoring Desertification" (GB/T 24255-2009), in the investigation and evaluation of arable sandy land in Hangjin Banner, vegetation coverage $\leq$ 10% is regarded as extremely-low-coverage vegetation, and the corresponding degree of desertification is extremely severe desertification. In addition, taking 10% $\leq$ vegetation coverage $\leq$ 30% as low-coverage vegetation, the corresponding degree of desertification is severe desertification; taking vegetation coverage $\geq$ 30% as medium–high vegetation, the corresponding degree of desertification is moderate–slight desertification [42]. This division is based on the idea of protective development and with reference to the overall situation of local land desertification, and other sandy areas can be selected for threshold selection and related research based on this method [43].

The current situation of land use is an important indicator for the investigation and evaluation of arable sandy land. In the investigation and evaluation of arable sandy land in Hangjin Banner, the vegetation coverage calculated by remote sensing is superimposed with the current situation of land use. Among the sandy land types, extremely severe sandy land (vegetation coverage $\leq$ 10%) and severe sandy land (10% $\leq$ vegetation coverage $\leq$ 30%) account for 96% of the total area of sandy land. In the grassland category, 1% of the grassland had extremely-low-coverage vegetation (vegetation coverage $\leq$ 10%), and 31% of the other grasslands had medium and high coverage (vegetation coverage $\geq$ 30%). Overall, the accuracy of sandy land surveying and mapping is relatively high [44,45]. However, for the purpose of research, we should further divide the land types in the current land use situation to meet the accuracy needs of the research. Therefore, on the basis of the current situation of land use, sandy land with vegetation coverage $\geq$ 10% in sandy land and grassland with vegetation coverage $\geq$ 10% in invisible sandy land were excluded.

5. Conclusions

In this study, Hangjin Banner was taken as the research area, and all sandy land was taken as the research object. The restricted factor exclusion method was used to investigate and evaluate arable sandy land in arid and semiarid areas. The results show that the total area of visible sandy land and invisible sandy land in Hangjin Banner is 1,274,935.9 hm^2. Among this area, the total area of arable sandy land is 97,550.1 hm^2, accounting for 7.7% of all sandy land. On the basis of invisible arable sand land and visible arable sand land, according to the land use type, invisible arable sand land can be divided into arable land, inland beach arable sand land, other grassland arable sand land, saline-alkali arable sand land, and very-low-coverage grassland (natural grazing grassland and artificial grazing grassland), accounting for 66.7%, 2.1%, 1.3%, 0.2%, and 5.8% of the area of arable sand land, respectively.

We believe that the research method of this paper is effective, which can provide a valuable reference for the sustainable development and utilization of arable sandy land and desertification control in arid and semiarid areas. Meanwhile, it should be noted that the development and utilization of arable sandy land is a systematic project, and the close cooperation and overall arrangement of all links of investigation and evaluation, planning and layout and engineering design are very necessary. We hope that this study can provide the arid and semiarid areas with similar development conditions as Hangjin Banner in the world, combined with the local actual situations, to use the restrictive factor exclusion method to determine the development and utilization area of arable sand, and formulate a more practical development and protection scheme of arable sand.

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Conflicts of Interest: The authors declare no conflict of interest.

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Article

Decision-Making Evaluation of the Pilot Project of Comprehensive Land Consolidation from the Perspective of Farmers and Social Investors: A Case Study of the Project Applied in Xianning City, Hubei Province, in 2020

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Abstract: Comprehensive land consolidation is an important means to implement the rural revitalization strategy. The decision-making of comprehensive land consolidation projects is the basis of scientifically selecting land consolidation projects, ensuring the quality of project, and making the project advance in an orderly manner. Compared with the traditional land consolidation project, the overall land consolidation project has a large demand for funds, and the participation of social capital has become an important way to solve the project funding problem. From the perspective of farmers and social investors, this research constructs a comprehensive land consolidation project decision-making evaluation index system and evaluation method from five aspects, including agricultural land consolidation, construction land consolidation, rural ecological protection and restoration, rural historical and cultural protection, and rural industrial development goals. The results show that there is a big difference in the evaluation results from the perspective of farmers and social investors. Considering the urgency of farmers' needs and the investment willingness of social investors in comprehensive land consolidation, the evaluation results are basically consistent with the actual project approval. The index system and evaluation method established in this study are helpful to scientifically select pilot projects of comprehensive land consolidation and invest limited government financial funds into the consolidation contents that are both urgently needed by farmers and willing to be invested by social investors.

Keywords: comprehensive land consolidation; pilot project; decision-making evaluation; farmers; social investors

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1. Introduction

With the tightening of resource and environmental constraints, problems such as disordered spatial distribution of rural land, inefficient use of resources, and deterioration of the ecological environment have become increasingly prominent [1–3]. The traditional land consolidation model that takes a single element as the consolidation object has been unable to cope with the continuous comprehensive problems in the process of rural development [4,5]. Under the background of the rural revitalization strategy, land consolidation has expanded from the single agricultural land consolidation to the comprehensive consolidation of the whole elements of "mountains, rivers, forests, fields, lakes, grasses and sand" [6–10]. The overall promotion of comprehensive land consolidation will help gradually narrow the gap between urban and rural development, stimulate the internal driving force of rural development, coordinate the harmonious development of man and nature, and ultimately achieve comprehensive rural revitalization [11–14].

As an important part of land consolidation project management, the decision-making is the basis of scientifically selecting land consolidation projects, ensuring the quality of project, and making the project advance in an orderly manner [15,16]. In recent years, China's annual investment in land consolidation has reached hundreds of billions of Yuan [17]. However, due to the characteristics of large capital demand and long return time for comprehensive land consolidation, the supply of consolidation funds is still difficult to meet its demand. Western countries also face the limitation of funds [18], so they will strictly allocate the limited funds to the most suitable areas in the land consolidation project initiation stage to ensure effective resource management and successful financial support [2,19]. In order to solve the problem of the shortage of funds for comprehensive land consolidation, the Ministry of Natural Resources strongly advocates and encourages social capital to participate in comprehensive land consolidation and ecological restoration, and local governments also actively explore ways to attract social capital to comprehensive land consolidation. In the case of insufficient government financial funds, how to leverage or attract social capital to participate and ensure the high-quality implementation of comprehensive land consolidation projects has become an important issue to be solved in the decision-making of comprehensive land consolidation projects.

To attract social capital to participate in comprehensive land consolidation projects, the most important thing is to understand the interests of social investors and set up projects with high investment willingness of social investors so as to attract investment from social investors. At present, the academic research on the decision-making of land consolidation project mainly starts from the perspective of land [9,19,20], and there is relatively little literature on the decision-making of land consolidation projects from the perspective of the microsubject of the social capital. With the gradual development of land consolidation work, some scholars have found that mandatory land consolidation has adverse effects on farmers [21], and land consolidation should fully respect the dominant position of farmers [19,22–24]. In some places, in the process of social investors' participation in comprehensive land consolidation, the phenomenon of damage to the rights of farmers also appeared. Therefore, the decision-making of a comprehensive land consolidation project should not only consider the interests of the investor, namely the social capital, but also the rights of local farmers. Farmers are the ultimate beneficiaries of comprehensive land consolidation [25], and social investors are an important force to promote comprehensive land consolidation projects. It has important theoretical and practical significance to construct a comprehensive land consolidation project decision-making evaluation index system from the perspective of farmers and social investors.

Based on the perspective of farmers and social investors, this paper constructs a comprehensive land consolidation project decision-making evaluation index system and evaluation method. We performed an empirical analysis by using the survey data of seven pilot projects of comprehensive land consolidation in Xianning, Hubei Province, in 2020 and the entropy weight TOPSIS method. It provides the theoretical basis and case support for standardizing the decision-making of the pilot project of comprehensive land consolidation and promoting the pilot work of comprehensive land consolidation.

2. Materials and Methods

2.1. Study Area and Data Sources

In April 2020, the Office of the Leading Group for Comprehensive Land Consolidation of Hubei Province issued the "Notice on Application for Comprehensive Land Consolidation Projects", requiring the province to carry out the application of comprehensive land consolidation projects. Xianning City, located in the Wuhan urban circle, organized the following 7 projects to apply for the 2020 Hubei Province Comprehensive Land Consolidation Pilot Project: Zhaoliqiao Town Project in Chibi City (Project A), Henggouqiao Town Project in Xian'an District (Project B), Xiangyanghu Town Project in Xian'an District (Project C), Dupu Town Project in Jiayu County (Project D), Daping Township Project in Tongcheng County (Project E), Tiancheng Town Project in Chongyang County (Project F), Honggang Town Project in Tongshan County (Project G) (see Appendix A: Figure A1 and Table A1). This paper takes 7 applied projects as examples to conduct empirical research (Figure 1).

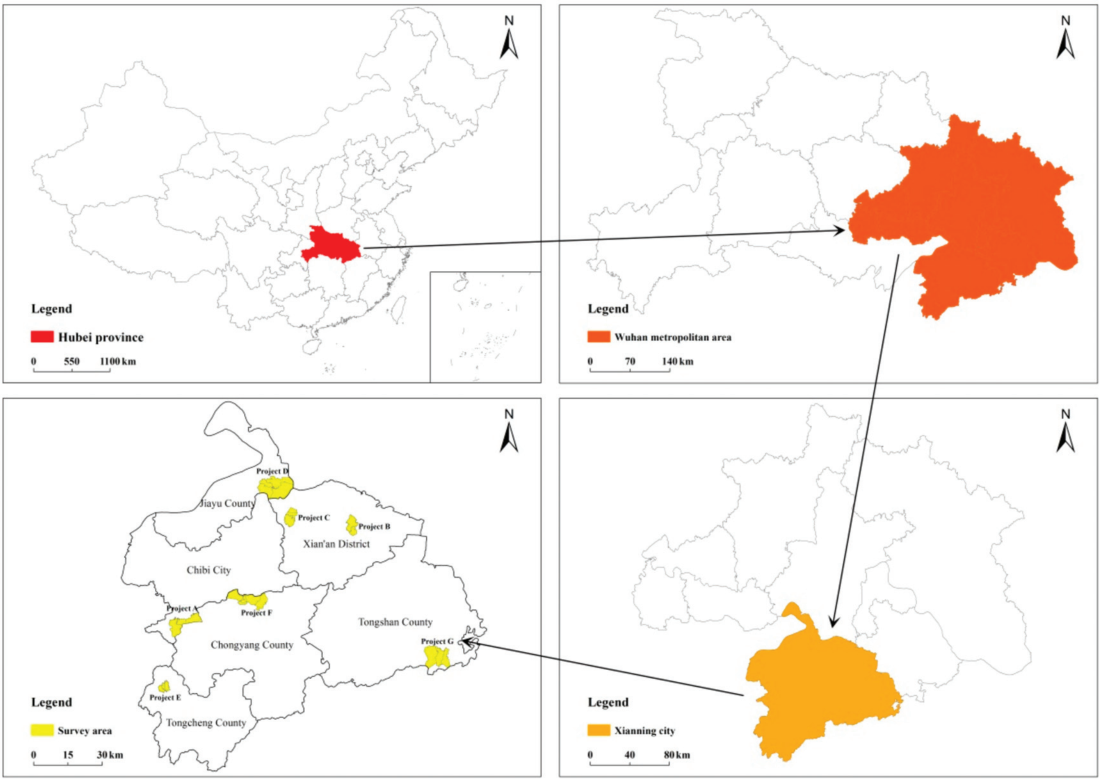

Figure 1. Survey area.

In order to obtain empirical data, the research group of more than 10 people conducted a questionnaire survey on farmers and social investors (new business entities) in the above-mentioned 7 project areas in January 2022. After removing invalid questionnaires, a total of 306 valid farmers questionnaires were obtained, including 47 items A, 35 items B, 45 items C, 47 items D, 43 items E, 41 items F, and 48 items G; and 20 valid social investor questionnaires, including 3 items A, 2 items B, 2 items C, 4 items D, 3 items E, 3 items F, and 3 items G (The details see Appendix A: Tables A2 and A3).

2.2. Research Methods

The entropy method is suitable for determining the weight of each index in the multi-index comprehensive evaluation. Because it calculates the weight based on the information entropy, the result is more objective [26–28]. The TOPSIS method (the distance method between superior and inferior solutions) is suitable for decision analysis for multiple targets [29]. Firstly, standardize the data to obtain a normalized vector r_{lz}, and establish a normalized decision matrix R. The calculation formula is:

$$r_{lz} = \frac{x_{lz} - x_{min}}{x_{max} - x_{min}} \quad (1)$$

In the formula: x_{lz} is the actual value of the z index of project area l; x_{max} and x_{min} are the maximum and minimum value of the single index, respectively, where $l = 1, 2, \cdots, m$, $z = 1, 2, \cdots, n$.

Then, use the entropy method to calculate the index weight, and its calculation formula is:

$$E_z = -k \sum_{l=1}^{m} f_{lz} \ln f_{lz} \quad (2)$$

$$w_z = \frac{1 - N_z}{n - \sum_{z=1}^{n} N_z} \quad (3)$$

In the formula: E_z represents the entropy value of the z index, and w_z represents the entropy weight coefficient of the z index; information entropy $k = \frac{1}{\ln m}$; the characteristic proportion of the index $f_{lz} = \frac{r_{lz}}{\sum_{i=1}^{m} r_{lz}}$, assuming that when $f_{lz} = 0$, $f_{lz} \ln f_{lz} = 0$.

On the basis of the normalized decision matrix, the entropy weight coefficient was added to establish a weighted normalized decision matrix. The calculation formula is:

$$v_{lz} = w_z \cdot r_{lz} \quad (4)$$

Determining the positive ideal solution V^+ and the negative ideal solution V^- according to v_{lz}, and calculating the distance D_l^+ from the evaluation vector to the positive ideal solution V^+ and D_l^- from the evaluation vector to the negative ideal solution V^-, the calculation formula is as follows:

$$V^+ = \{max\ v_{lz} \mid z = 1, 2, \cdots, n\} = \{v_1^+, \quad v_2^+, \quad \cdots, \quad v_n^+\} \quad (5)$$

$$V^- = \{min\ v_{lz} \mid z = 1, 2, \cdots, n\} = \{v_1^-, \quad v_2^-, \quad \cdots, \quad v_n^-\} \quad (6)$$

$$D_l^+ = \sqrt{\sum_{z=1}^{n} \left(v_{lz} - v_z^+\right)^2} (l = 1, 2, \cdots, m) \quad (7)$$

$$D_l^- = \sqrt{\sum_{z=1}^{n} \left(v_{lz} - v_z^-\right)^2} (l = 1, 2, \cdots, m) \quad (8)$$

Finally, the closeness was calculated, and the formula is as follows:

$$C_l = \frac{D_l^-}{D_l^+ + D_l^-}; (l = 1, 2, \cdots, m) \quad (9)$$

In the formula: $0 \leqslant C_l \leqslant 1$, the smaller the closeness C_l, the lower the degree; the greater the closeness C_l, the higher the degree.

2.3. Construction of Evaluation Index System

The comprehensive land consolidation mainly includes agricultural land consolidation, construction land consolidation, rural ecological protection and restoration, rural historical and cultural protection, etc., and the consolidation contents of these four aspects all serve the rural revitalization, especially the rural industrial development. Therefore, starting from the above-mentioned four aspects of the consolidation contents and industrial development goals, this paper analyzes the interests of farmers and social investors and then constructs a comprehensive land consolidation project decision-making evaluation index system.

2.3.1. Evaluation Index System from the Perspective of Farmers

Through the investigation, it was found that the majority of farmers are eager to change the backward production and living conditions in rural areas through comprehensive land consolidation. The worse the production and living conditions are, the higher the farmers' expectations of the comprehensive land consolidation project will be. Therefore, this paper constructs the comprehensive land consolidation projects decision-making evaluation index system from the perspective of farmers from the following five aspects.

The urgency for agricultural land consolidation. In the process of agricultural land consolidation, the interests of farmers mainly include: improvement of the comprehensive quality of existing paddy fields, transformation of dry land into paddy fields, improvement of the comprehensive quality of other agricultural land. This paper subdivides the urgency for agricultural land consolidation into the following three indicators: the urgency to improve the comprehensive quality of existing paddy fields, the urgency for transforming dry land into paddy fields, and the urgency to improve the comprehensive quality of other agricultural land. Among them, the urgency to improve the comprehensive quality of existing paddy fields includes four indicators: the completeness of paddy field irrigation facilities, the completeness of paddy field drainage and waterlogging facilities, the completeness of field road facilities, and the degree of paddy field fragmentation. The first three indicators are negative indicators, and the last one is a positive index. The urgency to transform dry land into paddy fields is represented by the difficulty of transforming dry land into paddy fields, which is a negative index. The urgency to improve the comprehensive quality of other agricultural land includes the urgency to improve the comprehensive quality of garden land, the urgency to improve the comprehensive quality of economic forest land, and the urgency to improve the comprehensive quality of the pond. The urgency to improve the comprehensive quality of the garden land is measured by the completeness of the irrigation facilities of the garden land and the degree of transportation convenience of the garden land. The urgency to improve the comprehensive quality of the economic forest land is measured by the completeness of the irrigation facilities of the economic forest land and the degree of transportation convenience of the economic forest land. The urgency to improve the comprehensive quality of the ponds is measured by the degree of siltation, the degree of leakage, the degree of irrigation convenience, and the degree of transportation convenience, all of which are negative indicators.

The urgency for construction land consolidation. In the process of construction land consolidation, the interests of farmers mainly include: improvement of rural infrastructure and public service facilities and efficient use of rural construction land. This paper subdivides the urgency for construction land consolidation into the following two indicators: the urgency to improve rural infrastructure and public service facilities and the urgency to achieve efficient use of rural construction land. Among them, the urgency to improve rural infrastructure and public service facilities is characterized by the completeness of rural infrastructure and the completeness of rural public service facilities. The urgency to achieve efficient use of rural construction land is characterized by the intensive utilization of rural construction land, all of which are negative indicators.

The urgency for rural ecological protection and restoration. In the process of rural ecological protection and restoration, the interests of farmers mainly include: ecological environment restoration and human settlements improvement. This paper subdivides the urgency for rural ecological protection and restoration into two indicators: the urgency to achieve ecological environment restoration and the urgency for human settlements improvement. Among them, the urgency for ecological environment restoration is represented by the degree of water pollution, soil pollution, soil erosion, mine environment damage, and vegetation degradation, all of which are positive indicators. The urgency for human settlements improvement is represented by the satisfaction degree of sanitary toilet renovation, domestic waste treatment, domestic sewage treatment, and village appearance, all of which are negative indicators.

The urgency for rural historical and cultural protection. Through the investigation, it was found that the majority of farmers are eager to protect and restore local rural historical and cultural resources through comprehensive land consolidation in order to develop rural leisure tourism. This paper subdivides the urgency for rural historical and cultural protection into the following four indicators: the richness of historical and cultural resources, the popularity of historical and cultural resources, the degree of destruction of historical and cultural relics, and the willingness to build village historiographers, all of which are positive indicators.

The urgency for industrial development. Through the investigation, it was found that the majority of farmers are eager to promote the development of local industries through comprehensive land consolidation in order to achieve the goals of rural beauty, industrial prosperity, and prosperity. This paper subdivides the urgency for industrial development into the following two indicators: the willingness to develop large-scale agriculture and the willingness to develop rural secondary and tertiary industries. These two indicators are both positive indicators, that is, the stronger the farmers' willingness to develop large-scale agriculture and rural secondary and tertiary industries, the stronger the farmers' desire to promote the development of local industries through comprehensive land consolidation, and the higher the urgency for industrial development. The opposite is also true.

To evaluate the decision-making of the comprehensive land consolidation project from the perspective of farmers is to judge the priority of the project by measuring the urgency of farmers' needs for comprehensive land consolidation. The higher the urgency of farmers' needs, the higher the order of project approval. In order to accurately measure the urgency of farmers' needs, this paper adopts the Likert 5-level scale as a tool to measure the urgency. The specific calculation method is shown in Table 1.

Table 1. Decision-making evaluation index system of pilot projects of comprehensive land consolidation from farmers' perspective.

Target Layer	Criterion Layer		Indicator Layer	Definition	Value
The urgency of farmers' needs for comprehensive land consolidation	The urgency for agricultural land consolidation (0.179)	The urgency to improve the comprehensive quality of existing paddy fields	The completeness of paddy field irrigation facilities X1 (0.066)	High degree of completeness—low degree of completeness	1–5
			The completeness of paddy field drainage and waterlogging facilities X2 (0.117)	High degree of completeness—low degree of completeness	1–5
			The completeness of field road facilities X3 (0.085)	High degree of completeness—low degree of completeness	1–5
			The degree of paddy field fragmentation X4 (0.032)	Low degree—high degree	1–5
		The urgency to transform paddy fields from dry land	The difficulty of transforming dry land into paddy fields X5 (0.179)	High difficulty—low difficulty	1–5
		The urgency to improve the comprehensive quality of other agricultural land	The completeness of the irrigation facilities of the garden land X6 (0.075)	High degree of completeness—low degree of completeness	1–5
			The degree of transportation convenience of the garden land X7 (0.054)	High degree—low degree	1–5
			The completeness of the irrigation facilities of the economic forest land X8 (0.033)	High degree of completeness—low degree of completeness	1–5
			The degree of transportation convenience of the economic forest land X9 (0.095)	High degree—low degree	1–5
			The degree of siltation of the pond X10 (0.053)	Low degree—high degree	1–5
			The degree of leakage of the pond X11 (0.066)	Low degree—high degree	1–5
			The degree of irrigation convenience of the pond X12 (0.078)	High degree—low degree	1–5
			The degree of transportation convenience of the pond X13 (0.067)	High degree—low degree	1–5

Table 1. *Cont.*

Target Layer	Criterion Layer		Indicator Layer	Definition	Value
	The urgency for construction land consolidation (0.213)	The urgency to improve rural infrastructure and public service facilities	The completeness of rural infrastructure X14 (0.306)	High degree of completeness—low degree of completeness	1–5
			The completeness of rural public service facilities X15 (0.363)	High degree of completeness—low degree of completeness	1–5
		The urgency to achieve efficient use of rural construction land	The intensive utilization of rural construction land X16 (0.331)	High Use—low use	1–5
	The urgency for rural ecological protection and restoration (0.181)	The urgency for ecological environment restoration	The degree of water pollution X17 (0.085)	Low degree—high degree	1–5
			The degree of soil pollution X18 (0.071)	Low degree—high degree	1–5
			The degree of soil erosion X19 (0.100)	Low degree—high degree	1–5
			The degree of mine environment damage X20 (0.136)	Low damage—high damage	1–5
			The degree of vegetation degradation X21 (0.116)	Low degree—high degree	1–5
		The urgency for human settlements improvement	The satisfaction degree of sanitary toilet renovation X22 (0.121)	High satisfaction—low satisfaction	1–5
			The satisfaction degree of domestic waste treatment X23 (0.160)	High satisfaction—low satisfaction	1–5
			The satisfaction degree of domestic sewage treatment X24 (0.101)	High satisfaction—low satisfaction	1–5
			The satisfaction degree of village appearance X25 (0.110)	High satisfaction—low satisfaction	1–5
	The urgency for rural historical and cultural protection (0.217)	The willingness to invest in rural historical and cultural protection	The richness of historical and cultural resources X26 (0.144)	Low degree—high degree	1–5
			The popularity of historical and cultural resources X27 (0.444)	Low popularity—high popularity	1–5
			The degree of destruction of historical and cultural relics X28 (0.197)	Low damage—high damage	1–5
			The willingness to build village historiographers X29 (0.215)	Low willingness—high willingness	1–5
	The urgency for industrial development (0.210)	The urgency for industrial development	The willingness to develop large-scale agriculture X30 (0.545)	Low willingness—high willingness	1–5
			The willingness to develop rural secondary and tertiary industries X31 (0.455)	Low willingness—high willingness	1–5

2.3.2. Evaluation Index System from the Perspective of Social Investors

The core demand of social investors to invest in the comprehensive land consolidation projects is to obtain income. The main sources of income include two aspects. First, the balance index of cultivated land occupation and compensation generated by land consolidation and the balance index linked to the increase and decrease in urban and rural construction land are used for transactions so as to obtain income (hereinafter referred to as "index transaction income"). Second, use local resource endowments to develop industries and obtain income through industrial operations. Therefore, the more favorable the existing resource endowment in the project area is for industrial development, the more balance indicators that can be obtained through consolidation, the stronger the willingness of social investors to invest in comprehensive land consolidation. The opposite is also true. Based on this, this paper constructs the comprehensive land consolidation projects decision-making evaluation index system from the perspective of social investors from the following five aspects.

The willingness to invest in agricultural land consolidation. In the process of agricultural land consolidation, the interests of social investors mainly include: the comprehensive quality of existing paddy fields, the potential of converting dry land to paddy fields, the comprehensive quality of other agricultural land, and the potential of new cultivated land from agricultural land consolidation and unused land development. In this paper, the willingness to invest in agricultural land consolidation is subdivided into the following four indicators: the willingness to invest in improving the comprehensive quality of existing paddy fields, the willingness to invest in transforming dry land into paddy fields, the willingness to invest in improving the comprehensive quality of other agricultural land, and the willingness to invest in new cultivated land. Among them, the willingness to invest in improving the comprehensive quality of existing paddy fields includes four indicators: the difficulty of improving paddy field irrigation facilities, the difficulty of improving paddy field drainage and waterlogging facilities, the difficulty of improving field road facilities, and the difficulty of reducing paddy field fragmentation, which are negative indicators. The willingness to invest in transforming dry land into paddy fields is represented by the difficulty of transforming dry land into paddy field, which is a negative index. The willingness to invest in improving the comprehensive quality of other agricultural land includes the willingness to invest in improving the comprehensive quality of garden land, economic forest land, and the pond. The willingness to invest in improving the comprehensive quality of garden land is measured by the difficulty of improving the irrigation facilities of the garden land and the degree of transportation convenience of the garden land. The willingness to invest in improving the comprehensive quality of economic forest land is measured by the difficulty of improving the irrigation facilities of economic forest land and the degree of transportation convenience of economic forest land. The willingness to invest in improving the comprehensive quality of the pond is measured by the difficulty of cleaning up, the difficulty of repairing leakages, the convenience of irrigation, and the degree of transportation convenience. Except for the difficulty of improving paddy field irrigation facilities, the difficulty of improving paddy field drainage and waterlogging facilities, the difficulty of cleaning up ponds, and the difficulty of repairing leakages of pond, which are negative indicators, all the other indicators are positive indicators. The willingness to invest in new cultivated land is measured by the proposed new cultivated land area of farmland consolidation and unused land development, which is a positive indicator.

The willingness to invest in construction land consolidation. In the process of construction land consolidation, the interests of social investors mainly include: the status of rural infrastructure, the status of rural public service facilities, and the potential of rural inefficient construction land reclamation. This paper subdivides the willingness to invest in construction land consolidation into the following two indicators: the willingness to invest in improving rural infrastructure and public service facilities and the willingness to invest in reclamation of rural inefficient construction land. Among them, the willingness to invest in improving rural infrastructure and public service facilities is represented by the difficulty of improving rural infrastructure and rural public service facilities, which are negative indicators. The willingness to invest in reclamation of rural inefficient construction land is represented by the proposed new cultivated land area of rural cultivated land reclamation, which is a positive indicator.

The willingness to invest in rural ecological protection and restoration. In the process of rural ecological protection and restoration, the interests of social investors mainly include: ecological environment and human settlements. In this paper, the willingness to invest in rural ecological protection and restoration is subdivided into two indicators: the willingness to invest in ecological environment restoration and the willingness to invest in human settlements improvement. Among them, the willingness to invest in ecological environment restoration is represented by the difficulty of water pollution restoration, soil pollution restoration, soil erosion restoration, mine environment restoration, and vegetation degradation restoration, all of which are negative indicators. The willingness to invest in human settlements improvement is represented by the satisfaction degree of sanitary toilet renovation, domestic waste treatment, domestic sewage treatment, and village appearance, all of which are positive indicators.

The willingness to invest in rural historical and cultural protection. The richer and more famous the local historical and cultural resources, the more willing social investors are to invest to develop the rural leisure tourism industry. This paper subdivides the willingness to invest in rural historical and cultural protection into the following three indicators: the richness of historical and cultural resources, the popularity of historical and cultural resources, and the difficulty of restoration of historical and cultural relics. The former two are positive indicators, and the latter is a negative indicator.

The willingness to invest in industrial development. In terms of industrial development, the interests of social investors mainly include: the superiority of tourism resources in the project area and the industrial foundation of the project area. In this paper, the willingness to invest in industrial development is subdivided into the following two indicators: the willingness to invest in tourism development and the willingness to invest in industrial scale expansion and quality improvement. Among them, the willingness to invest in tourism development is represented by the superiority of tourism resources, which is a positive indicator. The willingness to invest in the industrial scale expansion and quality improvement is represented by the popularity of industrial operators, the popularity of characteristic industries, and the inclusion level of characteristic industries in the planning, all of which are positive indicators.

To evaluate the decision-making of the comprehensive land improvement project from the perspective of social investors is to judge the priority of the project by measuring the willingness of social investors to invest in comprehensive land consolidation. The higher the willingness of social investors to invest in projects, the higher the order of project approval. In order to accurately measure the willingness of social investors to invest, this paper adopts the Likert 5-level scale as a tool to measure the willingness. The specific method is shown in Table 2.

2.3.3. Evaluation Index System from the Comprehensive Perspective of Farmers and Social Investors

The decision-making evaluation of comprehensive land consolidation projects from the comprehensive perspectives of farmers and social investors is to combine the previous evaluation of the urgency of farmers' needs for comprehensive land consolidation and the willingness of social investors to invest to comprehensively determine the priority of comprehensive land consolidation, and then determine the priority order of pilot application projects. The higher the urgency of farmers' needs and the willingness of social investors to invest, the higher the priority of comprehensive land consolidation projects, and the higher the order of project approval. See Table 3 for details of the decision-making evaluation index system of comprehensive land consolidation projects from the perspectives of farmers and social investors.

Table 2. Decision-making evaluation index system of pilot projects of comprehensive land consolidation from social investors' perspective.

Target Layer	Criterion Layer		Indicator Layer	Definition	Value
The willingness of social investors to invest in comprehensive land consolidation	The willingness to invest in agricultural land consolidation (0.335)	The willingness to invest in improving the comprehensive quality of existing paddy fields	The difficulty of improving paddy field irrigation facilities Y1 (0.068)	High difficulty—low difficulty	1–5
			The difficulty of improving paddy field drainage and waterlogging facilities Y2 (0.087)	High difficulty–low difficulty	1–5
			The difficulty of improving field road facilities Y3 (0.043)	High difficulty—low difficulty	1–5
			The difficulty of reducing paddy field fragmentation Y4 (0.049)	High difficulty—low difficulty	1–5
		The willingness to invest in transforming dry land into paddy fields	The difficulty of transforming dry land into paddy field Y5 (0.216)	High difficulty—low difficulty	1–5
		The willingness to invest in improving the comprehensive quality of other agricultural land	The difficulty of improving the irrigation facilities of the garden land Y6 (0.083)	High difficulty—low difficulty	1–5
			The degree of transportation convenience of the garden land Y7 (0.044)	Low degree—high degree	1–5
			The difficulty of improving the irrigation facilities of economic forest land s Y8 (0.095)	High difficulty—low difficulty	1–5
			The degree of transportation convenience of economic forest land Y9 (0.087)	Low degree—high degree	1–5
			The difficulty of cleaning up ponds Y10 (0.044)	High difficulty—low difficulty	1–5
			The difficulty of repairing leakages of the pond Y11 (0.043)	High difficulty—low difficulty	1–5
			The convenience of irrigation of the pond Y12 (0.037)	Low degree—high degree	1–5
			The degree of transportation convenience of the pond Y13 (0.042)	Low degree—high degree	1–5
		The willingness to invest in new cultivated land	The proposed new cultivated land area of farmland consolidation and unused land development Y14 (0.062)	Small area—large area	1–5

Table 2. *Cont.*

Target Layer	Criterion Layer		Indicator Layer	Definition	Value
	The willingness to invest in construction land consolidation (0.121)	The willingness to invest in improving rural infrastructure and public service facilities	The difficulty of improving rural infrastructure Y15 (0.325)	High difficulty—low difficulty	1–5
			The difficulty of improving rural public service facilities Y16 (0.354)	High difficulty—low difficulty	1–5
		The willingness to invest in reclamation of rural inefficient construction land	The proposed new cultivated land area of rural cultivated land reclamation Y17 (0.321)	Small area—large area	1–5
	The willingness to invest in rural ecological protection and restoration (0.179)	The willingness to invest in ecological environment restoration	The difficulty of water pollution restoration Y18 (0.090)	High difficulty—low difficulty	1–5
			The difficulty of soil pollution restoration Y19 (0.110)	High difficulty—low difficulty	1–5
			The difficulty of soil erosion restoration Y20 (0.093)	High difficulty—low difficulty	1–5
			The difficulty of mine environment restoration Y21 (0.116)	High difficulty—low difficulty	1–5
			The difficulty of mine environment restoration Y22 (0.107)	High difficulty—low difficulty	1–5
		The willingness to invest in human settlements improvement	The satisfaction degree of sanitary toilet renovation Y23 (0.087)	Low satisfaction—high satisfaction	1–5
			The satisfaction degree of domestic waste treatment Y24 (0.107)	Low satisfaction—high satisfaction	1–5
			The satisfaction degree of domestic sewage treatment Y25 (0.099)	Low satisfaction—high satisfaction	1–5
			The satisfaction degree of village appearance Y26 (0.191)	Low satisfaction—high satisfaction	1–5
	The willingness to invest in rural historical and cultural protection (0.208)	The willingness to invest in rural historical and cultural protection	The richness of historical and cultural resources Y27 (0.185)	Low degree—high degree	1–5
			The popularity of historical and cultural resources Y28 (0.570)	Low popularity—high popularity	1–5

Table 2. *Cont.*

Target Layer	Criterion Layer		Indicator Layer	Definition	Value
			The difficulty of restoration of historical and cultural relics Y29 (0.245)	High difficulty—low difficulty	1–5
		The willingness to invest in tourism development	The superiority of tourism resources Y30 (0.386)	low superiority—high superiority	1–5
	The willingness to invest in industrial development (0.157)	The willingness to invest in industrial scale expansion and quality improvement	The popularity of industrial operators Y31 (0.192)	Low popularity—high popularity	1–5
			The popularity of characteristic industries Y32 (0.271)	Low popularity—high popularity	1–5
			The inclusion level of characteristic industries in the planning Y33 (0.151)	Low level—high level	1–5

Table 3. Decision-making evaluation index system of pilot projects of comprehensive land consolidation from the comprehensive perspective of farmers and social investors.

Target Layer	Criterion Layer	Indicator Layer	Definition
The priority of comprehensive land consolidation	The urgency of farmers' needs for comprehensive land consolidation (0.307)	The urgency for agricultural land consolidation (0.179)	X1–X13
		The urgency for construction land consolidation (0.213)	X14–X16
		The urgency for rural ecological protection and restoration (0.181)	X17–X25
		The urgency for rural historical and cultural protection (0.217)	X26–X29
		The urgency for industrial development (0.210)	X30–X31
	The willingness of social investors to invest in comprehensive land consolidation (0.693)	The willingness to invest in agricultural land consolidation (0.335)	Y1–Y14
		The willingness to invest in construction land consolidation (0.121)	Y15–Y17
		The willingness to invest in rural ecological protection and restoration (0.179)	Y18–Y26
		The willingness to invest in rural historical and cultural protection (0.208)	Y27–Y29
		The willingness to invest in industrial development (0.157)	Y30–Y33

3. Results

3.1. Decision-Making Evaluation Results of Comprehensive Land Consolidation Projects from Two Separate Perspectives

After sorting out the valid sample data and processing it through the simple arithmetic average method, the entropy weight TOPSIS method was used to carry out a quantitative analysis on the urgency of farmers' needs and the willingness of social investors to invest in the seven declared projects and to obtain decision-making evaluation results of comprehensive land consolidation projects from different perspectives. The results are shown in Table 4.

As can be seen from Table 4, from the perspective of the urgency of farmers' needs for comprehensive land consolidation, projects A and C should be established first, followed by projects G, F, E, D, and B. However, from the perspective of investment willingness of social investors, the order of project approval is C, E, D, F, A, G, and B. It can be seen that there is a big difference in the evaluation results of project approval from the perspective of farmers and social investors, mainly due to the different interests and concerns of farmers and social investors. Farmers are the masters of the village and the ultimate beneficiaries of comprehensive land consolidation. Compared with the index benefits brought by comprehensive land consolidation, they pay more attention to the consolidation content closely related to their own production and life, such as agricultural land consolidation to improve the quality of cultivated land, rural ecological protection and restoration to improve the quality of human settlements, and development of large-scale agriculture and industrial integration. As an investor, the core appeal of social investors participating in comprehensive land consolidation is to obtain index transaction income and industrial operation income. Therefore, compared with the interests of farmers, social investors pay more attention to the tradable surplus indicators provided by comprehensive land consolidation and the advantageous resources supporting the development of rural industries, such as beautiful ecological environment, rich historical and cultural resources, tourism resources and industrial base, etc.

Table 4. Decision-making evaluation results of the comprehensive land consolidation projects from two separate perspectives.

Declaration Project	Farmers' Perspective		Social Investors' Perspective	
	Urgency of Need	Sort	Willingness to Invest	Sort
Zhaoliqiao Town Project in Chibi City (A)	0.540	1	0.373	5
Henggouqiao Town Project in Xian'an District (B)	0.307	7	0.278	7
Xiangyanghu Town Project in Xian'an District (C)	0.540	1	0.715	1
Dupu Town Project in Jiayu County (D)	0.446	6	0.418	3
Daping Township Project in Tongcheng County (E)	0.451	5	0.455	2
Tiancheng Town Project in Chongyang County (F)	0.469	4	0.414	4
Honggang Town Project in Tongshan County (G)	0.489	3	0.314	6

From the above analysis, it can be seen there will be great differences in the evaluation results when the decision-making of comprehensive land consolidation pilot projects is carried out solely from the perspectives of farmers and social investors. Therefore, the decision-making evaluation of comprehensive land consolidation project should comprehensively consider the interests of farmers and social investors in order to make the decision-making evaluation results more scientific and reasonable.

3.2. Decision-Making Evaluation Results of Comprehensive Land Consolidation Projects from the Comprehensive Perspective of Farmers and Social Investors

To combine the evaluation results of the urgency of farmers' needs and the willingness of social investors to invest in the seven declared projects, the entropy weight TOPSIS method was also used to obtain the decision-making evaluation results of comprehensive land consolidation projects from the perspective of farmers and social investors. The results are shown in Table 5.

Table 5. Decision-making evaluation results of the comprehensive land consolidation projects from the comprehensive perspective of farmers and social investors.

Declaration Project	Based on the Perspective of Farmers and Social Investors		Actual Project Results
	Priority	Sort	
Zhaoliqiao Town Project in Chibi City (A)	0.424	5	Not approved
Henggouqiao Town Project in Xian'an District (B)	0.287	7	Municipal pilot project
Xiangyanghu Town Project in Xian'an District (C)	0.661	1	Provincial pilot projects
Dupu Town Project in Jiayu County (D)	0.427	4	Not approved
Daping Township Project in Tongcheng County (E)	0.454	2	Provincial pilot projects
Tiancheng Town Project in Chongyang County (F)	0.431	3	Provincial pilot projects
Honggang Town Project in Tongshan County (G)	0.368	6	Not approved

As can be seen from Table 5, regarding the priority of declared projects for comprehensive land consolidation from the perspective of farmers and social investors, the C project (0.661) should be given priority, followed by the E project (0.454), followed by the F project (0.431), D item (0.427), A item (0.424), G item (0.368), and B item (0.287). The above results comprehensively consider the urgency of farmers' needs and the willingness of social investors to invest in the comprehensive land consolidation, and the evaluation results are basically consistent with the actual project establishment. Among them, projects C, E and F, which are the top three in the priority ranking of the declared projects for comprehensive land consolidation, were identified as the provincial pilot project in the comprehensive land consolidation project decision-making evaluation organized by the Office of the Leading Group for Comprehensive Land Consolidation in Hubei Province in 2020. However, the B project with the lowest priority was identified as a municipal pilot project, while the D project with the fourth priority and the A project with the fifth priority were not approved. It can be seen that the current comprehensive land consolidation project decision-making evaluation in Hubei Province basically considers the interests of farmers and social investors, which are two important subjects, and generally seems to be reasonable. However, there is still room for further improvement. No matter whether from the perspective of farmers or social investors, project B was ranked last in the order of project approval, but it was listed as a municipal pilot project, which shows that there is a certain deviation in comprehensive land consolidation project decision-making evaluation in Hubei Province. In the future, we should comprehensively consider the urgency of farmers' needs and the willingness of social investors to invest and finally determine the priority of comprehensive land consolidation projects. This will not only safeguard the rights of farmers but also leverage the participation of social capital and, finally, ensure the smooth implementation of comprehensive land consolidation projects.

4. Discussion

4.1. Project Priority Analysis

On the whole, the priority order evaluation results of comprehensive land consolidation project from the comprehensive perspective of farmers and social investors are basically consistent with the actual project establishment. Whether it is the urgency of farmers' needs or the willingness of social investors to invest, Project C has the highest score, and Project C has also been confirmed as a provincial pilot project in reality. Through field research, it was found that C project area state-owned farms accounted for 44.18% of the total area. State-owned farms have the advantage of mechanization and organization, which is conducive to the development of agricultural modernization and industrial management. The project area has already invested in two beautiful countryside projects, two water conservancy projects, and five land consolidation projects, which have effectively improved the human settlements, ecological environment, and cultivated land quality. The project area is rich in cultural resources, and the former site of cultural celebrities in Xiangyanghu was listed in the seventh batch of national key cultural relics protection unit in 2013. The farm advantages, environmental advantages, industrial advantages, and cultural advantages of Project C made it listed as a provincial pilot project.

However, there is a certain deviation between the priority of the B project and the actual project approval result. Project B is located in a provincial modern agricultural industrial park and was listed as a provincial pilot project in the comprehensive land consolidation of Hubei Province in 2020. Still, no matter whether from the perspective of farmers or social investors, the order of project B is ranked last. Through the investigation, it was found that the population outflow in the B project area is very serious, and there are many "empty nests" of young people going out with the elderly and children staying behind, which makes less the urgency of farmers' needs for comprehensive land consolidation in the project area. The industrial parks in the project area are in pursuit of economic benefits, ignoring infrastructure construction, seriously restricting the further development of the industrial base in the project area, which is also the reason for the low investment willingness of social investors.

In general, the inconsistency between the decision-making priorities and the actual project approval results shows that there is a certain deviation in the current comprehensive land consolidation project decision-making evaluation in Hubei Province. Generally speaking, the government is willing to invest in villages with better existing resource endowments, while farmers and social investors have different concerns. For farmers, the worse the existing agricultural land, construction land, and ecological environment in the countryside, the higher the urgency of farmers' needs. Social investors pay more attention to the tradable surplus indicators provided by comprehensive land consolidation and the future development potential of the countryside.

4.2. Research on Decision-Making of Comprehensive Land Consolidation Project in Other Countries

Land consolidation requires difficult and conflicting decisions such as where to revitalize the declining countryside [11]. In many European countries, especially those receiving European Union (EU) support for land consolidation projects, it is important to carefully allocate funds to the most suitable areas [30]. Traditionally, these decisions have been made by groups, some linked to the area being consolidated and others from the government, all of whom attempt to create the best possible decision [2]. During a comprehensive literature analysis and interviews with land consolidation experts, it was noted that certain countries, such as Finland, use country-wide maps to identify potential areas for land consolidation. Some countries undertake various marketing activities, information campaigns, and other methods to raise public awareness. One of the recent examples is the Dutch Kadaster, which celebrated 100 years of practice in implementing land consolidation projects in 2016 with the release of Move a Lot, a smart device game that allows players to "play" to re-adjust land consolidation project areas. This approach can mobilize the enthusiasm of farmers, maximize the protection of farmers' rights, and earn the support of active local leaders—"social activists" [31]. Recent studies have highlighted the need to identify the most suitable and prioritized land consolidation areas at different levels of governance [32–36]. However, the scale and the criteria vary from country to country and are influenced by the national as well as regional policies and strategies.

In a word, the establishment of comprehensive land consolidation projects is a common problem all over the world. To learn how to invest the limited renovation funds into the most suitable and leading regions, countries need to explore the most suitable road for themselves.

4.3. Deficiencies and Suggestions for Improvement

The construction of the comprehensive land consolidation project decision-making evaluation index system from the perspectives of farmers and social investors is a supplement to the current independent policy decision-making. However, there are still the following deficiencies: (1) This paper only considers the interests of farmers and social investors to establish a comprehensive land consolidation project decision-making evaluation index system. However, the comprehensive land consolidation also involves multiple stakeholders such as local governments and village collectives. In the future, a comprehensive land consolidation project decision-making evaluation index system coordinated by multiple stakeholders should be established. (2) In order to avoid possible problems in the decision-making stage of project approval, a dynamic adjustment mechanism for pilot projects of comprehensive land consolidation should be established in the future, removing from the pilot list those that have been established but are unable to be implemented or have poor results. Moreover, the municipal pilot projects with good implementation effects will be adjusted to provincial pilot projects to obtain the support of provincial financial funds.

5. Conclusions

From the perspectives of farmers and social investors, this paper builds a comprehensive land consolidation project decision-making evaluation index system and makes an empirical analysis by using the survey data of seven pilot projects of comprehensive land consolidation in Xianning, Hubei Province, in 2020. Finally, the following research conclusions were obtained:

There will be great differences in the evaluation results when the decision-making of comprehensive land consolidation pilot projects is carried out solely from the perspectives of farmers and social investors. The reason is that farmers and social investors have different interests and concerns. Farmers pay more attention to whether comprehensive land consolidation can improve their production and living conditions, promote industrial development, and increase income. Social investors pay more attention to whether comprehensive land consolidation can produce indicators transaction income and industrial operating income.

It is reasonable and feasible to establish a comprehensive land consolidation project decision-making evaluation system when considering the interests of farmers and social investors. Social investors are the main investors in the comprehensive land consolidation, and farmers are the ultimate beneficiaries of the comprehensive land consolidation. Both are the core stakeholders of the comprehensive land consolidation. The decision-making evaluation of the comprehensive land consolidation project should comprehensively consider the interests and demands of farmers and social investors to make the evaluation results more scientific and reasonable.

The limited government financial funds should be invested in the consolidation content that the farmers need very much and social investors are willing to invest in. There is a large demand for funds for the comprehensive land consolidation project, which requires not only government financial capital investment but also a large amount of social capital investment. Thus, in the early stage of the pilot work of comprehensive land consolidation, limited government financial funds should be invested in places where farmers are in great need of improvement and in which social investors are willing to invest. In this way, it can not only attract social capital to participate in the comprehensive land consolidation so as to solve the current imbalance between the supply and demand of funds for the comprehensive land consolidation but also truly enhance the sense of gain of the farmers in the comprehensive land consolidation project area and promote common prosperity.

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Appendix A

Table A1. Overview of each application project in the study area.

Project	A	B	C	D	E	F	G
Geographic location	The south of Zhaoliqiao Town in Chibi City	The south of Henggouqiao Town in Xian'an District	The east of Xiangyanghu Town in Xian'an District	The south of Dupu Town in Jiayu County	The south of Daping Township in Tongcheng County	The northern frontier of Tiancheng Town in Chongyang County	The southwest of Honggang Town in Tongshan County
Geographic type	Low mountains and hills	Low mountains and hills	Gentle slope plain	Plains and hills	Downland	Basin	Low mountains and hills
Population of Project Area (person)	6870	6442	4884	14,793	8986	7983	4954
Project Area (ha)	3958.57	2141.37	2260.11	8323.70	1195.70	5261.22	5849.22
Cultivation area (ha)	359.09	641.87	501.13	1368.58	597.79	308.89	202.65
Per capita income (yuan)	11,358	16,655	24,414	18,873	16,361	19,794	7500

Table A2. Survey of individual characteristics of interviewed farmers.

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Content	Classification	Sample Size (Copies)	Proportion (%)
Gender	Man	265	86.60
	Woman	41	13.40
Age (years)	<40	7	2.29
	[40, 50)	34	11.11
	[50, 60)	104	33.99
	[60, 70)	99	32.35
	≥70	62	20.26
Level of education	Illiteracy	46	15.03
	Primary school	124	40.52
	Junior high school	98	32.03
	High school or technical secondary school	34	11.11
	College degree and above	4	1.31
Whether the village is cadre	Yes	6	2.00
	No	300	98.00
Types of employment	Agricultural production	166	54.24
	Local business	16	5.23
	Local workers	76	24.84
	Nonlocal business	0	0
	Nonlocal workers	48	15.69

Table A3. Overview of social investors interviewed.

Survey Content	Sorting Criterion	Number of Samples (Copies)	Sample Proportion (%)
New types of business entities	Professional investors	2	10.00
	Family farm	1	5.00
	Farmers’ professional cooperative	7	35.00
	Corporate champion	10	50.00
Type of industry	Primary industry	10	50.00
	Secondary industry	7	35.00
	Tertiary industry	1	5.00
	Integration of primary and secondary industries	1	5.00
	Integration of primary and tertiary industries	1	5.00
	Integration of secondary and tertiary industries	0	0
Annual output value (ten thousand yuan)	≤50	7	35.00
	[50, 100)	4	20.00
	[100, 500)	6	30.00
	[500, 1000)	1	5.00
	≥1000	2	10.00

Figure A1. Basic information of the project area.

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Article

The Willingness and Technology Preferences of Farmers and Their Influencing Factors for Soil Remediation

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Abstract: Farmers are one of the major uncertainty factors in remediation of contamination farmland. Based on the face-to-face questionnaire survey data of 553 farmers in 4 heavy metal-contaminated agricultural soil remediation projects in China, this study used methods, such as structural equation modeling and random forest to explore farmers' willingness to remediate, technology preference, and their key influencing factors for the first time. The results showed that farmers were willing to remediate contaminated soil and preferred phytoremediation, with 82.8% choosing phytoremediation, 12.5% choosing passivation, and 4.7% believing that the soil did not need to be remediated. In terms of willingness to remediate, the perceived benefits from participation in current remediation projects directly contributed to future willingness, with participation status (total impact coefficient 0.86) and perceived benefits (impact coefficient 0.49) being the main factors positively influencing farmers' willingness. With regard to technology preference, technical characteristics (soil quality, 17.1%; secondary contamination, 16.8%; and remediation period, 11.5%) were the main influencing factors. The sustainability of passivation effect and the possible secondary contamination restrict the promotion of passivation, whereas the cessation of agricultural production during the long remediation period restricts the promotion of phytoremediation. It is recommended to increase farmers' willingness to remediate by improving their perceived benefits and continuously overcoming the technical barriers by: (i) developing efficient and green passivators; and (ii) improving the efficiency of phytoremediation as well as intercropping or rotating cash crops while remediating. The results have important reference value for soil remediation in agricultural countries with small arable land per capita.

Keywords: soil contamination; phytoremediation; passivation; farmer; questionnaire survey

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1. Introduction

Owing to rapid industrialization, urbanization, population growth, and a lack of environmental awareness, environmental degradation and pollution problems have emerged [1,2] among which soil heavy metal pollution has become a global environmental dilemma [3,4]. It has been reported that approximately 20% of soil in the world is contaminated, with over 10 million contaminated sites covering more than 20 million hectares of land, more than 50% of which are contaminated with harmful heavy metals [5]. Approximately 600,000 ha of soil in the United States has been contaminated with heavy metals [4]. Approximately 470,000 ha of agricultural soil in Japan has been contaminated with heavy metals [6]. In China, farmland per capita is less than half of the world average, but the total area of farmland contaminated by heavy metals is nearly 20 Mha, accounting for nearly 19.4% of the total farmland [7].

Soil heavy metal pollution brings food security threats and serious economic losses. The combined impact of heavy metal pollution on the global economy is estimated to exceed $10 billion annually [5,8]. A survey supported by the European Commission estimates that the social loss caused by soil pollution is approximately 17.3 billion euros per year [8]. In

China, nearly 12 million tons of grain are polluted by heavy metals every year [9]. Therefore, actions must be taken to remediate contaminated soil. The second and third Sustainable Development Goals (SDGs) for 2030, adopted by the United Nations General Assembly, also articulate the need to mitigate food threats [10]. China attaches great importance to the environmental quality of its agricultural soils. In May 2016, the Soil Pollution Prevention and Control Action Plan was issued, and 200 pilot demonstrations for contaminated soil were conducted. From 2016 to 2021, approximately 38 billion yuan was invested in the field of soil pollution prevention and control. In 2020, there were 668 ongoing soil remediation projects nationwide of which 42.4% were agricultural soil remediation projects.

For heavy metal-contaminated agricultural soil, the remediation mechanisms are based on two basic principles: one is to reduce the concentration of heavy metals in the soil and completely remove the pollutants and the other is to use engineering technology to transform the pollutants to less harmful forms [11–14]. Phytoextraction (phytoremediation) and passivation are the most widely used representative technologies for engineering applications based on the above two remediation principles. Phytoextraction is one of the most promising phytoremediation technologies, which uses the root system of (hyper)accumulators to uptake contaminants from the soil and transfer them to aboveground biomass for accumulation, achieving complete removal of contaminants through gradual harvesting of the aboveground biomass [11,15]. Passivation remediation, also known as chemical stabilization, is a technology that reduces the toxicity and biological effectiveness of heavy metal contaminants in the soil environment by adding exogenous passivators to contaminated soil and converting heavy metals to non-activated, less toxic forms through surface complexation, chemical precipitation, ion exchange, adsorption, and so on [16,17]. However, the remediation of contaminated farmland involves arable land utilization not only in terms of technology [18,19] but also in terms of the behavior of farmers on micro level.

Although contaminated agricultural soil remediation projects are collective actions led by the government, farmers are the closest stakeholders to farmland contamination and the executors of remediation projects. If farmers perceive the remediation technologies to be detrimental to their interests, this may hinder effective implementation of the project, which will be a major uncertainty factor in solving the hidden dangers of food safety, especially for agricultural countries with small per capita arable land. It turns out that a gap exists between farmers' behaviors and policy expectations [20]. Therefore, it is necessary to study how to encourage farmers to actively participate in soil remediation, and farmers' willingness to participate in remediation and their preference for remediation technologies are important factors that should be considered in the formulation of sustainable soil remediation policies.

The study of issues related to farmland from farmers' behaviors and attitudes has become an important research perspective [21,22]. Research shows that with the application of various technologies, farmers' attitudes are increasingly determining the success of land use policies and that research on farmers' attitudes can contribute to policy innovation and practical guidance on many land use issues [21,23,24]. Various studies have examined farmers' behaviors and attitudes under certain policies and explored the factors that influence farmers' decision-making behaviors [19–21,23,25]. The main factors that may influence farmers' behaviors can be divided in household head characteristics, household production characteristics, and technical characteristics [20,26,27]. On the issue of farmland soil pollution, Zhou et al. [19] studied the spontaneous adaption behaviors of farmers in the mining area, such as abandoning farming and adjusting crops, and their results showed that a low level of adaptation perception for which technology was the most important limiting factor followed by money limited the adaptation behaviors of farmers; Yu et al. [28] investigated farmers' comprehensive assessment of the policy of remediation during fallow, such as planting green manure and biological adsorption, and found that it was positively influenced by the cognition of government implementation, the cognition of policy function and the evaluation of value perception. However, phytoremediation and passivation are the two most commonly used techniques for heavy metal-contaminated farmland. There is still a lack of research on farmers' attitudes towards different soil remediation technologies, the constraints restricting farmers' participation in different technologies remain unclear.

In the above context, with the aim of providing a scientific basis for increasing farmers' willingness to participate in remediation, promoting the implementation of agricultural soil remediation projects, and ensuring food security, our study focuses on answering the following questions: What is the attitude of farmers towards soil remediation and what is their preference for remediation technologies? How can farmers' willingness to participate in soil remediation be increased? How can remediation technologies be further optimized from the perspective of farmers? Therefore, in this study, we conducted face-to-face structured interviews with 553 farmers in 4 contaminated agricultural soil remediation project sites in China to: (i) analyze farmers' willingness to remediate and technical preferences in terms of their individual characteristics, household production characteristics, current status of remediation participation, and technical characteristics; (ii) explore the key factors affecting the popularization and application of soil remediation technologies; and (iii) propose suggestions for optimizing technical parameters for remediation in conjunction with farmers' willingness (Figure 1). It is of great theoretical and practical significance to study in depth farmers' willingness and technical preferences to participate in soil remediation projects and to construct an effective participation mechanism. The results of this study will have important reference significance for the remediation of contaminated soil in agricultural countries with small arable land per capita.

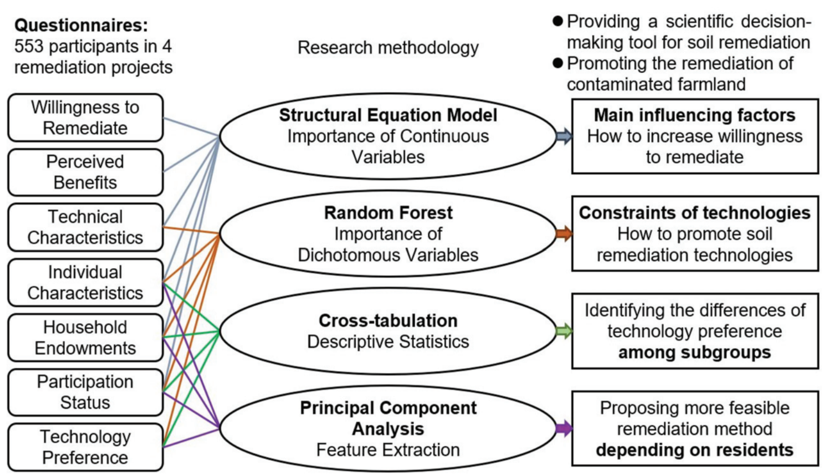

Figure 1. Flow chart of the research.

2. Materials and Methods

2.1. Data Sources

This study surveyed farmers in four soil remediation project areas in China with different levels of soil contamination, where both phytoremediation and passivation remediation were conducted, to ensure that farmers had knowledge of both remediation techniques. Household questionnaire surveys were conducted from January to September 2019 using random sampling and one-to-one structured interview methods. A total of 553 valid questionnaires were obtained from 98 households in Luancheng District, Shijiazhuang City, Hebei Province (A); 147 households in Mianzhu City, Sichuan Province (B); 190 households in Shimen County, Hunan Province (C); and 118 households in Yangshuo County, Guangxi Province (D) (Figure 2). See Supplementary Table S1 for an overview of the study area.

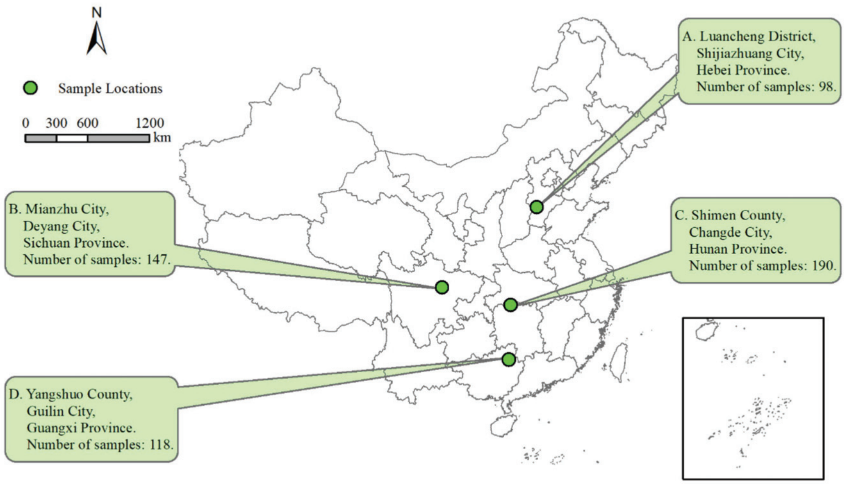

Figure 2. Details of the considered study area.

To ensure the scientific credibility and rationality of the questionnaire, the first draft of the questionnaire was designed through a literature review and expert consultation, which was improved based on the results of a random pre-investigation of 50 farmers in the project area of Shimen County, Hunan Province. The main content of the questionnaire consisted of five parts: basic information about the farmers interviewed (such as gender, age, education), household and production characteristics (including family size, farmland area, income composition), current status of participation in soil remediation (such as farmland area remediated, labor income), satisfaction with current remediation and willingness to remediate in the future, preference for remediation technology, and impact of technical characteristics (see Supplementary Table S2). Among them, farmers' characteristics affect household preferences [29]. Household production characteristics may limit farmers' choices in terms of livelihood strategies, and have received the most attention in recent studies [27,30]. Technology characteristics are farmers' psychological perceptions of different remediation technologies and may influence their rate of adoption of technologies. The participation status is an essential variable and may be an important factor influencing farmers' perceptions of different remediation technologies. To ensure the quality of the survey data, a formal survey was conducted in the form of face-to-face communication between the investigator and respondents, and the investigator filled out the questionnaire.

2.2. Research Methodology

2.2.1. Descriptive Statistics of Farmer Characteristics and Remediation Intentions

To describe the significance of the differences between the backgrounds (individual and household) of the different surveyed populations and the willingness of farmers to participate in future soil remediation and technology selection, a cross-tabulation function in IBM SPSS Statistics software (version 24.0) was used. The remediation and technical intention (non-participation, passivation, phytoremediation) were taken as columns, and the characteristics of farmers were taken as rows to compare the frequency distribution of two independent samples of the rows and columns. Among the characteristics of farmers, continuous variables, such as farmland and income, were defined and transformed into 5-level categorical variables to represent different levels of population. Based on the chi-square test to determine its significance, the original hypothesis of the cross-tabulation was that the two variables of rows and columns were independent of each other. If the chi-square test statistic was less than the critical value of significance level 0.05, the original hypothesis was overturned, indicating that there was a significant difference in remediation technology intention between different row variables (farmers' characteristics). Supplementary Table S2 presents the descriptive statistics of the sample farmers' characteristics.

2.2.2. Structural Equation Model of Farmers' Willingness to Remediate

To study the main factors influencing farmers' willingness to participate in soil remediation, a structural equation model (SEM) was constructed using IBM SPSS Statistics Amos 24.0, which is a widely used method in the study of farmers' behaviors and attitudes, mainly for continuous variables. SEM mainly focuses on modeling the relationships among latent variables, which can effectively solve the problem of farmers' cognition and other problems that are difficult to directly observe, and clearly depicts the behavioral and attitudinal processes of farmers [23,31]. Models using SEM can be divided in two types: measurement and structural models. The measurement model describes how latent variables are measured or conceptualized by corresponding observable variables and is established based on factor analysis, whereas the structural model describes the relationship between different latent variables and is established based on path analysis.

The matrix equations of the measurement model are:

$$X = \Lambda_x \xi + \delta \tag{1}$$

$$Y = \Lambda_y \eta + \varepsilon \tag{2}$$

where ξ and η are exogenous and endogenous latent variables, respectively; X is the exogenous observable variable corresponding to ξ; Y is the endogenous observable variable corresponding to η; Λ_x is the loading matrix of X on ξ; Λ_y is the loading matrix of Y on η; and δ and ε are the measurement errors of X and Y, respectively.

The matrix equation of the structure model is:

$$\eta = \Gamma \xi + \zeta \tag{3}$$

where Γ denotes the effect of ξ on η and ζ is the explanatory error vector that represents the residual term of the structural equation.

In general, farmers' individual characteristics, such as age, gender, and education, household endowments, such as household income and farmland area, and technical characteristics may influence their attitudes toward soil remediation [21,27,32]. Perceived benefits represent the subjective evaluation of soil remediation by farmers. Based on the relevant literature [33,34] combined with the actual situation, we set up questions to evaluate the perceived benefits of farmers, such as whether remediation affects food supply and whether the household income increases. In this study, we surveyed farmers in areas where soil remediation projects have been carried out, whose current participation status in remediation may have been influenced by factors, such as individual characteristics, household endowments, and may have an impact on future intentions. Therefore, we constructed a framework with individual characteristics, household endowments, technical characteristics, participation status, and perceived benefits as exogenous latent variables, and farmers' willingness as endogenous latent variable (Figure 3). The 18 observable variables under the 6 latent variables were all continuous variables and measured uniformly on a 5-level Richter scale. The variable descriptions and statistical values are presented in the Supplementary Table S3.

To examine the evaluation of model, fit indices were used, particularly chi-square, the ratio of chi-square to degrees of freedom (Chi/DF), the goodness of fit index (GFI), adjusted goodness of fit index (AGFI), and root mean squared error of approximation (RMSEA). Both GFI and AGFI estimates ranged from 0 to 1, and if the value was above 0.9, it was acceptable. The acceptable model fit indicated by RMSEA value is 0.08 [35].

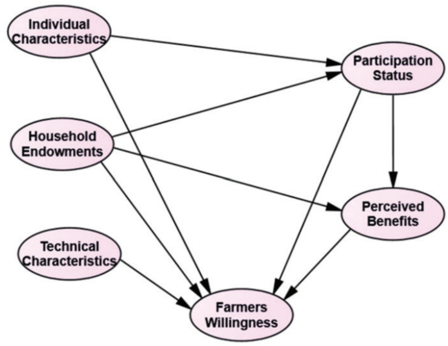

Figure 3. Framework analyzing the factors influencing farmer's willingness to participate in soil remediation.

2.2.3. Random Forest Model of Farmers' Technology Preferences

To explore the main factors influencing farmers' technology preferences for soil remediation, random forest (RF) dichotomy algorithm was used. The RF is a combined classification model based on classification and regression tree (CART), which is a supervised machine learning algorithm that can obtain small errors and high classification accuracy from a limited training set of samples and can be used to evaluate the importance of impact factors [36]. In RF, each node is split using the best value in a randomly selected subset of predictor variables at that node. This counterintuitive strategy performs efficiently compared with many other data mining techniques, including discriminant analysis, support vector machines, and neural networks, and is robust to overfitting [36].

The RF model was constructed using R4.2.1 software with the dichotomous variable of farmers' technology preference to phytoremediation or passivation as dependent variables and farmers' individual characteristics (gender, age, education), household endowment (such as population, farmland, income), participation status, and technological characteristics as independent variables, and finally the Gini index method was applied to evaluate the importance of the variables influencing farmers' technology preference classification. MeanDecreaseGini calculates the impact of each variable on the heterogeneity of the observations at each node of the classification tree using the Gini index, thus comparing the importance of the variables. The larger the value, the greater the importance of the variable. In this study, we normalized all variable importance indices to sum to 100% for presentation [37]. A total of 18 independent variables were used as the original survey data. The variable descriptions and statistical values are presented in the Supplementary Table S7.

2.2.4. Farmer Features Extraction

To further extract the characteristics of farmers who chose each remediation technology, a principal component analysis (PCA) was performed on the data of farmers who chose phytoremediation and passivation separately (IBM SPSS Statistics 24.0). The validity of each variable was determined based on the communality, which indicates how much each variable is expressed by the common factor, and it is generally accepted that variables greater than 0.7 are well expressed by the common factor. Therefore, we used the variables with a communality greater than 0.7 as factors that better summarize the characteristics of the farmers (households) selected for a certain remediation technology. The frequency distribution of these variables was determined to identify the characteristics of farmers who chose this remediation technology.

Data calculations and statistical analyses were performed using Microsoft Excel 2019 and IBM SPSS Statistics 24.0. Figures were drawn using OriginLab Origin 2022.

3. Results and Discussion

3.1. Farmers' Characteristics and Remediation Intention

With the development of existing soil remediation projects and a better understanding of the two remediation technologies, farmers' intentions for soil remediation have changed, and phytoremediation has become a popular remediation mode. Farmers with farmland transferred for soil remediation were defined as those participating in remediation. Among the 553 sample farmers, 22.6% did not participate in remediation, 54.1% participated in phytoremediation, 13.9% participated in passivation, and 9.4% participated in both remediation modes. Regarding future soil remediation intentions, 4.7% of the sample farmers believed that the soil did not need remediation, 82.8% expressed a preference for phytoremediation, and 12.5% preferred passivation (Figure 4a).

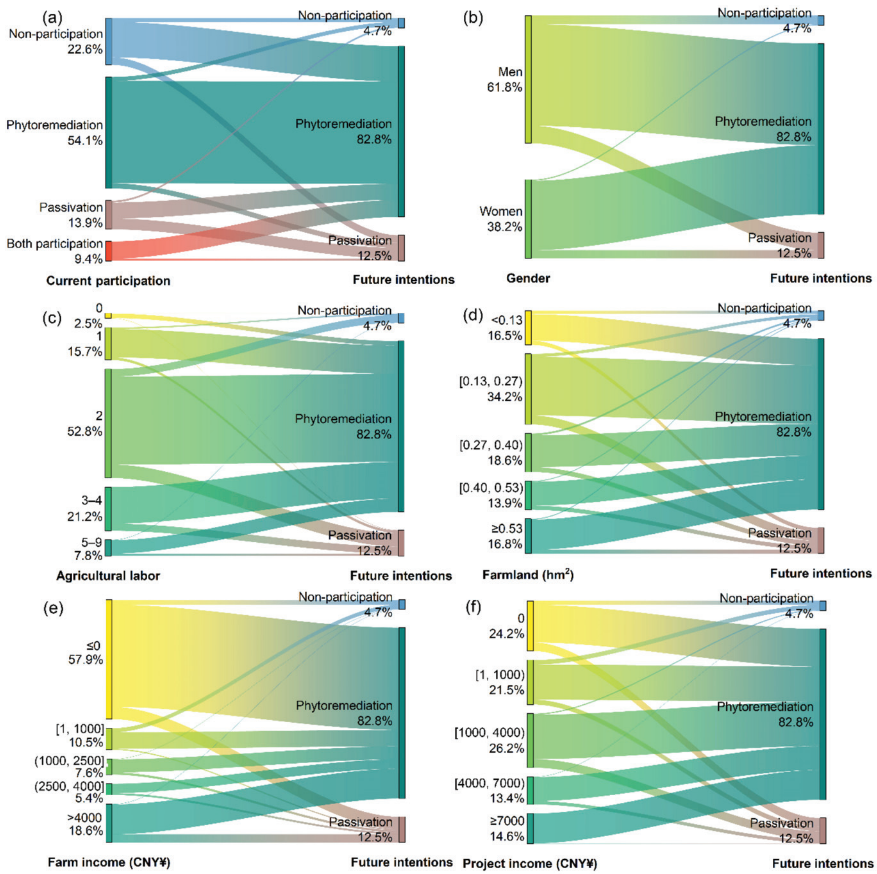

Figure 4. Farmers' characteristics and remediation intention. Future intentions of farmers with different (**a**) current participation, (**b**) gender, (**c**) agricultural labor, (**d**) farmland, (**e**) farm income, (**f**) project income for soil remediation.

Among the objective indicators of the sample farmers' characteristics (Supplementary Table S2), there were significant differences ($p < 0.05$) in soil remediation intentions among different levels of the population in terms of gender, agricultural labor, farmland, farm income, and project income.

- Women had a greater willingness to remediate than men (Figure 4b). Studies often show that women in agriculture are more environmentally conscious than men [38],

which may be related to the fact that women are generally more risk-averse than men [25,39,40];
- Farmers with more household agricultural labor had a greater willingness to remediate and an increased propensity to passivation compared with those with less agricultural labor (Figure 4c). Consistent with the findings of Ponce, et al. [41], agricultural labor has a positive impact on households' environmentally friendly behavior. In this study, they preferred passivation in order to ensure "no unemployment";
- Farmers with more farmland were more willing to remediate than those with less farmland (Figure 4d). According to hierarchical theory assumptions, once basic material needs can be met, one can focus on improving quality of life, such as environmental quality [41]. Hence, households with more farmland would be more willing to participate in soil remediation after a portion of their farmland production meets their basic needs;
- Farmers with a high farm income had an increased propensity to passivate relative to those with a lower farm income (Figure 4e). In order to maintain the stability of agricultural production and household economy, households with high income from farmland needed to take adaptation measures [19]. At the same time, they had to maintain the agricultural production function of the soil and thus had an increased propensity for passivation;
- Farmers with high project income had an increased propensity for phytoremediation relative to those with lower project income (Figure 4f). This is attributed to the fact that phytoremediation requires more labor for hyperaccumulator management, with 72.3−100% of the high project income coming from phytoremediation. Economic benefits are generally regarded by scholars as the starting point for farmers' participation in farmland conservation [42]. Economic incentives are often used as a means of increasing farmers' perceptions of adaptation and thus their adaptive behavior [43]. In this respect, phytoremediation has an advantage over passivation.

Agricultural research has observed relationships between farmers' environmental behavior and various demographic characteristics, such as age, education, and gender, which may be associated with decisions to participate in agri-environmental programs [38]. Many studies have shown that farmer's age and education level are key factors influencing their environmental behaviors [27]. Younger farmers are more likely to engage in adaptive production behaviors or environmental improvements than older farmers [27,44], and farmers with higher education levels are more likely to engage in health-related adaptive behaviors [19]. In contrast, farmers' willingness to remediate soil in this study was not significantly related to their age or education level. This may be explained by the high attrition of young labor in our study area (only 3.1% under the age of 40) and the generally low educational attainment of the remaining middle-aged and older labor force (only 8.5% high school and above), a common phenomenon in rural China, resulting in an under-representation of younger and better-educated farmers in the samples.

3.2. Farmers' Willingness to Remediate Soil

The results of the SEM showed that the five exogenous latent variables explained 95% of the variability in farmers' willingness to remediate soil and that participation status and perceived benefits were the main factors influencing the strength of farmers' willingness to participate in soil remediation (Figure 5). The direct path coefficient of participation status on farmers' willingness to remediate was 0.42, and it indirectly affected farmers' willingness by affecting perceived benefits, with a total path coefficient as high as 0.86. There was a significant positive correlation between the two ($p < 0.05$), indicating that the more actively farmers participated in remediation, the stronger their willingness to remediate soil in the future. In terms of each observable variable of participation status, PS1 (farmland area for remediation) had the largest contribution, with a standardized coefficient of 0.98, followed by PS2 (project labor income) with a standardized coefficient of 0.78.

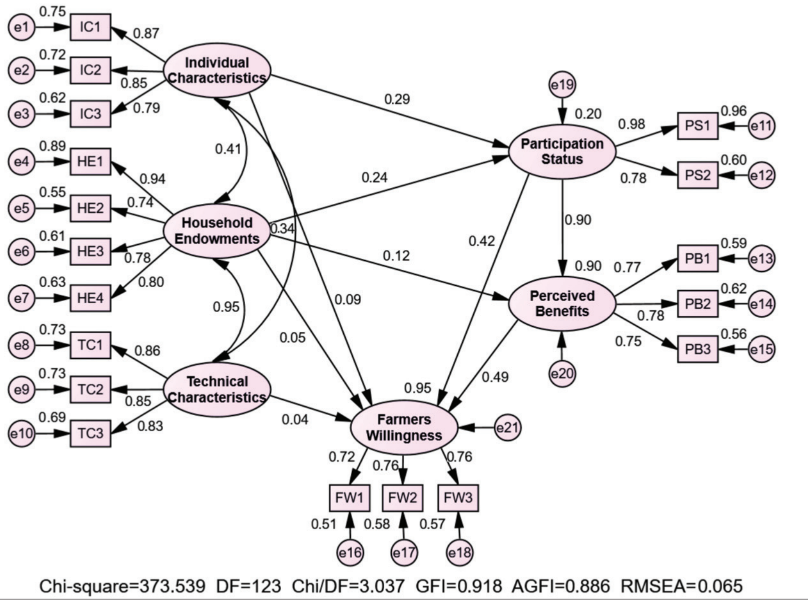

Figure 5. SEM of farmers' willingness to participate in soil remediation. Note: From the unstandardized regression weights, there were only two insignificant paths ($p > 0.05$): household endowments to farmers' willingness and technology characteristics to farmers' willingness. The reliability analysis and validity tests of the model are presented in Supplementary Tables S4–S6.

The path coefficient for the effect of perceived benefits on farmers' willingness to remediate was 0.49, with a significant positive correlation ($p < 0.05$), indicating that the higher the farmers' perceived benefits of participating in remediation, the stronger their willingness to remediate soil in the future. In terms of each observable variable of perceived benefits, the contribution of each observable variable was close, with a PB2 (subsidies for participation in remediation can cover losses) standardized coefficient of 0.78, followed by a PB1 (remediation does not affect food supply) standardized coefficient of 0.77, and a PB3 (participating in remediation can improve income) standardized coefficient of 0.75. This indicated that the farmers' perceived benefits were sourced more from the non-loss of contaminated farmland; that is, it was necessary to ensure that at least the farmland involved in soil remediation had an income comparable to that of farmland with normal production functions.

According to rational behavior theory, perceived value is the comparison between the benefits and risks that farmers experience from their behavior. Individual farmers' behaviors follows the paradigm of "cognitive trade-off–perceived value–willingness to act–behavioral response" in action logic [20,45]. Perceived benefit refers to the result of subjective evaluation made by individuals through product benefits, service quality, emotional satisfaction, and so on [46]. In the study of farmers' economic behavior, perceived benefits are considered an important basis [20]. The higher the level of farmers' perceived benefits, the higher the level of comprehensive assessment. A high level of perceived benefits reflects farmers' positive attitudes towards agricultural policies [23]. Similar results were obtained in this study, where farmers' perceived benefits from participation in current soil remediation projects to obtain land rent and labor income directly contribute to future willingness to remediate. The perceived risks came mainly from the possible risks associated with the technical characteristics of remediation, which were much smaller than the health risks of soil heavy metal stress, and had little impact on farmers' willingness to participate in remediation (path coefficient of 0.04, technical characteristics).

3.3. Farmers' Technology Preference

The RF results showed that technical characteristics were the most important factors in dichotomizing farmers' choice of phytoremediation or passivation; they followed the order: soil quality > secondary contamination > remediation period (Figure 6a). Although farmers' attention to technical characteristics had little effect on their willingness to participate in soil remediation, it directly affected their preference for remediation technologies.

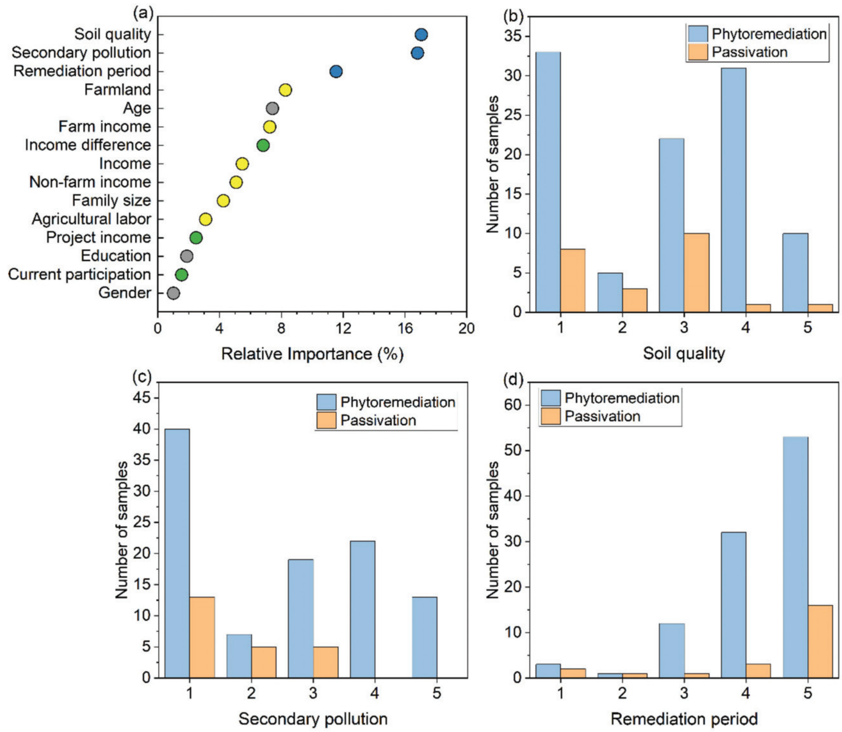

Figure 6. Factors influencing farmers' technology preference. (**a**) The relative importance of the variables of farmers' technology preference. Frequency distribution of respondents' scores on (**b**) soil quality, (**c**) secondary pollution and (**d**) remediation period. Note: (**a**) was based on the results of the MeanDecreaseGini of the RF, and the sum of all factors was normalized to 100%. Then, the importance values of the independent variables were readjusted. The blue, yellow, green, and gray circles are technical characteristic variables, household characteristic variables, current participation variables, and personal characteristic variables, respectively. There were significant differences ($p < 0.05$) in the scores of soil quality, secondary contamination, and remediation period between the sample farmers who chose phytoremediation and passivation after the Mann–Whitney U test (data not normally distributed).

Specifically, the relative importance of soil quality was 17.1%. The scores of farmers who chose phytoremediation and passivation on soil quality were 3.57 ± 1.21 and 2.49 ± 1.04, respectively, indicating that farmers who paid more attention to the possible impact of remediation technology on soil quality were more inclined to choose phytoremediation (Figure 6b). The relative importance of secondary contamination was 16.8%. The scores of farmers who chose phytoremediation and passivation on secondary contamination were 3.57 ± 1.21 and 2.49 ± 1.04, respectively, indicating that farmers who were more concerned about possible secondary contamination from remediation technologies were more inclined to choose phytoremediation (Figure 6c). Passivation remediation has been proven to be an effective, convenient, and low-cost remediation method [16,47], and many passivators have been widely used in remediation practices for metal-contaminated soils [48]. However, the durability of the stabilization effect of passivation under dynamic environmental conditions during long-term remediation and the possible negative effects of passivator application (secondary contamination) remain well-known bottlenecks [16,28,49]. At the same time, these technical barriers to passivation are the main factors limiting its application in agricultural soil remediation.

The relative importance of the remediation period was 11.5%. The scores of farmers who chose phytoremediation and passivation on remediation period were 4.11 ± 0.96 and 4.62 ± 0.97, respectively, suggesting that farmers who placed more value on the remediation period had a higher propensity for passivation (Figure 6d). Phytoremediation is recognized as an eco-friendly, green, and sustainable approach to soil remediation, but it also faces important performance and efficiency issues. For most heavy metals, remediation of contaminated soils by phytoremediation alone spans decades [50,51]. That is, agricultural production needs to be interrupted for a long period, which is also the main factor restricting farmers' choices of phytoremediation. From another perspective, a higher score (full score of 5) indicated that the remediation period was a factor that farmers care about when participating in soil remediation. The desire for healthy soil quality was evident in the fact that some farmers undertake a longer remediation period to bring their farmland back to full health.

3.4. Farmers Feature Extraction

Based on the results of the PCA (Supplementary Tables S8–S11) of the communality, annual income, non-farm income, and education were the factors that best summarized the characteristics of the farmers who selected phytoremediation (Figure 7a). Taking the range of obviously higher frequency distribution of the factors as the characteristics of the main farmers (households) who chose this technology, it can be seen that the main characteristics of farmers who chose phytoremediation were annual household income of 0−16,000 CNY ¥/y (Figure 7b), non-farm income of 0−4000 CNY ¥/y (Figure 7c), and education level of primary school (Figure 7d).

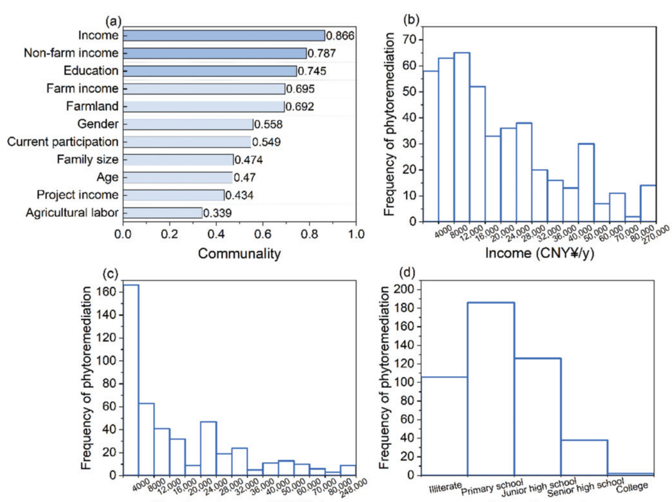

Figure 7. Characteristics of farmers intended for phytoremediation. (**a**) communality of characteristics of farmers intended for phytoremediation extracted by PCA. The dark blue, communality > 0.7. Frequency distribution of (**b**) income, (**c**) non-farm income, and (**d**) education level of farmers who chose phytoremediation.

Farm income, annual income, agricultural labor, and farmland were the factors that best summarized the characteristics of the farmers who chose passivation (Figure 8a). From the frequency distribution plot of each factor, the main farmer (household) characteristics for selecting passivation were farm income ≤ 0 (Figure 8b), annual income of 4000−8000 CNY ¥/y (Figure 8c), agricultural laborers of 3 (Figure 8d), and farmland area of 0.13−0.4 hm^2 (Figure 8e).

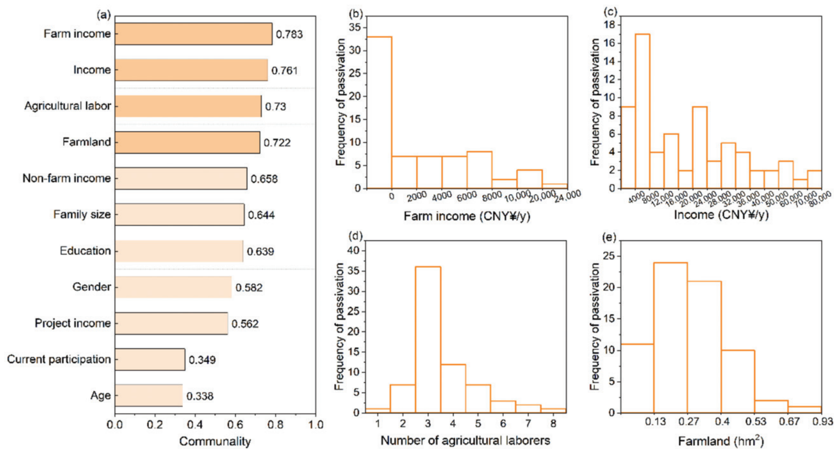

Figure 8. Characteristics of farmers intended for passivation. (**a**) communality of characteristics of farmers intended for passivation extracted by PCA. The dark yellow, communality > 0.7. Frequency distribution of (**b**) farm income, (**c**) income, (**d**) agricultural labor, and (**e**) farmland of farmers who chose passivation.

When formulating soil remediation policies, the farmers' characteristics archived by the local government can be used to preliminarily identify their possible soil remediation technology preference based on the above results, which can be included as one of the important considerations in the comparison of technology options to further ensure the successful implementation of soil remediation projects from the aspect of farmers' willingness to participate.

4. Conclusions

Based on 553 farmers' face-to-face questionnaire data from four heavy metal-contaminated agricultural soil remediation project sites in China, this study explored farmers' willingness and technology preference for agricultural soil remediation and their key influencing factors using SEM, RF, and other methods.

(1) In general, farmers in the survey area were willing to remediate the soil and preferred phytoremediation;
(2) Perceived benefits was the main factors influencing farmers' willingness to participate in soil remediation. The perceived benefits of land rent and labor income received by farmers through their participation in current soil remediation projects directly affected their willingness to remediate in the future;
(3) Technical characteristics (soil quality, secondary contamination, and remediation period) were the most important factors for farmers to choose remediation technologies. The sustainability of soil heavy metal passivation and possible secondary contamination were the main factors limiting farmers' choices of passivation remediation. The long remediation period and cessation of agricultural production were the main factors limiting farmers' choice of phytoremediation.

5. Recommendations and Limitations

The main conclusions of this study have the following implications for the promotion of soil remediation technology and the formulation of policies to improve farmer satisfaction. For scholars: first, further develop efficient and green passivators to overcome the sustainability and possible secondary pollution problems of passivation; second, further develop the corresponding activators with hyperaccumulator applications to improve the efficiency of phytoremediation. For companies: strengthen the long-term supervision after remediation to promote the safe application of passivators. For government: when applying phytoremediation, consider intercropping or crop rotation remediation modes of low-accumulation crops with hyperaccumulators without interrupting production; in areas where farmers' willingness to remediate soil is low, increase their satisfaction and willingness by raising the level of their perceived benefits. These suggestions for government and companies should be carefully considered when carrying out soil remediation to solve food safety problems, especially in agricultural countries with limited per capita arable land.

This study investigates farmers' willingness and technology preference to participate in soil remediation and the important influencing factors to provide a scientific basis to promote the remediation of heavy metal-contaminated farmland from farmers' perspectives. However, there are some limitations in this study. First, we only surveyed 553 farmers in 4 different regions of China, although the study areas have different pollution levels and cropping structures, the limited sample size may bias the results, and the generalizability to other countries and regions needs to be further verified. Second, we only investigated phytoremediation and passivation, the two most commonly used techniques for heavy metal contaminated farmland, without considering other techniques, such as alternative planting and deep plowing, which deserve further study. Third, our questionnaire did not involve subjective indicators, such as government implementation perceptions and subjective norms that may affect farmers' participation behaviors, which should be considered more comprehensively in future studies. Therefore, future study will consider more study areas, more technologies applied in remediation practices of heavy metal contaminated farmland, and it will construct a theoretical framework of farmers' participation behaviors toward different soil remediation technologies.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/land11101821/s1, S1: Table S1 Survey area; S2: Survey questionnaire; S3: Table S2 Descriptive statistics of sample farmers; S4: SEM, Table S3 Variable description and data statistics of the SEM, Table S4 Latent variable reliability test, Table S5 KMO and Bartlett's test, Table S6 Model structure validity (model fitness); S5: Random forest, Table S7 Random forest variable descriptions and data statistics; S6: Principal component analysis, Table S8 KMO and Bartlett's test (phytoremediation), Table S9 Total variance explanation of PCA (phytoremediation), Table S10 KMO and Bartlett's test (passivation), Table S11 Total variance explanation of PCA (passivation).

Author Contributions: Conceptualization, J.Y.; data curation, J.Y.; formal analysis, Y.Y.; funding acquisition, J.Y.; investigation, Y.Y.; methodology, Y.Y.; project administration, J.Y.; resources, J.Y.; software, Y.Y.; supervision, L.W.; validation, L.W.; visualization, Y.Y.; writing—original draft, Y.Y.; writing—review and editing, L.W. and J.Y. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: The data presented in this study are available on request from the corresponding author.

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Article

Land Certificated Program and Farmland "Stickiness" of Rural Labor: Based on the Perspective of Land Production Function

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Abstract: The instability of farmland rights is the fundamental reason for the decrease in the "stickiness" of farmland in China. The Land Certificated Program (LCP) plays an important role in clarifying the ownership of land and stabilizing the property rights of land, as well as enhancing the land production function. Most existing literature focuses on the impact of the LCP on non-agricultural labor participation, while research on agricultural labor participation is scarce. This paper analyzes the impact of the LCP on farmland "stickiness" based on the perspective of land production function. This paper also applies propensity score matching (PSM) using CLDS data from 2016 and 2018 to evaluate the policy effect of the LCP on farmland "stickiness", and conducts heterogeneity analysis and the robustness test. In addition, this paper examines the mechanism of the influence of LCP on farmland "stickiness" by using the mediating effect model. The results of this analysis showed that: (1) The impact of the LCP on farmland "stickiness" is significant, as the rate of agricultural labor participation has increased by 4.8% to 4.9%. (2) The incentive effect is heterogeneous, and has significant impacts on non-professional households, as well as on small and medium-sized of farms. (3) The sensitivity test revealed that unobservable factors do not have an impact on the LCP estimation results, and the results of the PSM estimation were robust. (4) The policy effect of the LCP at the village level also confirms the robustness of the promotion effect and the mechanism. (5) Land production function has a partial mediating effect on the impact of the LCP on farmland "stickiness". Given these results, we must begin to consolidate, expand and make good use of the results of the LCP, support the connection between smallholders and modern agriculture, and enhance the land production function in order to stabilize agricultural production and realize agricultural modernization.

Keywords: Land Certificated Program (LCP); farmland "stickiness"; land production function; property rights; agricultural policy

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1. Introduction

Land, as a factor of production, has a production function, as it provides jobs and income for producers. In rural areas, the economic activities basically revolve around the relationship between land and labor. This is particularly true in traditional "rural China" society, which is based on agriculture and living on land; therefore, rural labor "sticks" to land [1]. In order to meet household subsistence needs and secure economic income, rural labor is engaged in agricultural production, which is behaviorally reflected in the dependence of rural labor on the land. However, with the development of the market economy in rural areas, land has come to serve multiple other functions, such as security and property functionalities [2]. This is also the case in the process of China's structural transformation, as the functional orientation of land, as well as the strengths and weaknesses of the land production function of farmland, change with these new developments. This in turn loosens the relationship between labor and land, thereby altering the "stickiness" of land [3]. According to the labor value theory, agricultural labor participation is the enacted form of land production function. Specifically, as land is an indispensable resource in agricultural production, the utilization of land production function and the realization of economic value must be condensed in human labor. Therefore, as land "stickiness" refers to the dependence of rural labor on land, the production function of land determines the "stickiness" between farmland and rural labor, in turn, the land "stickiness" is expressed by the degree of agricultural labor participation.

Since the China's reformation and opening up to the world, under the influence of the land system and the urban–rural dual system, the function of land in China's rural areas has changed, the production function has gradually decreased, and the land "stickiness" of rural labor has gradually weakened. In order to track these new developments, this paper constructs an analytical framework that analyses the weakening of land "stickiness" (Figure 1). China's current rural land system adheres to collective ownership, which is an internal member's right, and grants all members of the village equal rights to enjoy the village's land [4]. Therefore, in order to achieve equity in land ownership, regular and irregular adjustments according to changes in household size are necessary [5]. Regular adjustments refer to land reallocation at the end of the contract period. In 1983, land-use rights were allocated to the households in a village for a period of 15 years each. In 1998, the contract period of land-use rights was increased from 15 to 30 years. In 2008, the land contract period was further increased from 30 years to an unspecified "long-term" period. In 2017, farmers' land-use right contracts were extended by yet another 30 years upon expiration. Irregular adjustments, meanwhile, refer to land reallocation due to population changes. Using egalitarian principles, the size of land assigned to a household was determined by the number of household members and/or labors [6]. This led to frequent land reallocations within villages to correct for demographic changes that occurred within the contract period. For example, Brandt et al. [7] found that land was reallocated 1.7 times on average per village from 1982 to 1995. Meanwhile, Ren et al. [8] found that 33% of the villages experienced land reallocation after the 1998 land contracting round. These adjustments brought instability to land property rights, which in turn led to the inefficient allocation of land and labor and a reduction in agricultural returns [9,10]. These decreases in land production function weakened land "stickiness" and decreased agricultural labor participation. At the same time, due to the influence of the urban–rural dual system, the non-permanent transfer of "leaving the countryside without leaving the land" has become the main rural–urban pattern in China. [11]. However, migrating laborers still retain rural land or rent out land to relatives and acquaintances [12]. As land's main function has transitioned to that of security, agricultural production efficiency has remained low, the "stickiness" of the land has weakened, and the agricultural labor participation rate has decreased. The corresponding low agricultural labor participation has brought a series of problems between urban and rural areas, such as an increase in urban–rural income disparity, rural poverty, and rural recession [13].

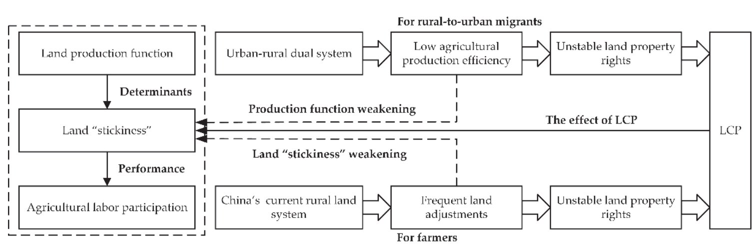


Figure 1. Analytical framework for land "stickiness".

Through the above analysis, it can be found that the external manifestation of the weakening of land "stickiness" is the low degree of agricultural labor participation; the internal motivation is the instability of land rights and the weakening of land production functions caused by the land system and urban–rural dual system.

Therefore, in order to increase the participation of agricultural labor, it is urgent to stabilize rural land property rights, improve farmers' agricultural production expectations, strengthen land production function, and enhance land "stickiness".

In order to stabilize rural land property rights, the Chinese central government has twice implemented the Land Certificated Program (LCP), first in 2003 and then in 2009. The aim of the LCP is to guarantee land property security and provide a legal definition of contractual management rights [14]. In 2003, the government initially implemented the LCP through the Rural Land Contracting Law. This initial program, which lasted through 2007, was called the first round of the LCP. The first round was applicable to over 94.6% of all rural households [15]. However, the LCP implementation during this period was sketchy, with unclear land information on plot size and boundaries [16]. In 2009, the Chinese central government began the new round of the LCP, which was called the latest national LCP. This time, all households with land in a village were required to participate. The implementation of the latest round of the LCP was divided into three stages. The first stage was known as the small-scale village-level pilot stage. Beginning in 2009, small-scale village-level pilot work for the LCP was carried out in eight provinces and municipalities under the direct supervision of the central government. The second stage involved nationwide piloting at the county level. This stage of LCP piloting began in 1 to 3 counties (cities and districts) that displayed strong representation in each province. In all, the process, which took place in March 2011, involved a total of 12,150 villages in 710 townships across 50 counties (cities and districts). In the third and final stage a province-wide pilot phase was implemented. The province-wide piloting started in the three provinces of Shandong, Anhui, and Sichuan, while 27 whole-country pilots were carried out in 2014. Nine additional provinces were added as whole-province pilot units in 2015, and the whole-county pilots were expanded in other places. By 2017, the LCP had been extended to cover almost the whole country. In November 2020, the registration and certification of contracted rural land was basically completed, as the certification rate exceeded 96%. The most important role of this program was to establish clearly registered ownership rights, contract rights, and operational rights, confirm that rural households had the right to the possession, use, mortgage, and benefit of their respective contract land, and validate that the rural household could transfer these property rights to others in legitimate ways. According to the requirement of central government, the process of the latest LCP mainly included public mobilization, land survey, results announcement, signature confirmation, and issuing of certification [17]. The goals of the latest LCP in 2009 were to (a) ensure that county governments could effectively solve the issues left over from history, including inaccurate contracted land size and unclear spatial location; (b) fundamentally guarantee governmental safeguarding of farmers' land-management rights and contract rights in the form of legally valid certificates in order to reduce farmers' worries of losing their land; and (c) clarify the transaction parties of land property rights through the LCP to optimize the rural land transaction market and reduce the land transaction cost [18].

The latest national Land Certificated Program (LCP) stabilized the contracting relationship, clarified the land property rights, and strengthened the integrity of land rights by providing land contractual management rights certificates. Therefore, the aims of this study are twofold. The first is to investigate the effect of LCP on land "stickiness" through theoretical analysis and empirical tests. The second aim is to explore how the LCP affects the land "stickiness" of rural labor based on the perspective of land production function.

2. Literature Review

Existing academic research on the policy effect of LCP has mainly focused on the development of the agricultural industry and the livelihood of farmers. First, in terms of the agricultural industry, the LCP affects the input of land, labor, investment, and technology, which in turn promotes the improvement of agricultural production efficiency and the development of agriculture [14,16,19–22]. Second, in terms of farmers' livelihoods, the LCP has changed farmers' choices of livelihood strategies and narrowed the gap in welfare levels among farmers [23–25].

Thus, as agricultural labor participation is the external manifestation of land "stickiness", this paper focuses on the factors involved in rural labor and discusses the impact of the LCP on rural labor participation.

There have been many studies on the LCP and labor participation, and their views can be roughly divided into three different categories. First, the LCP promotes non-agricultural labor participation or rural out-migration [26–28]. As the LCP clarifies land property rights, reduces the risk of land loss for farmers, and accelerates land transfer, it thereby promotes the transfer of rural idle labor to non-agricultural industries. Second, the LCP reduces the expected losses caused by the adjustment of farmland and stimulates the enthusiasm of farmers to invest in agricultural production, thereby inhibiting the transfer of rural labor to off-farm employment [29]. Specifically, the irregular adjustment of farmland is akin to levying random taxes on farmers [30], which means that in the unforeseen future, farmers' land and medium- and long-term investments attached to the land will inevitably suffer losses. The more frequent the adjustment, the greater the expected loss of farmers. On the contrary, the stability created for farmland by the LCP will reduce the random taxes levied against farmers and reduce their expected losses. This should in turn enhance their enthusiasm for engaging in agricultural production, and reducing the transfer of labor to off-farm employment. Third, the LCP has no significant impact on the non-agricultural labor participation of the rural labor because the off-farm employment of rural labor is closely related to labor's human capital, local social conditions, and other factors [31].

By reviewing the existing literature, we found that: First, there is no consensus among scholars on the impact of the LCP on rural labor. Second, most of the existing studies focus on the impact of the LCP on rural labor off-farm employment or rural out-migration, while the literature on the policy effect of LCP determination on agricultural labor participation is relatively lacking. Due to the heterogeneity of the endowment of rural labor, not all rural labor will realize the transfer from agricultural to non-agricultural work. On the one hand, farmers have formed high asset specificity in long-term agricultural production, such as agricultural machinery and technology. In order to avoid economic losses after abandoning agricultural production, these farmers will be encouraged to continue engaging in agricultural production after experiencing the stability brought by the LCP. On the other hand, due to the constraints of human capital, some rural labor can only stay in the agricultural field [32]. In addition, the LCP mainly promotes the off-farm employment of rural idle labor groups [33]. Therefore, it is particularly important to evaluate the policy effect of the LCP on the participation of agricultural labor. Thirdly, the heterogeneity of the policy effect of the LCP among different rural household types and different farm sizes also requires further analysis. With the development of agricultural modernization, rural household types are beginning to diversify as the co-existence of professional and non-professional households becomes more common. Meanwhile, the market of farmland transfer is constantly developing, and this results in changes in farm size. This begs the question, does the relationship between the LCP and land "stickiness" change due to differences in rural household types and changes in farm size? That is, does the policy effect of the LCP have preferences in terms of household types and farm size? Without further research into this question, it will continue to be difficult to fully estimate the policy effect of the LCP on the land "stickiness" of rural labor.

To fill these knowledge gaps, we address three main questions through empirical research: (1) Does the LCP enhance or weaken the land "stickiness" of rural labor? (2) Can it be applied equally among the different rural household types and the different farm sizes? (3) How does the LCP and land production function affect land "stickiness"?

The answers to the above questions have important theoretical value and practical significance. The results of this research could serve to protect farmers' rights, promote the development of agricultural production, improve the level of agricultural modernization, and achieve the goal of rural revitalization in China.

Hence, based on the perspective of land production function, this paper firstly constructs the conceptual framework of "LCP–land production function–land 'stickiness'" to theoretically analyze the mechanism of the property rights exclusion effect and the incentive effect of LCP on the land "stickiness" of rural labor via land production function. Secondly, using mixed cross-sectional data from the 2016 and 2018 China Labor-force Dynamics Survey (CLDS), the propensity score matching (PSM) model is used to empirically test the effect of LCP on land "stickiness". Heterogeneity analysis and robustness tests are also conducted. Furthermore, we introduce a mediation effect model to test the mechanism of the effect of the LCP on the land "stickiness" of rural labor. Finally, we propose policy recommendations to provide references for stabilizing the property rights of farmland, enhancing its production functions, and promoting agricultural development.

3. Theoretical Framework

3.1. Property Rights Exclusion Effect, Land Production Function, and Land "Stickiness"

The Land Certificated Program has a property rights exclusion effect. The property rights exclusion effect is the exclusivity of contractual rights in farmland. The LCP measured each plot with detailed information, including location, size, and boundaries. The disputes with unclear land information on plot size and boundaries were addressed. Consequently, the LCP was able to guarantee the exclusivity of farmland property rights by clarifying the four areas of farmland and specifying property rights ownership [34]. Now, it continues to promote the improvement of farmland production functions and the redistribution of agricultural labor.

In the past, when farmland property rights were found to be unclear, they were frequently adjusted. On the one hand, farmers could not obtain exclusionary rights through legal empowerment under this system. On the other hand, the exclusionary rights granted by village rules and regulations were not mandatory; therefore, the exclusivity of farmland property rights was weakened [35]. Therefore, in order to avoid the possible risk of land loss, farmers had to bear certain exclusion costs to maintain their contractual rights while going out to work [36]. These farmers were often willing to operate farmland at low cost, or even to transfer farmland to acquaintances for free. As a result, the production function of land and the land "stickiness" of rural labor were weakened.

Therefore, the purpose of implementing the LCP was to permanently determine contractual rights to farmland by measuring each plot. It strengthens the exclusivity of contractual rights to farmland, reduces the risk of land loss, and strengthens the production function of land. This in turn affects the labor allocation decisions of rural households. Laborers are now more inclined to engage in agricultural production, increase the degree of agricultural labor participation, and enhance land "stickiness". At the same time, due to historical legacy problems, such as the poorly defined property rights of agricultural land and the operational flexibility of local governments in the process of implementing the LCP, farmers inevitably pay more attention to the productive function of the land. This enables them to preserve their contractual rights by increasing their labor input, increasing their labor participation, and strengthening the "stickiness" of the land. In this way, farmers can obtain the most favorable "standard of certificated land" and maximize their interests.

3.2. Property Rights Incentive Effect, Land Production Function, and Land "Stickiness"

The Land Certificated Program also has a property rights incentive effect. The property rights incentive effect is the incentive of farmland returns. The LCP formalized and legalized contract rights though the issuance of land certificates. At the same time, it strengthened farmers' residual claims to farmland returns by stabilizing long-term land contract relationships [37]. Hence the farmers can use the tenure security to mortgage land, stimulate the improvement of farmland production functions and reallocate agricultural labor.

Prior to the program, with the instability of farmland property rights, farmers' residual claims to farmland returns were not stable. This meant that once the farmland was reallocated to adjust to population needs, both the medium- and long-term investments in agriculture attached to the farmland were lost, and household income from agriculture was reduced. This in turn led to the inefficient use of farmland and agricultural production. Therefore, in order to avoid the possible risk of farmland adjustment, farmers' demand for land production function decreases, thus reducing agricultural labor input and weakening land "stickiness". Driven by comparative interests, farmers then choose to engage in non-agricultural production in urban areas in order to relieve the pressure of survival and improve quality of life, further weakening the land production function and land "stickiness".

The LCP provides an institutional guarantee for agricultural operators to stabilize agricultural production and enhance the land production function by ensuring the stability of farmland property rights and guaranteeing farmers' residual claims to farmland returns. It stimulates and enhances farmers' enthusiasm and stability in agricultural production [29], and the land production function is strengthened. This stabilization of residual claims to farmland and higher expected returns from agricultural operations can, to a certain extent, encourage farmers to increase their participation in agricultural labor, thereby increasing the supply of agricultural labor and land "stickiness" of rural labor.

In summary, the LCP has a property rights exclusion effect and an incentive effect. On the one hand, the LCP confirms contractual rights and ensures farmland exclusivity through the land survey. On the other hand, the LCP guarantees the stability of land property rights and ensures farmers' residual claims to farmland returns through the issuance of certificates. This improves the land production function, thus promoting the reallocation of agricultural labor, increasing the degree of agricultural labor participation, and increasing the land "stickiness" of rural labor. The specific influence path is shown in Figure 2.

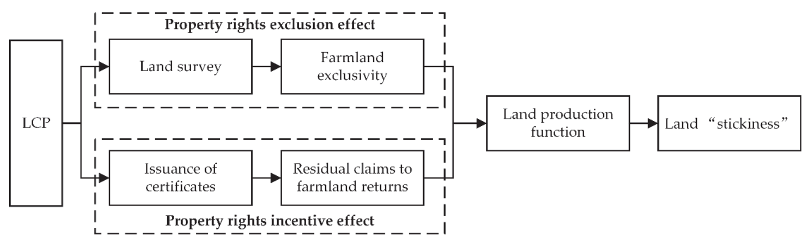


Figure 2. The impact path of the LCP on land "stickiness".

Based on these observations and previous studies, we hypothesize that the LCP has a significantly positive effect on the land "stickiness" of the rural labor, and land production function plays an important role in it. In other words, the LCP exerts a significantly positive effect on land "stickiness" via its influence on land production function.

4. Data, Variables, and Models

4.1. Data

The data used in this paper come from the 2016 and 2018 China Labor-force Dynamics Survey (CLDS) data provided by the Social Science Survey Center of Sun Yat-sen University. This survey is conducted once every two years, with the labor force aged 15–64 as the target population. It utilizes a multi-stage, multi-level sampling method proportional to the size of the labor force. Since the CLDS2018 household samples are all new samples, we were unable to compose panel data. Thus, this paper uses two rounds of surveys consisting of mixed cross-sectional data from 2016 and 2018. This paper focuses on studying the impact of the Land Certificated Program (LCP) on rural households' agricultural labor participation. In order to do so, rural households were used as the research subjects, from which mainly household and community-level data were used. The survey data were then processed and screened to obtain a valid sample of 3936 rural households. The sample farm households covered 247 villages in 26 provinces across China, and the regional distribution of the sample farm households showed that there were 1399, 1217, and 1320 farm households in the eastern, central and western regions, respectively.

The process of sample selection was as follows: (1) construct the variables needed for this study based on the variables already available in the database; e.g., the variable of the number of rural household members was obtained by using the coding count of each member of the farm household; (2) delete the samples of rural households that were non-agricultural, and keep only those samples whose household type was agricultural; (3) delete the samples of rural households that did not possess farmland; (4) delete the missing values of key variables, e.g., delete the missing value of question F6.2a "Has the household received the Certificate of Rural Land Contract Management Rights" and delete the missing value of question F6.4a "The number of people engaged in agricultural production in your household last year".

4.2. Variables

1. Dependent variable: land "stickiness" of rural labor. According to the above analysis, agricultural labor participation is the external expression of land "stickiness". Thus, this paper adopts the agricultural labor participation rates to represent the land "stickiness" of rural labor. This was determined by calculating the ratio of labor participated in farming activities [38]. On average, the ratio of agricultural participation was 44.3% in this sample.

2. Independent variable: Land Certificated Program (LCP). The CLDS2016 and CLDS2018 surveys provide data on the agricultural production of rural households in 2015 and 2017, respectively. In this period, the LCP was being promoted in the form of a province-wide pilot or county-wide pilot, and had not yet even been extended to the whole country in 2015. Although the LCP had been extended across the entire country by 2017, not all rural households had carried out certificated land work simultaneously for the same pilot unit, which provides a good opportunity for this paper to study the policy effects of the LCP.

This paper draws on the studies of Zhou et al. [39] to measure "whether the farm household has received the Certificate of Rural Land Contract Management Rights" in order to determine whether the farmland was certificated. If the answer to this question was "yes", then the value of LCP was "1"; if not, the value was "0". Using this processing method, the number of observations in the sample of households that had received the Certificate of Rural Land Contract Management Rights was 2335, while the number of observations in the sample of households that had not yet received the Certificate of Rural Land Contract Management Rights was 1601. Thus, the overall certification rate of the sample was 59.3%, which is similar to the results of previous studies [17].

3. Control variables. We also controlled for the characteristics of farmers individuals, households, and villages in our analysis.

The individual characteristics were gender, age, age squared, education, political outlook, and health of the household heads. The social and cultural norms were the leading causes of gender inequality [40]. Females' household responsibilities (such as caretaking children, household chores, and so on) limited both their available labor and time to farm [41]. It was therefore expected that males were more inclined to engage in agricultural production. The age of the household head was used as a proxy for the family's farming experience [42]. Therefore, older farmers were expected to be more productive in agriculture. However, as their age increases, the physical ability of farmers who have consistently engaged in agricultural production will naturally be restricted. Hence, the square of age was added to the model to capture the possible non-linearities in its impact [43,44]. The average age of household head is 53.877 years. Household heads with more education were assumed to have more off-farm skills and therefore be more likely to engage in off-farm employment. Zhang et al. [45] found that rural individuals with more education had increasing access to off-farm jobs. In addition, De Rrauw and Rozelle [46] estimated an average return to education of 6.4% in off-farm wage employment in rural China. Thus, it was expected that the education would have a negative impact on farm employment. The average number of years of education was generally low, at approximately 7 years. Finally, political outlook and individual health played an important role in improving human capital and enhancing the labor market outcomes. Earlier studies found that having a political cadre in the family increased the family members' off-farm employment [47,48]. Shu Lei [44] found that health was an important factor affecting agricultural production. Thus, political outlook and health were also included in the model. On average, the percentage of household heads who were not party members was 8.3%, and 50% of the household heads reported their health status as "healthy".

The household characteristics were total family income, land per capita, labor ratio and the types of farming households. Total family income was determined with respect to household wealth, which may have a negative impact on farm employment, as participation in off-farm employment may require a minimum level of assets [49]. For outcomes measured in terms of monetary value (for example, productivity, value of credit received, and consumption), studies usually reported treatment effects on the scale of the natural logarithm [20]. In order to induce normality in skewed income distribution, this paper treated total family income logarithmically [49]. Land per capita was the ratio of the farmland size and the number of people living in the same family. Large land per capita ratios were expected to increase households' probability of agricultural production, as more agricultural labor was needed to farm more land [50]. The mean of the land per capita was 2.533 mu. Labor ratio was the share of labor population between the ages of 15 and 64. Household labor availability also has an impact on household labor allocation between farm employment and off-farm employment [51]. It was expected that the labor ratio would have a negative impact on farm employment, since the limited amount of arable land per capita in China forced any surplus labor forces to be more inclined to engage in off-farm employment. As for farming type, households were divided into professional households and non-professional households, which accounted for 89.58% and 10.42% of the samples, respectively. The professional households were expected to have more farming skills and therefore to be more productive in agriculture.

The village characteristics were the proportion of the village population engaged in agriculture, the existence of non-agricultural economy in the village, the index of village support services, the distance of the village from the township government, and the topography of the village. As seen in Table 1, the mean of the proportion of the village population engaged in agriculture was 71.919, indicating that approximately 72% of the farmers in the village were involved in agriculture. Where there was a higher proportion of the village population engaged in agriculture, there was less non-agricultural economy in the village, which indicates that the level of economic development in the village was low. When this is the case, the farmers can only engage in agricultural production to maintain demand. On the contrary, the existence of a non-agricultural economy in a village indicates that the level of economic development in the village is high, and that farmers tend to regularly engage in non-agricultural production. In our sample, 18% of villages had a non-agricultural economy. The index of village support services represented the level of support and security for agricultural production at the village level. Village support services are likely to increase the ratio of agricultural production, as it can reduce the sunk costs and realize increasing returns [52]. In this paper, support services mainly included unified irrigation and drainage services, machine plowing services, unified pest prevention services, unified purchase of production materials services, planting planning services, and organization of farmers for agricultural production. Each service available to the farmers was assigned a value of "1", and each service not available was assigned a value of "0". The values were added together to obtain the village support service index. The distance of the village from the township government was also a key factor influencing farmers' agricultural production, as the rural households located further away from the township government were more likely to participate in agricultural production than households located nearby [53]. The average distance of the village from the township was 6.330 km in our sample. According to Xie et al. [54], we controlled for whether a laborer was from a plain village. If the village was a plain village, it was given a value of "1"; if not, it was given a value of "0".

The specific definitions of the above variables and the results of the descriptive statistical analysis are shown in Table 1.

Table 1. Definitions and Descriptions of Variables.

Variable Types	Variable Names	Variable Definitions	Mean	SD	Min	Max
Dependent variable	Land "stickiness"	The ratio of labor participating in farming activities (%)	0.443	0.248	0	1
Independent variable	LCP	1 if a farmer owns a land certificate, and 0 otherwise	0.593	0.491	0	1
Individual characteristics	Gender	1 if the head of household is male, and 0 otherwise	0.869	0.337	0	1
	Age	Age of the head of household (years)	53.877	10.915	18	89
	Age squared	Age ∗ Age/100 (years)	30.219	11.863	3.24	79.21
	Education	Years of formal education of the head of household (years)	7.186	3.154	0	16
	Political outlook	1 if the head of household is party member, and 0 otherwise	0.083	0.276	0	1
	Health	1 if the head of household is healthy, and 0 otherwise	0.500	0.500	0	1
Household characteristics	Income	Total household income in 2015 or 2017 (yuan, logarithm)	9.709	1.853	0	14.914
	Land per capita	The ratio of the farmland size and the number of family members (mu)	2.533	7.124	0.01	250
	Labor ratio	Share of labor population aged 15–64	0.810	0.315	0	1
	Household type	1 if the household is professional, and 0 otherwise	0.104	0.306	0	1
Village characteristics	Population engaged in agriculture ratio	The ratio of the village population engaged in agriculture (%)	71.919	31.084	0	100
	Non-agricultural economy	1 if the village has non-agricultural economic, and 0 otherwise	0.182	0.386	0	1
	Support service index	The total number of farmers enjoying village support services	2.090	1.396	0	6
	Distance of the village from the township	The distance of the village from the township government (km)	6.330	5.936	0	50
	Village topography	1 if the village is plain, and 0 otherwise	0.477	0.500	0	1

4.3. Models

4.3.1. Propensity Score Matching (PSM) Method

In order to test the impact of the LCP on the land "stickiness" of rural laborers, this paper constructs an empirical model of land "stickiness" in the following form.

$$Y_i = a_0 + a_1 R_i + a_2 X_i + \varepsilon_i \quad (1)$$

where Y denotes the labor land "stickiness" of farming households i; R_i denotes whether the LCP was implemented; X_i is a series of control variables, including individual characteristics, household characteristics, and village characteristics; a_1 and a_2 are the coefficients to be estimated for LCP and control variables, respectively; a_0 is a constant term; and ε_i is the error term.

Notably, as the LCP was gradually implemented using a moderated piloting system, "selective" bias might arise as a result. The LCP was affected by its circumstances, such as the social, historical, or economic conditions [17]. On the one hand, the local governments of the initial pilot regions were required to invest copious human, material, and financial resources into supporting the LCP, which placed stress on these regions in terms of their economic development. On the other hand, after the LCP, the farmland would no longer be adjusted, which ultimately affected the existing interest pattern in rural areas and even hinder the implementation of the policy [55]. Therefore, the promotion of the LCP inevitably put certain demands on the strength of a village's collective organizations. Thus, in order to ensure the effectiveness of the LCP pilots, the government tended to select the areas with relatively high levels of economic development and the villages with stronger rural collective organizations or less traditional farmland adjustment as the pilot areas for the LCP. This ultimately resulted in the problem of sample selection bias faced in this study. At the same time, there was a level of heterogeneity in land "stickiness", individual characteristics, household characteristics, and village characteristics between the groups with and without LCP (see Table 2). Therefore, if a simple regression analysis were used to estimate the policy effect of LCP on the land "stickiness" of rural laborers, the estimation results may be biased.

Table 2. Average individual, household, and village characteristics by LCP status.

Variable Types	Variable Names	LCP	Non-LCP	Diff: (1)-(2)
		(1)	(2)	
Dependent variables	Land "stickiness"	0.468 (0.255)	0.407 (0.232)	0.061 ***
Individual characteristics	Gender	0.877 (0.329)	0.858 (0.349)	0.019 *
	Age	53.307 (10.701)	54.710 (11.170)	−1.403 ***
	Age squared	29.561 (11.537)	31.178 (12.263)	−1.618 ***
	Education	7.288 (3.129)	7.037 (3.185)	0.251 **
	Political outlook	0.093 (0.290)	0.069 (0.253)	0.024 ***
	Health	0.534 (0.499)	0.450 (0.498)	0.084 ***
Household characteristics	Income	9.708 (1.941)	9.710 (1.717)	−0.002
	Land per capita	2.886 (5.827)	2.020 (8.650)	0.866 ***
	Labor ratio	0.810 (0.305)	0.811 (0.329)	−0.001
	Household type	0.123 (0.329)	0.076 (0.265)	0.047 ***

Table 2. *Cont.*

Variable Types	Variable Names	LCP (1)	Non-LCP (2)	Diff: (1)-(2)
Village characteristics	Population engaged in agriculture ratio	72.614 (30.570)	70.905 (31.800)	1.710 *
	Non-agricultural economy	0.170 (0.376)	0.200 (0.400)	−0.030 **
	Support service index	2.139 (1.376)	2.018 (1.423)	0.121 ***
	Distance of the village from the township	6.501 (6.203)	6.154 (5.516)	0.422 **
	Village topography	0.471 (0.499)	0.485 (0.500)	−0.014
Observation		2335	1601	—

Note: Standard deviations are shown in parentheses. ***, **, and * denote significance at 1% level, 5% level, and 10% level, respectively. Significance levels are obtained from *t*-tests or chi-square tests, depending on whether the variable is categorical or continuous.

Based on the possible "selective" bias of the sample and the heterogeneity of individual characteristics, household characteristics and village characteristics, this paper adopted the propensity score matching (PSM) method to estimate the effect of the LCP on the land "stickiness" of rural labor. The basic idea of this method was to construct a sample of uncertificated farmland for the sample of certificated farmland by introducing a counterfactual framework, and to ensure that the characteristics of both samples are similar except for the farmland rights [56]. The difference of land "stickiness" between the two samples can be regarded as the result of two different experiments (with and without LCP) on the same individual. Therefore the difference was the policy effect of the LCP on labor land "stickiness".

Specifically, in this paper, the land "stickiness" of farmer i with confirmed farmland rights ($R = 1$) was set as Y_i^R, which was the treatment group; the land "stickiness" of farmer i with unconfirmed farmland rights ($R = 0$) was set as Y_i^{NR}, which was the control group. The effect of farmland rights on labor land "stickiness" was thus determined as:

$$T_i = Y_i^R - Y_i^{NR} \tag{2}$$

In Equation (2), since it was not possible to observe the land "stickiness" of farmer i both before and after the farmland was certificated, the counterfactual framework was constructed in this paper as:

$$\begin{aligned} T_i &= E(Y_i^R|R=1) - E(Y_i^{NR}|R=0) \\ &= E(Y_i^R|R=1) - E(Y_i^{NR}|R=0) + E(Y_i^{NR}|R=1) - E(Y_i^{NR}|R=1) \\ &= E[(Y_i^R - Y_i^{NR})|R=1] + [E(Y_i^{NR}|R=1) - E(Y_i^{NR}|R=0)] \end{aligned} \tag{3}$$

In Equation (3), $E\left[\left(Y_i^R - Y_i^{NR}\right)|R=1\right]$ is the average treatment effect on the treated (ATT) of LCP on land "stickiness", and $\left[E\left(Y_i^{NR}|R=1\right) - E\left(Y_i^{NR}|R=0\right)\right]$ is the selection bias.

In the above analysis, the certificated farmland group and the uncertificated farmland group were not randomly assigned, so they had a level of selection bias. The PSM method constructs the control group with similar characteristics to the treatment group as much as possible by matching the scores of the whole sample. In this way, we were able to effectively reduce the sample's selection bias and obtain the effective estimate of the average treatment effect on the treated (ATT). The main estimation steps were as follows.

First, we used a logit model to estimate the conditional probability fitted value of rural households to carry out certificated farmland, i.e., the expression of the propensity score value is

$$PS = Pr(R = 1|X_i) = E(R = 0|X_i) \tag{4}$$

In Equation (4), PS is the propensity score value; R = 1 indicates certificated farmland farmers; R = 0 indicates certificated farmland farmers; and X_i indicates observable individual, household, and village characteristics.

Next, the treatment group was matched with the control group. To verify the robustness of the matching results, two methods, nearest neighbor matching (NNM) and kernel-based matching (KBM), were selected for matching in this paper.

Then, the common support test and the balance test for propensity score estimation were performed. The common support test was utilized to determine whether the treatment and control groups had a common support region and whether there was any partial overlap in the range of values. The balance test was used to determine the matching quality by comparing whether there was a significant difference between the treatment and control groups in terms of explanatory variables.

Finally, the ATT was calculated to determine the effect of the LCP on the land "stickiness" of rural laborers.

4.3.2. Mediation Effect Model

In order to further study the influence path of the LCP on rural labor land "stickiness", and test whether there was a mediating effect of land production function between the LCP and labor land "stickiness", we constructed the following model.

$$M_i = b + \beta_2 R_i + \lambda_2 X_i + \varepsilon_{2i} \tag{5}$$

$$Y_i = c + \beta_3 R_i + \beta_4 M_i + \lambda_3 X_i + \varepsilon_{3i} \tag{6}$$

where the meanings of Y_i and R_i are kept consistent with Equation (1); M_i is the mediating variable, i.e., the land production function; β_1, β_2, β_3 and β_4 are parameters to be estimated; a, b and c are constant terms, and ε_{1i}, ε_{2i} and ε_{3i} are random error terms.

5. Analysis and Results

5.1. The Estimation Results of the PSM Model

5.1.1. Propensity Score Estimation

The most direct way to measure the impact of the LCP on labor land "stickiness" is to compare the land "stickiness" of certificated rural households with that of non-certificated rural households. However, these two categories (certificated and uncertificated) are mutually exclusive, which makes it impossible to observe the effects of the same household's "certificated" and "uncertificated" farmland at the same time. Therefore, this paper constructed a logit model and a marginal effects model with certificated farmland as the dependent variable, and then estimated individual, household, and community characteristics to obtain the propensity scores of each variable. The estimation results are shown in Table 3. The explanatory variables all had variance inflation factors (VIFs) of less than ten, except for age and age squared. Although the VIFs of age and age squared were more than ten, according to Allison's research, multicollinearity will have no adverse consequences when high VIFs are caused by the inclusion of powers or products of other variables [57]. Hence, the estimated model was free of any serious multicollinearity.

From Table 3, we can see that age, political outlook, and health status among individual characteristics had significant effects on the LCP. There was an inverted "U"-type relationship between age and the LCP. This indicates that as the age of the head of the household increased, so did the probability of the household participating in the LCP. However, when the age increased to a certain degree, this same probability decreased in turn. Political outlook and health status had positive effects on the LCP and were significant at the 5% and 1% statistical levels, respectively. In terms of household characteristics, land per capita and household type had positive effects at the 1% statistical level, and the probability of the LCP increased by 0.7% for each unit increase in land per capita.

Compared with non-professional households in agricultural production, the probability of the LCP was 11.3% higher for professional households. In terms of village characteristics, the non-agricultural economy had a negative effect on the LCP, and this was significant at the 5% level. This means that villages with a developed non-agricultural economy had less dependence on farmland, and a low probability of participating in the LCP to secure farmland property rights. The support service index and distance to township government had positive effects on LCP, as they were significant at the 1% and 5% levels, respectively. The topography of the village had a negative effect on the LCP at the 10% statistical level, and the probability of the LCP in plain areas was lower than that in non-plain areas. This is because the LCP is easier to promote and implement in the non-plain areas as these farmers are less dependent on land.

Table 3. Logit model results of factors determining LCP.

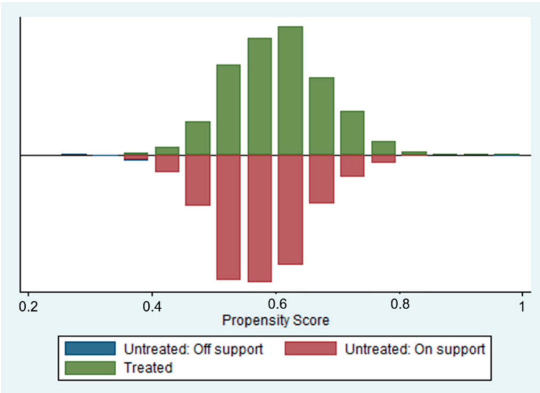
Variable Types	Variable Names	Logit		Marginal Effect	
		Coefficient	SE	Coefficient	SE
Individual characteristics	Gender	0.086	0.100	0.020	0.023
	Age	0.058 **	0.024	0.014 **	0.006
	Age squared	−0.060 ***	0.022	−0.014 ***	0.005
	Education	0.006	0.011	0.001	0.003
	Political outlook	0.310 **	0.127	0.073 **	0.030
	Health	0.311 ***	0.069	0.073 ***	0.016
Household characteristics	Income	−0.020	0.019	−0.005	0.004
	Land per capita	0.028 ***	0.009	0.007 ***	0.002
	Labor ratio	−0.100	0.110	−0.024	0.026
	Household type	0.480 ***	0.116	0.113 ***	0.027
Village characteristics	Population engaged in agriculture ratio	0.001	0.001	0.000	0.000
	Non-agricultural economy	−0.172 **	0.087	−0.040 **	0.020
	Support service index	0.091 ***	0.024	0.021 ***	0.006
	Distance to township government	0.013 **	0.006	0.003 **	0.001
	Village topography	−0.115 *	0.069	−0.027 *	0.016
Constant		−1.313 **	0.653	—	—

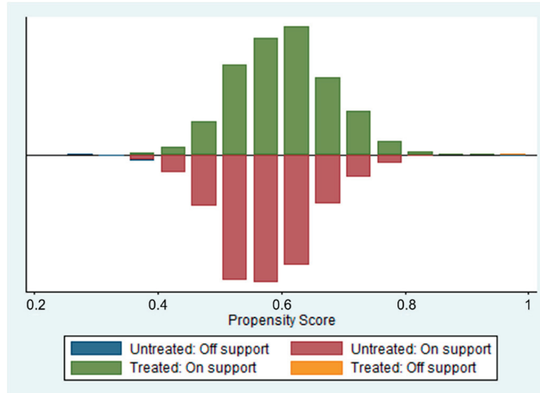
Note: ***, **, and * denote significance at 1% level, 5% level, and 10% level, respectively.

5.1.2. Matching Quality Tests: Common Support Test and Balance Test

The common support test aimed to determine whether there was a significant difference between the propensity score values of the treatment group (the certificated farmland group) and the control group (the uncertificated farmland group). If the common range of propensity scores of the two sample groups was large, it indicated a good matching result. Otherwise, it would lead to biased estimation results. The results of the common support test were matched using the nearest neighbor matching and kernel-based matching methods. As shown in Figure 3, most of the observations were within the common support region and only a small number of samples were not in the common support region after matching. Therefore, the common support test was satisfied by the matching estimation using the nearest neighbor matching and kernel-based matching methods in this paper, indicating a good matching effect.

The balance test aimed to examine whether there are significant systematic differences in the variables of individual characteristics, household characteristics and village characteristics between the treatment groups and the control groups. If there was no significant difference after matching, this indicated that individuals with the same characteristics could be found to match between the two groups and the matching effect was good; if not, the matching effect was poor.





(**a**) (**b**)

Figure 3. Propensity score distribution and common support for propensity score estimation: (**a**) with nearest neighbor matching; (**b**) with kernel-based matching.

In Table 4 it is shown that after applying the nearest neighbor matching method, the standardized deviation of each variable after matching was controlled within 10%. Following this, the standardized deviation of most of the control variables decreased compared with that before matching. Except for the variables of total household income, proportion of working population, and village topography, the deviation of all variables after matching decreased substantially. In addition, the variables including gender, education, and political outlook in individual characteristics, and type of farm household in household characteristics, as well as the variables of population engaged in agriculture ratio, non-agricultural economy, support services index, and distance to township government in village characteristics, were significantly different between the treated and control group samples before matching, and there were also no systematic differences after matching. These indicate that the differences in characteristics between the treated and control groups were basically eliminated, and the two groups of samples became more similar and comparable.

Table 4. PSM quality indicators before and after matching.

Variables	Unmatched Matched	Nearest Neighbor Matching			Kernel-Based Matching		
		Bias (%)	∣Bias∣ Reduction (%)	*t*-test (*p*>∣t∣)	Bias (%)	∣Bias∣ Reduction (%)	*t*-test (*p* > ∣t∣)
		Individual characteristics					
Gender	U	5.4		0.092 *	5.4		0.092 *
	M	1.9	65.2	0.509	0.2	96.5	0.946
Age	U	−12.8		0.000 ***	−12.8		0.000 ***
	M	4.8	62.6	0.090 *	0.3	98.0	0.927
Age squared	U	−13.6		0.000 ***	−13.6		0.000 ***
	M	5.2	61.9	0.061 *	0.5	96.3	0.858
Education	U	8.0		0.014 **	8.0		0.014 **
	M	−2.8	64.7	0.322	0.5	96.6	0.859
Political outlook	U	8.7		0.008 ***	8.7		0.008 ***
	M	2.4	73.0	0.442	0.8	91.2	0.804
Health	U	16.8		0.000 ***	16.8		0.000 ***
	M	−8.5	49.3	0.004 ***	−0.7	95.8	0.809

Table 4. *Cont.*

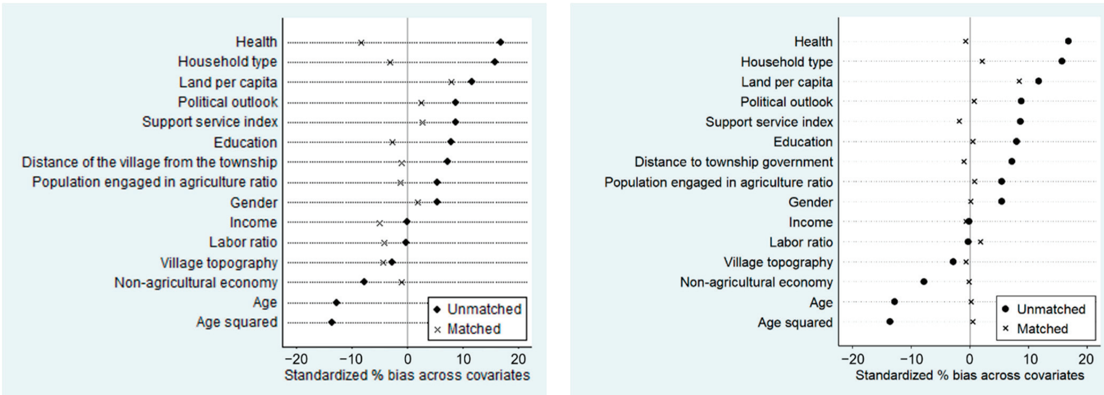
Variables	Unmatched Matched	Nearest Neighbor Matching			Kernel-Based Matching		
		Bias (%)	|Bias| Reduction (%)	*t*-test (*p*>|t|)	Bias (%)	|Bias| Reduction (%)	*t*-test (*p* > |t|)
		Household characteristics					
Income	U	−0.1		0.968	−0.1		0.968
	M	−5.1	−3786.9	0.071 *	−0.7	−394.1	0.826
Land per capita	U	11.7		0.000 ***	11.7		0.000 ***
	M	7.9	32.7	0.000 ***	8.4	28.5	0.000 ***
Labor ratio	U	−0.3		0.938	−0.3		0.938
	M	−4.3	−1606.5	0.128	1.8	−630.5	0.520
Household type	U	15.8		0.000 ***	15.8		0.000 ***
	M	−3.3	79.1	0.314	2.1	86.8	0.513
		Village characteristics					
Population engaged in	U	5.5		0.090 *	5.5		0.090 *
agriculture ratio	M	−1.3	76.0	0.647	0.8	84.5	0.770
Non-agricultural	U	−7.8		0.015 **	−7.8		0.015 **
economy	M	−1.2	84.5	0.670	−0.2	98.0	0.956
Support service index	U	8.6		0.008 ***	8.6		0.008 ***
	M	2.6	70.2	0.388	−1.8	79.2	0.548
Distance to township	U	7.2		0.029 **	7.2		0.029 **
	M	−1.2	83.4	0.706	−1.0	85.7	0.736
Village topography	U	−2.8		0.380	−2.8		0.380
	M	−4.5	−56.5	0.128	−0.6	78.4	0.834

Note: ***, **, and * denote significance at 1% level, 5% level, and 10% level, respectively.

Further, similar results were also obtained using the kernel-based matching method. Compared with before matching, the standardized deviations of each variable were significantly reduced, and all variables were controlled within 10%. Except for income and labor ration, the percentage of deviation reduction in all variables decreased significantly. These indicate that the systematic difference changes between the treatment and control groups before and after matching were consistent with the nearest neighbor matching.

Meanwhile, according to the distribution of standardized deviations used for both methods (see Figure 4), the distribution of standardized deviations of each variable before matching was relatively discrete. This indicates that the individual characteristics, household characteristics, and village characteristics of the certificated farmland group and the uncertificated farmland group before matching were significantly different. After applying the nearest neighbor matching and kernel-based matching methods, the standardized deviations of each variable were less than 10%, and most of them were concentrated around 0, which shows a significant reduction compared with the pre-matching period. This also indicates that the matched group of the LCP and the group without the LCP were better balanced at the level of control variables, and there was no longer a significant difference.

In summary, the results of the balance test using the two matching methods of nearest neighbor matching and kernel-based matching remained consistent. This indicates that the sample matching passed the balance test.



(**a**) (**b**)

Figure 4. Standardized % bias across covariates: (**a**) with nearest neighbor matching; (**b**) with kernel-based matching.

5.1.3. Analysis of Matching Results

The nearest neighbor matching and kernel-based matching methods were used to assess the effect of LCP on the land "stickiness" of rural labor (see Table 5). In general, the ATT values obtained by both matching methods were relatively close to each other, indicating that the analysis results were robust. In the nearest neighbor matching, the ATT value of LCP was 0.049. Meanwhile, in the kernel-based matching, the ATT value of LCP was 0.048. Both ATT values were statistically significant at the 1% level. In other words, the implementation of the LCP will contribute to an increase in the agricultural labor force participation rate by about 4.8% to 4.9%. This indicates that the LCP has a positive effect on agricultural labor participation and enhances the land "stickiness" of rural labor.

Table 5. The ATT of LCP on land "stickiness".

Matching Methods	Unmatched Matched	Mean		ATT	SE	T Value
		T	C			
Nearest neighbor matching	U	0.468	0.407	0.061 ***	0.008	7.65
	M	0.468	0.419	0.049 ***	0.010	4.70
Kernel-based matching	U	0.468	0.407	0.061 ***	0.008	7.65
	M	0.467	0.419	0.048 ***	0.008	5.95

Note: Treatment group (T) and control group (C). *** denote significance at 1% level.

In addition, the unmatched ATT value of 0.061 was slightly higher than the matched result. This suggests that sample selection bias and variability in sample characteristics can overestimate the policy effect of LCP, and that simple regression model estimates are biased.

5.2. Heterogeneity Analysis

With the development of urbanization and industrialization, rural society has become divided. The main agricultural operators present a situation of co-existence of professional and part-time households. At the same time, with the improvement of the farmland rented market, farmland resources can be reallocated in the rural market, which in turn provides the possibility for professional agricultural production households to increase their farm sizes. To this end, this section examines whether the policy effects of the LCP on labor land "stickiness" are heterogeneous in terms of the rural household types and farm size. Does the policy effect of the LCP have preferences in terms of household types and farm size?

In this paper, the types of rural households are divided into professional and non-professional households in agricultural production. At the same time, drawing on the idea of grouping in Opler's study [58], the samples of farm size less than 25% are defined as small scale, the samples of farm size between 25% and 75% are defined as medium scale, and the samples of farm size more than 75% are defined as large scale.

From Table 6, we can see that in terms of rural household type, the promotional effect of the LCP on agricultural labor participation of non-professional household groups was significant, while the promotional effect on agricultural labor participation of professional household groups was not significant. In terms of farm size, the promotional effect of the LCP had the largest effect on medium-sized farms, with an ATT value of 0.060, and it was significant at the 1% statistical level; the second largest effect was on small-sized farms, with an ATT value of 0.042, and it was significant at the 10% level; and the effect on large-sized farms was not significant.

Table 6. Heterogeneity analysis results.

Matching Methods	Unmatched Matched	Rural Household Types		Farm Size		
		PH	NPH	Small	Medium	Large
Nearest neighbor matching	U	0.041 (0.027)	0.061 *** (0.008)	0.058 *** (0.016)	0.070 *** (0.012)	0.036 ** (0.015)
	M	0.043 (0.038)	0.032 *** (0.011)	0.042 * (0.021)	0.060 *** (0.015)	0.032 (0.020)

Note: Standard errors are shown in parentheses. Professional households (PH) and non-professional households (NPH). ***, **, and * denote significance at 1% level, 5% level, and 10% level, respectively.

The above analysis shows that the policy promotion effect of the LCP on land "stickiness" of rural labor is mainly reflected in the group of non-professional agricultural production households, medium-sized farms, and small-sized farms, while the promotion effect on professional agricultural production households and large-sized farms is not significant.

5.3. Robustness Tests

5.3.1. Robustness Test I: Sensitivity Analysis

The key underlying assumption of the PSM method is that a farmer's decision to participate in LCP is solely dependent on observed factors [59]. However, the real-life decisions of farmers on whether to participate in the LCP are also affected to some extent by unobservable factors. As such, this section uses Rosenbaum bounds estimation for sensitivity analysis [60]. When $\gamma = 1$, this indicates that rural households are equally likely to participate in LCP. When different values are assigned to γ, Rosenbaum bounds estimates give the upper and lower significance levels of the impact of LCP at different levels of variation in likelihood, the Hodges–Lehmann point estimates of the upper and lower bounds, and the confidence intervals of the upper and lower bounds. These act as indications of whether heterogeneity in unobserved factors significantly alters the estimates. If unobservable heterogeneity significantly alters the estimation results, this indicates that the PSM method based on observable heterogeneity is not suitable for estimating the policy effects of the LCP.

According to the Table 7, even though there was more than twice the likelihood of a difference in the LCP due to unobservable heterogeneity, the effect of the LCP on land "stickiness" of rural labor was still positive, with significance levels below 1%. The Hodges–Lehmann point estimates and confidence intervals were greater than 0 at the 5% significance level. This indicates that the LCP had a significant positive effect on land "stickiness" of rural labor, and unobservable heterogeneity did not affect the estimation results. This suggests that the results obtained by the PSM method are robust.

Table 7. Rosenbaum bounds sensitivity analysis.

γ	Sig+	Sig−	t-hat+	t-hat−	CI+	CI−
1.0	0.0000	0.0000	0.4167	0.4167	0.4167	0.4167
1.1	0.0000	0.0000	0.4167	0.4167	0.4000	0.4333
1.2	0.0000	0.0000	0.3958	0.4333	0.3889	0.4500
1.3	0.0000	0.0000	0.3875	0.4500	0.3750	0.4500
1.4	0.0000	0.0000	0.3750	0.4500	0.3750	0.4583
1.5	0.0000	0.0000	0.3750	0.4583	0.3667	0.4625
1.6	0.0000	0.0000	0.3667	0.4583	0.3667	0.4762
1.7	0.0000	0.0000	0.3667	0.4762	0.3500	0.5000
1.8	0.0000	0.0000	0.3500	0.5000	0.3500	0.5000
1.9	0.0000	0.0000	0.3500	0.5000	0.3429	0.5000
2.0	0.0000	0.0000	0.3485	0.5000	0.3333	0.5000

Note: sig+: upper bound significance level. sig− lower bound significance level. t-hat+: upper bound Hodges–Lehmann point estimate. t-hat−: lower bound Hodges–Lehmann point estimate. CI+: upper bound confidence interval (a = 0.95). CI−: lower bound confidence interval (a = 0.95).

5.3.2. Robustness Test II: Replacement of LCP Variables

The issuance of certificates is the last part of the confirmation of the LCP, and at the same time, the land certificate is an important legal document to define the property rights of farmland. However, the latest LCP has problems such as the relative lag of the titling process [61]. Specifically, though the confirmation of farmland property rights in villages has been completed, the progress of issuing certificates is inconsistent among villages and some farmers have not yet even obtained farmland certificates. Firstly, due to the complex situation and unclear land boundaries in some areas, a resulting high error rate in land measurement has led to obvious differences in land area before and after titling. These discrepancies have slowed down the progress of certificate issuance. Secondly, due to historical legacy issues, the cadastral information of rural households has changed drastically since the second round of contracting. Conflicts concerning land among rural households, disputes between family members, and inter-generational conflicts are constant and often result in the temporary hold of certificate issuance. Thirdly, there is conflict in the objectives between farmers who go out to work and dedicate their time to apply for certification, the farmers who do not receive the certificates in time, and the certificates ending up being temporarily kept by the village collective.

In response to the inconsistent progress with the issuing of certificates to farmers within villages, this paper used the variable of "village level LCP" as a proxy variable for the LCP. The aim was to eliminate intra-village differences in rural household certificate holdings and to test whether the village level LCP has an impact on land "stickiness". Drawing on Sun et al. [62], this paper defined a village as a "certificated land village" if the certificate issuance rate of farmers was greater than or equal to 60%; otherwise, it defined a village as a "certificated land village". The nearest neighbor matching and kernel-based matching methods were also used to assess the policy effects of village level LCP on labor land "stickiness". The empirical results are shown in Table 8.

Table 8. The ATT of village level LCP on land "stickiness".

Matching Methods	Unmatched Matched	Mean		ATT	SE	T Value
		T	C			
Nearest neighbor matching	U	0.481	0.395	0.085 ***	0.008	10.88
	M	0.481	0.406	0.074 ***	0.011	7.03
Kernel-based matching	U	0.481	0.395	0.085 ***	0.008	10.88
	M	0.481	0.407	0.074 ***	0.008	8.90

Note: Treatment group (T) and control group (C). *** denote significance at 1% level.

The results show that village level LCP had a positive contribution to the "stickiness" of rural labor. These results are consistent with the empirical results at household levels. Specifically, the matched ATT of village level LCP was 0.074, and both were statistically significant at the 1% level, as the promotion effect of village level LCP on land "stickiness" was 7.4%.

5.4. Mechanism Analysis: How LCP Affect Land "Stickiness"

Through our theoretical analysis, the theoretical framework of "LCP–land production function–land 'stickiness'" was constructed. In this part, the mediating effect model was used to verify whether there was a mediating effect of land production function.

Drawing on the Equations (5) and (6) to test the mediating effect in turn, it was assumed that the LCP enhanced the land "stickiness" of rural labor by strengthening the land production function, and the LCP significantly enhanced the land production function. Conversely, the land production function had no mediating effect. In this paper, we used "agricultural business income" as the proxy variable of land production function, and the higher agriculture income, the more significant the land production function. In the inverse scenario, the productive function of the land was weakened.

In Table 9, model I shows that the LCP significantly enhanced land production function, and model II shows that the effect of the LCP and land production function on land "stickiness" was significant at 1% statistical level. The results show that the LCP had a significantly positive effect on the land "stickiness" of rural labor, and land production function played an important role in it. In other words, the LCP exerted a significant influence on land "stickiness" via its influence on land production function. The research hypothesis is verified.

Table 9. Results of the test for mediating effects of land production function.

Variables	Model I	Model II	Model III	Model IV	Model V	Model VI
	Land Production Function	**Land "Stickiness"**	**Land Production Function**	**Land "Stickiness"**	**Land Production Function**	**Land "Stickiness"**
LCP	0.629 ***	0.049 ***	—	—	—	—
	(0.120)	(0.009)	—	—	—	—
Village level LCP	—	—	0.957 ***	0.068 ***	—	—
	—	—	(0.120)	(0.009)	—	—
Village level LCP rate	—	—	—	—	1.684 ***	0.128 ***
	—	—	—	—	(0.196)	(0.014)
Land production function	—	0.010 ***	—	0.010 ***	—	0.009 ***
	—	(0.001)	—	(0.001)	—	(0.001)
Individual characteristics	Y	Y	Y	Y	Y	Y
Household characteristics	Y	Y	Y	Y	Y	Y
Village characteristics	Y	Y	Y	Y	Y	Y
Observation	3915	3915	3915	3915	3915	3915

Note: Standard errors are shown in parentheses. *** denote significance at 1% level.

In addition, the mediating effect of the land production function was examined using two proxy variables, "village level LCP" and "village level LCP rate" (Table 9, Model III–Model VI), and the results are consistent with the above. Although there were differences in the titling status of rural households within villages, and some households had not yet received farmland certificates, rural households in these areas still had higher expectations of the effect of the LCP in terms of stabilizing contractual relationships. Thus, the property rights exclusion and incentive effects of the LCP strengthened the land production function and increased the land "stickiness" of rural labor.

6. Discussion

In this section, we discuss the potential contributions, interesting results and limitations of this research.

The first discussion concerns the major contributions to the existing literature. This paper contributes to the current studies in four ways. (1) We constructed an analytical framework of land "stickiness". Our analysis showed that the insecurity of land property rights is the internal cause of the weakening of the land "stickiness" of rural labor. We went on to explain the necessity of implementing the LCP in China from the perspective of land production function. (2) Though previous studies have examined the effect of the LCP on off-farm employment or rural out-migration [26–28], there is a relatively small amount of literature concerning the policy effect of the LCP on agricultural labor participation. Since agricultural labor participation is the external manifestation of land "stickiness", our paper is the first attempt to estimate the policy effect of the LCP on the land "stickiness" of rural labor. (3) Against the background of rural social division, we studied the heterogeneity of the policy effects in different rural household types and different farm sizes. In other words, we verified whether the policy effect of the LCP has preferences in terms of household types and farm size. (4) Although there are some studies investigating the impact of the LCP on labor reallocation, the mechanism of its influence remains unclear. In order to fill in the literature gap, in this study, we explored the effect of the LCP on land "stickiness" of rural labor with theoretical analysis and empirical tests, as well as the mediating role of land production function. Additionally, in the robustness tests section, we conducted a Rosenbaum bounds sensitivity analysis to determine the influence of unobservable factors on the policy effect of the LCP. Given the inconsistency in the progress of the LCP, this paper used the village level LCP to examine the policy effect and mechanism of the LCP on the land "stickiness" of rural labor.

The following discussion concerns the interesting findings. Firstly, using the PSM method, this paper found that the LCP has a significantly positive effect on land "stickiness" of rural labor and that the LCP promotes the agricultural labor participation. A few studies have shown that the LCP can promote the off-employment and migration of rural labor. For instance, de Janvry et al. [63] found that under the Mexican Land Certificated Program from 1993 to 2006, "households obtaining certificates were subsequently 28% more likely to have a migrant member". However, this does not contradict the conclusions of this paper. Due to the heterogeneity of the endowment of rural labor, not all rural labor will undergo the transition from agricultural production to off-farm employment. (1) During the long-term agricultural production, some farmers have formed high asset specificity, such as agricultural machinery and technology. If they abandon agricultural production, they will face high "sunk costs", and the stronger the asset specificity, the higher the sunk costs [64]. For this reason, these farmers will continue to engage in agricultural production after the LCP. (2) Some rural labor faces the constraints of human capital, such as aging and low education, and as such, they cannot leave the agricultural field [32]. Furthermore, Li [33] found that the LCP mainly promotes the off-farm employment of rural idle labor groups.

Secondly, based on the heterogeneity analysis, we found that the policy promotion effect of the LCP on labor land "stickiness" is mainly reflected in the group of non-professional agricultural production households, medium-sized farms, and small-scale farms, while its promotional effect on professional agricultural production households and large-scale farms is not significant. The possible reasons for this are as follows. (1) Professional agricultural production households have more advanced agricultural production machinery and scientific management methods, and their demand for agricultural labor input is lower than that of non-professional households. (2) Large-scale farms overcome the limitation of farmland fragmentation and increase the input of agricultural machinery, which in turn increases the mechanization level of agricultural production and has a certain substitution effect on agricultural labor input [65]. These findings also contribute to the LCP in other developing countries with plenty of smallholders.

The final discussion is about the limitations of this study. (1) We used mixed cross-sectional data from 2016 and 2018. Due to data limitations, it was not possible to compose the panel data, and, therefore, this paper does not strictly reflect the dynamic changes of land "stickiness", especially against the background of the COVID-19 pandemic and the global grain crisis, during which the land "stickiness" of rural labor may have changed. In future research, we aim to use the latest panel data as the basis for detailed research to further explore the effect of the LCP on land "stickiness". (2) According to our analysis, the promotional effect of LCP on land "stickiness" is the result of the combined effect of property rights exclusion effect and incentive effect. However, due to the research data, this paper cannot respectively distinguish the extent of the property rights exclusion effect and the incentive effect on land "stickiness". In the future, we will continue to deepen the effect mechanism of LCP. Specifically, we will estimate the extent of the impact of the property rights exclusion effect and incentive effect, respectively. (3) Due to the data limitations, we could not locate the data on the land quality in the CLDS data. We therefore used village topography as a proxy for the land quality variable. Meanwhile, the initial land allocation under the Household Contract Responsibility System (HCRS) was primarily egalitarian, according to the proximity, fertility, irrigation, and other conditions of plots. As a result, there were no significant differences in land quality between households within villages. In addition, this paper used the PSM method. The basic idea of matching was to find in a large uncertificated farmland group whose samples are similar to the certificated farmland group in all relevant pre-treatment individual characteristics, household characteristics, and village characteristics. Thus, it could correctly evaluate the pure policy effect of the LCP on farmland "stickiness". Therefore, the issue of omitted variable can be ignored in the case of this study.

7. Conclusions and Policy Implications

7.1. Conclusions

In this paper, we started from the premise that the "stickiness" of farmland is weakening. We went on to show that there is an urgent to improve the efficiency of agricultural production by stabilizing the property rights of farmland, improving its production function, and enhancing land "stickiness". Firstly, based on the perspective of land production function, this paper analyzed the LCP impact on land "stickiness". Secondly, the PSM method was applied to estimate the policy effects of the LCP on the land "stickiness" of rural labor. Thirdly, heterogeneity analysis of rural household type and farm size, as well as the necessary robustness tests, were also conducted. Finally, the mediating effect model was applied to examine the mechanism of the LCP on land "stickiness" at the household and village levels.

The results of our study revealed the following: (1) The LCP had a positive promoting effect on the land "stickiness" of rural labor, which in turn increased the agricultural labor participation rate by 4.8~4.9%. (2) The heterogeneity analysis of rural household types showed that the policy promoting effect of the LCP on land "stickiness" had a great impact on non-professional households compared to professional households. In terms of farm size, the promotional effect of the LCP on medium-sized farms was the largest, followed by small-sized farms, while the promotion effect on large-sized farms was not significant. (3) The robustness results confirmed that: first, unobservable factors did not affect the estimation results of the effect of the LCP; second, the policy promotion effect was still significant after adopting the village level LCP variables, and the estimation results were robust. (4) The mediating effect on land production function was significant. The LCP enhanced the "stickiness" of rural labor through enhancing land production function. Meanwhile, the village level LCP variables also further verified the mechanism of land production function.

7.2. Policy Implications

Given the results of our analysis, the necessity of consolidating the results of the LCP, promoting the resolution of historical problems, and continuously strengthening the protection of farmers' contracted land management rights is even more clear. We must work to expand the application of the results of the LCP, improve the management of contracted land, provide institutional guarantees for the second round of land extension, and ensure the stability of farmers' original contracted land.

Secondly, our research verified that policy and financial supports are biased towards small and medium-sized farms. Studies have shown that the promotional effect of the LCP on non-professional households and small and medium-sized farmers is significant. Therefore, we should increase policy supports for them and accelerate the construction of a policy system to support the development of smallholders, as well as improve their agricultural production, management capacity, and production efficiency. We should encourage cooperation and interaction between smallholders and new agricultural operators, and realize the linkage between smallholders and modern agriculture in order to accelerate the modernization of agriculture and rural areas.

Thirdly, enhancing the land production function will have a major impact on efficiency. In order to achieve this, we must improve the construction of agricultural infrastructure, such as water conservation and maintenance of field roads. We must also implement the Land Consolidation Program to alleviate the fragmentation of farmland and decrease the gaps in plot quality. Finally, we must work to accelerate the construction of an agricultural information technology platform, integrate the information on agricultural production factors, and promote the efficient allocation of labor, land, and other factors to maximize the production function.

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The Theoretical Approach and Practice of Farmland Rights System Reform from Decentralization to Centralization Promoting Agricultural Modernization: Evidence from Yuyang District in Shaanxi, China

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Abstract: The Chinese government is attempting to readjust the relationship of farmland rights by farmland rights system reform to optimize the allocation of farmland by market means. Therefore, this study is aimed at exploring the effectiveness of the farmland rights system reform from decentralization to centralization and its impacts on agricultural modernization. In this study, the shift theory of land rights is introduced to analyze the approach of the reform promoting agricultural modernization, and the practice of Yuyang District as evidence illustrates that the reform is a further extension of the land marketization reform, which clears the obstacles of market allocation of farmlands and promotes agricultural modernization by achieving three objectives of agricultural production. The results of this study show the reform is beneficial to a high level of yield, efficient production, and environment friendly in agricultural production, so the reform indirectly promotes agricultural modernization. Meanwhile, Yuyang District's experiences show that the farmland issue is a complex one, which should be considered from the perspectives of public benefits and private benefits, and appropriate farmland rights system reform is a policy accelerator for facilitating agricultural modernization. Generally, this study not only innovatively links the farmland rights system reform with the three objectives of agricultural production to analysis impact mechanism of the reform on agricultural modernization, but it also confirms the effectiveness of the reform design of the central government and provides some advanced experiences for other regions.

Keywords: the farmland right system reform; creditor rights; real rights; agricultural modernization

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1. Introduction

To achieve the vision of fully building a modern country by 2050, the Chinese government is vigorously promoting agricultural modernization to make up for the shortcomings of modernization. The efficient use of farmland is the foundation of agricultural modernization, so the farmland rights system must always be geared towards achieving agricultural modernization [1]. However, historical experiences show that productive forces and production relations are not static. The productive forces can progress with the development of science and technology, thus generating the need to adjust production relations. Therefore, the farmland rights system reform has become a major way to adjust production relations. Through the adjustment of the rights relationship stipulated under the old farmland rights system, it builds a new farmland rights relationship that can meet the new needs of agricultural modernization and makes the production relationships compatible with advanced productive forces, which creates conditions for farmland capitalization and activates production factors in rural regions [2,3]. It underpins that farmland rights system reform is an important prerequisite for agricultural modernization, so it is very necessary to explore the approach of farmland rights system reform for the study of achieving agricultural modernization.

Many scholars have carried out research on this issue. The academic community generally considers the farmland rights system reform in China to be an initiative system reform led by the government. It has some positive characteristics, including effective planning by the government based on prospects in advance, the promotion of grassroots exploration in coordination during the event, and monitoring of multiple subjects after the event [4]. These characteristics reflect the efforts made in institutional design to achieve the established reform goals. In this reform system, the government played a key role: by amending the law and redistributing land rights, it created favorable conditions for the optimal allocation of farmland, thus making up for the lack of market capability [5]. Meanwhile, village committees, as the implementers of policies at the grassroots level, have natural advantages in terms of integrating rural resources and communicating between the government and the farmer in view of their inherent characteristics of being born in the rural society, embedded in the rural relationship network, and maintaining close contact with the government [6]. These advantages help village committees play important roles in farmland rights system reform [7]. In China, the latest farmland rights system reform is based on the idle or inefficiently used farmland in rural regions and attempts to optimize the allocation of farmland by building a clear farmland rights system and a perfect farmland circulation market because reformers and experts believe that these attempts will help the market to play a decisive role in the allocation of farmland, and it is beneficial for improving the efficiency of agricultural land use [8–10]. For this aim, the Chinese government proposed that the rights of farmland should be transformed from the separation of two rights systems to the separation of three rights systems, and the task has become one of the key tasks in the farmland rights system reform in China [11]. The purpose of this task is to revitalize the right to use farmlands while protecting the right of farmers to earn by separating the households' contracted management right of farmland, in other words, achieving appropriate scale management of farmland while increasing farmers' property income [12]. At present, farmland rights system reform has achieved some good results in China. The rights of farmland in the vast majority of rural regions in China have been redefined, and the clear property rights relationship has significantly reduced the transaction cost of farmland circulation, which promotes the circulation of numerous farmlands into new agricultural business entities, and the appropriate scale management of farmland gradually emerges, which initially achieved the expected policy goals of the reform [13].

However, in practice, most of these circulation activities are still spontaneous transactions by farmers in the land market, which often occur between farmers [14]. It optimizes the allocation of farmland to a certain degree, but there are still two obvious drawbacks. Firstly, farmland demanders must reach an agreement with each farmer of the farmland they need in order to achieve the appropriate scale management of farmland. This not only involves high transaction costs in the process of signing the agreement, but some farmers may also be unwilling to circulate their farmland, causing the fragmentation of farmland, which means these farmlands cannot meet the needs of land demanders, so it is difficult to attract high-quality business entities and improve agricultural production efficiency [15]. Secondly, there is widespread informal land circulation between relatives and friends in rural regions. There is a lack of formal contracts, agreements, and other circulation credentials, and the circulation price of farmland is often lower than the market price, which aggravates the rights risk of farmland circulation [16,17], and when the actual circulation price of farmland is lower than the market price, it is not conducive to farmers to improve their farmland productivity [18]. Reading the existing literature, most studies still focus on the positive impact of farmland rights system reform on the realization of the market-oriented allocation of farmland, but few scholars pay attention to some of the issues that restrict the agricultural development after the farmland rights system reform.

Therefore, this study is aimed to explore the effectiveness of the farmland rights system reform from decentralization to centralization and its impacts on agricultural modernization. Above all, this study will sort out the practice of farmland rights system reform in Yuyang District. Then, it will explore how to use theory to objectively and rationally prove that the practice is effective. Finally, it will discuss how to evaluate the reform performance in Yuyang District based on a method of quantitative analysis. In short, it tries to find a way to optimize the system based on the property rights theory for avoiding some potential challenges in the process of farmland rights system reform and introduces Yuyang's practice to verify the feasibility of this method.

2. Theoretical Approach, Methodology and Data Sources

2.1. The Theoretical Approach Based on the Shift Theory of Land Rights

The shift theory of land rights is a development of the property rights theory in Western economics, which is mainly used to study land, a special property with both public and private benefits [19]. In China, the ownership of land has long been owned by the country and rural collectives, but the right to use land can be circulated in accordance with the law, and the right to benefit and dispose of land is also circulated to some degree among different owners with the circulation of the right to use. There is no doubt that land is also of great private benefit in China [20]. Most countries and regions implement private ownership of land, but they also provide some degrees of legal protection for the government's violation of private land rights due to public benefits from the institutional level [21,22]. Obviously, whether in Eastern countries or Western countries, the rights relationship of land is very complicated. However, the main property rights theory is aimed at the study of private property, so it is difficult to fully explain the real-world land issues because, sometimes, keeping land rights moderately ambiguous to some degree, or strengthening term duration limits, are necessary and beneficial [23]. Therefore, a theory of property rights specially used to explain land issues is very necessary, which is why the shift theory of land rights is proposed, and it has three opinions [19].

Firstly, in essence, the real rights and the creditor rights of land are only the difference in the control rights of the right holder, and the control rights are in a process of continuous change. As shown in Figure 1, when the right to control changes from large to small, the real rights shift to the creditor rights until the right holder exercises full creditor rights. On the contrary, the creditor rights shift to the real rights until the right holder exercises full real rights.

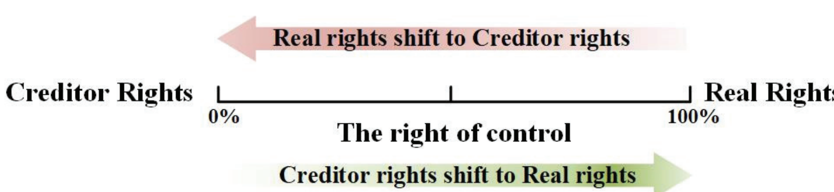

Figure 1. The right of control of the right holder.

Secondly, there are at least two owners who own the real rights of land, a public owner and a private owner, and they share 100% of the real rights of the land (Figure 2). When the real rights of land of the private owner become larger, the real rights of land of the public owner will become smaller, and the private benefits of land will become larger, which is called privatization. The opposite of this is called publicization.

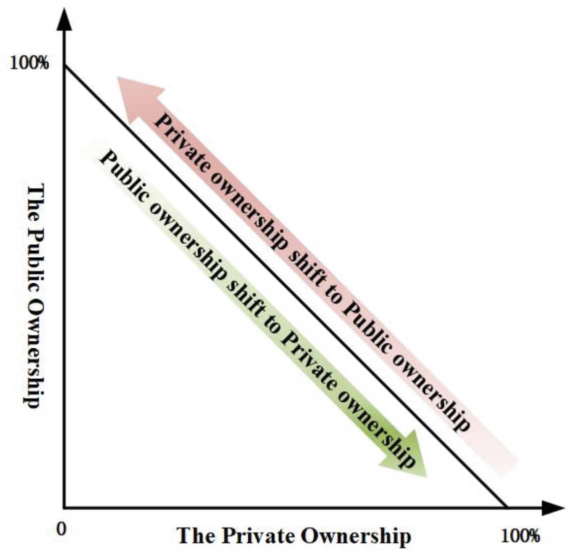

Figure 2. The real right of land between the public owner and the private owner.

Thirdly, for the land, the control right of land is shifted between the public owner and the private owner and the real rights and the creditor rights, which have formed a mechanism to realize the rational distribution of land rights and promote the reconciliation of public and private benefits.

According to the shift theory of land rights, a theoretical approach of analysis farmland issue is established (Figure 3). In the separation of two rights system of farmland, the Chinese government stabilizes the rights relationship of farmland and endow farmers with the right to circulate farmland by a series of policies [24–26]. In this period, the control rights of the land of farmers further shifted from creditor rights to real rights. The real rights of farmland involve farmers that have gradually exceeded the creditor rights, and the farmland also changed from a property biased towards public benefits to a property that is more inclined towards yielding private benefits. However, rural collectives have gradually lost the right to adjust farmland due to the protection of farmers' rights by laws and policies [27]. With the improvement of productivity, rural collectives still have the ownership of farmland in name, but in reality, they cannot adjust the contracted land of farmers for the demand of advanced productivity due to the failure of the shift in farmland rights from decentralization to centralization, so the fragmentation of farmland caused by rights has become increasingly serious.

In order to alleviate the fragmentation of farmland, the Chinese government further promotes the market-oriented reform of farmland and implements the separation of three rights systems to encourage appropriate scale management of farmland [2,12,28,29]. In the new reform, the government not only redefines and clears the ambiguous rights relationship of farmland due to mismanagement, informal circulation, illegal reclamation, etc., but encourages rural collectives to try to achieve appropriate scale management of farmland by the farmland shareholding cooperation. The policy adjustments provide some new ideas for rural collectives to adjust farmland, and more opportunities are given for the shift in farmland rights from decentralization to centralization. Rural collectives can activate owner rights of farmland by the farmland shareholding cooperation so that rural collectives have the right to readjust farmland by market means. It means the control right of farmland of farmers is shifting from real rights to creditor rights, and the real right of farmland is shifting from private ownership to public ownership. Therefore, the fragmentation of farmland is gradually alleviated by the adjustment of rural collectives. It notes that farmers still have considerable real rights because the decisions of the farmland shareholding cooperation are made by farmers, rather than the government, and farmers are free to enter or exit the shareholding cooperation organization. The private benefits of farmland are still dominant, but the proportion of public benefits of farmland is higher than the former.

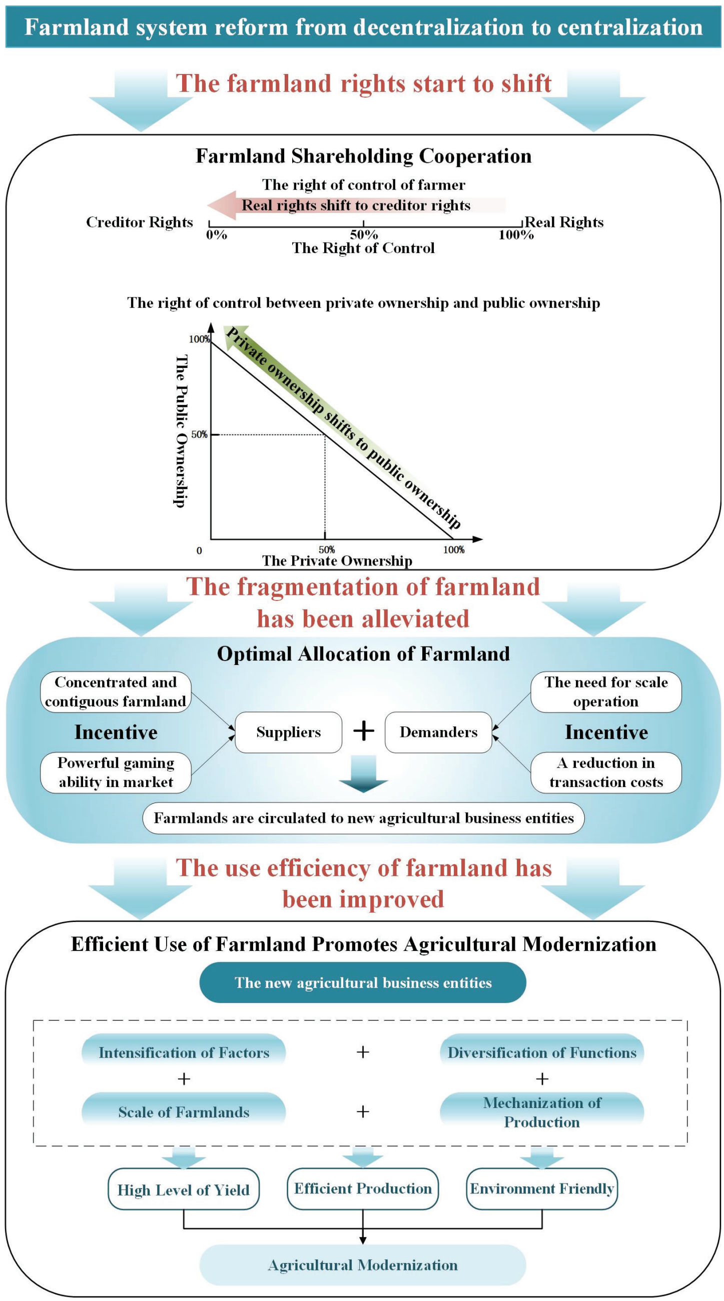

Figure 3. The theoretical approach of reform promoting agricultural modernization.

When the rural collectives manage most of the farmlands of their villages, the rural collective is the land supplier because of the increase in the quantity and quality of the supplied farmland, which is attractive to abundant high-quality farmland demanders, and a powerful gaming capability in the farmland market is given to them, which helps rural collectives to gain more benefits in the game [30]. Farmland demanders are very willing to trade with these high-quality farmland suppliers. They not only meet their business needs, but also reduce the transaction cost of circulation farmland, so these high-quality farmland suppliers are often regarded by them as the best choice. There is no doubt that the market-oriented farmland circulation that rural collectives participate in overcomes the issues of high transaction costs and fragmentation of farmland in the market-oriented land circulation that farmers directly participate in [15], and it improves the bargaining power of farmers and rural collectives, which enables farmers more capabilities to obtain benefits and resist risks, thereby reducing informal land circulation and avoiding rights risks and inefficient use of farmland [31]. It can be seen that the reform has contributed to the realization of land circulation activities with more quantity, on a larger scale, and more concentrated and contiguous land, while the large-scale, concentrated, and contiguous land is necessary for agricultural modernization, and it has also prompted the transformation of agricultural practitioner from traditional farmers to new agricultural business entities.

Intensification of factors, scale of farmlands, diversification of functions, and mechanization of production are typical characteristics of modern agriculture [32–34]. Compared with traditional farmers, new agricultural business entities are closer to the characteristics of agricultural modernization [35]. In the aspect of intensification of factors, these new agricultural business entities concentrate on less production factor inputs and overcome the law of diminishing return by advanced production technology, equipment, and management methods, in order to obtain higher yields and earnings of per unit of farmland [36]. In the aspect of scale of farmlands, new agricultural business entities can provide generous remuneration to numerous farmland suppliers, so it is easier for them to achieve the advantages of scale compared to traditional farmers [37,38]. In the aspect of diversification of functions, new agricultural business entities can not only exert the economic and social functions of agriculture by providing numerous agricultural products, but they can also fully explore the ecological functions of agriculture by optimizing planting structure, developing advanced technologies, and improving production methods [39]. In the aspect of mechanization of production, new agricultural business entities are more willing to improve the work efficiency of all production links by introducing advanced machinery and equipment, compared with traditional farmers, and some of them pay attention to research and the development of advanced technologies [40–43]. Therefore, new agricultural business entities play key roles in the process of agricultural modernization. They improve the use efficiency of farmland by pursuing intensification of factors, scale of farmlands, diversification of functions, and mechanization of production, which service development objects of high level of yield, efficient production and environment friendliness, and promote the process of agricultural modernization.

2.2. Indicators Selection of Evaluating Reform Performance

According to Chinese official documents, high levels of yield, efficient production, and environmental friendliness are regarded as the three main objectives in agricultural production. In order to ensure national food security, it is necessary to ensure the supply of important agricultural products and to deal with the uncertainty of the external environment with the certainty of stable domestic production, so a high level of production is one of missions of agricultural modernization [44–46]. Meanwhile, in order to adapt to the development of productivity and changes in production relations, more capital, technology, and talents are required to be invested in agriculture, so efficient production is another mission of agricultural modernization [47–49]. Furthermore, in order to reduce the negative impact of chemical fertilizers and pesticides on farmland, and to achieve sustainable use of farmland and improve the quality of agricultural products, it is necessary for agricultural production to change towards environment friendliness. [50,51]. Therefore, high levels of yield, efficient production, and environmental friendliness are appropriate to evaluate the degree of agricultural modernization.

Focusing on Yuyang District, the farmland rights system reform from decentralization to centralization adjusts the farmland area and the number of plots of farmers, so the relationship among average area per household, average number of plots per household, and average yield of unit farmland can be used to evaluate whether high yields have been achieved after the reform. The unit farmland area remains unchanged, and mechanization rate, labor productivity, and higher capital input-output ratio of unit farmland are higher, which means that the use efficiency of unit farmland has improved [32,52], so changes in these indicators can be used to evaluate whether the reform has promoted the efficiency of agricultural production. In addition to ensuring the production of food and raw materials, farmland also plays an important role in ecological chain support and gas regulation services, so ecosystem service value (ESV) and agricultural carbon emissions can be used to evaluate the environmental friendliness of agricultural production [53]. By measuring the change of ESV, total carbon emission, and carbon emission intensity before and after the reform, the result can be evaluated whether the reform has promoted the environmental friendliness of agriculture production. Table 1 shows the indicators system constructed to evaluate the impact degree of reform promoting agricultural modernization. Various indicators have an indirect impact on agricultural modernization by affecting the objectives of high levels of yield, efficient production, and environmental friendliness.

Table 1. Indicator system for evaluating impacts of the reform on agricultural modernization.

Base Layer	Indicators	Index Calculation
High level of yield	Average area per household (mu[1])	Original data
	Average number of plots per household (piece)	Original data
	Average yield of unit farmland (kg)	Original data
Efficient production	Mechanization rate (%)	Original data
	Labor productivity (%)	Gross output value of agriculture/Number of people employed in agriculture
	Input-output ratio of unit farmland (%)	The economic revenue of unit farmland/The economic cost of unit farmland
Environment friendly	Ecological service value	Crop area × Crop price × Regional correction factor × Value equivalent factors of various ecosystem services, followed by its consequent sum
	Total carbon emissions (t)	The amount of a single carbon emission source × The corresponding carbon emission coefficient, followed by its consequent sum
	Carbon intensity (t/hm^2)	Total carbon emissions/Farmland area

2.3. The Methodology and Data Sources

Case analysis is a commonly used method to summarize theoretical results from practice, so this study will adopt this method to sort out the practice of farmland rights system reform from decentralization to centralization in Yuyang District. Above all, this study will introduce the general situation of Yuyang District. By sorting out the local history of changes in the farmland rights system since 1980, it clarifies the problems that existed in the local farmland before the latest reform was implemented and analyzes the causes of the problems. Besides, this study will explore the practice of farmland rights system reform in Yuyang. It aims to summarize the process of reform, to analyze the direction of shift in farmland rights, and to search out the causes of these changes. Finally, this study will survey the impact path of the reform on agricultural modernization and evaluate the reform performance by comparing key indicators before and after the reform.

Questionnaire surveys, in-depth interviews, and document analysis are used to collect data required for this study. The study group went to Yuyang District four times in September 2020, July 2021, February 2022, and August 2022 to conduct field research. Questionnaire surveys were conducted in Yuyang in the first and fourth research fields, and these surveys helped the study group to collect numerous relevant data. In the second and third research fields, the study group lived in Yuyang District for more than three months. Through in-depth interviews with government cadres, village cadres, and farmers, the practice of reform and impacts on agricultural modernization were fully understood by the study group. Meanwhile, some relevant documents have been obtained with the help of local government. Table 2 shows the data obtained by the field research of study group, which provide strong support for this study.

Table 2. The data obtained by the field research of this study group.

Time	Questionnaire (Rural Collectives)	Questionnaire (Farmers)	Interview Records	Work Documents
September 2020	31	347	0	0
July 2021	3	15	3	10
February 2022	11	47	19	28
August 2022	29	489	0	0

3. The Practice of The Farmland Rights System Reform in Yuyang District

3.1. The General Situation of Yuyang District

Yuyang District is the center of Yulin City, the second largest city in Shaanxi Province. It is located in the arid and semi-arid regions of China and the interlaced zone of agriculture and animal husbandry. With the Great Wall as the boundary, the land in the north is relatively flat, and the land in the south is mainly mountainous. The GDP of Yuyang District reached 135.5 billion yuan[2] in 2021. In the 1980s, with the implementation of the household contract responsibility system for farmland, it successfully stimulated farmers' enthusiasm for production and effectively solved the issue of food. However, the "fat and thin matching" method of farmland division, based on the principle of fairness, led to the fragmentation of farmland. Each peasant family in Yuyang District has an average of 15 mu and 16 pieces of farmland, and each peasant family in the southern part has an average of 12 mu and 18 pieces of farmland. With the process of urbanization, 80% of the local rural laborers have left the countryside and choose to work in cities. There is a limited labor capacity of the elderly left behind, so they usually only cultivate some farmland close to home, with a large area and good soil conditions for the purpose of subsistence. The fragmentation of farmland has delayed the process of refined division of labor and specialization in agricultural production. Meanwhile, some issues, such as low input per mu of farmland, low farmland utilization efficiency, and abandoned farmland, have begun to appear. These issues have seriously hindered the development of agricultural modernization.

However, rural collectives in Yuyang District have difficulties adjusting these inefficient farmlands, so the failure of farmland rights from decentralization to centralization has occurred. Many reasons cause this result. Firstly, the central government's policy of 'increasing people without increasing farmland, and decreasing people without reducing farmland' made rural collectives in Yuyang District lose the right to adjust farmland after the second round of farmland contracting. In practice, some rural collectives in Yuyang District have tried to adjust the distribution of farmland for the purpose of giving landless people farmland for their livelihood, but this ultimately failed. Their attempts were strongly opposed by members of their collectives and led to collective petitions by farmers. Finally, the local government resolved the conflict by coordination, but some people responsible for making these attempts were punished accordingly. There is no doubt that these incidents provided lessons for other rural collectives in Yuyang District, strengthened the notion that farmland cannot be adjusted, and blocked the attempt to shift farmland rights from decentralization to centralization. The other reason is that rural collectives did not have enough standardized asset management before, coupled with the informal circulation and irregular reclamation among farmers, there were common issues of unclear boundaries and ownership of farmland, which undoubtedly increased the transaction costs of farmland circulation in the formal market. The increase in the transaction cost of farmland circulation means that it is more difficult to realize the shift in farmland rights from decentralization to centralization by market means.

Under the combined effect of administrative and market challenges, the failure of farmland rights from decentralization to centralization has occurred, resulting in a structural imbalance between the supply and demand of farmland. According to official statistics, 31,900 of the 118,000 peasant households in Yuyang District have no farmland, but on average, 7% of the farmland in each township is in a state of abandonment. The lack of farmland supply and the phenomenon of farmland abandonment coexist. Moreover, when rural collectives face the needs of social capital to invest in the development of scale planting industries locally, there is often no land available, which eventually leads to the abortion of social investment and damages the overall welfare of the collective.

3.2. The Farmland Rights System Reform from Decentralization to Centralization in Yuyang District

In order to solve the issue of farmland, the Yuyang District Government actively responded to the call of the central government for the reform of land marketization. In 2017, the Yuyang District Government promoted the farmland rights system reform with the 'one household one plot' system as the core and further promoted the farmland shareholding cooperation in some qualified rural collectives, on this basis, to realize the shift of farmland rights from decentralization to centralization (Figure 4). The 'one household one plot' system reform is a method of realizing each peasant family farming one piece of farmland by the adjustment of farmland rights, construction of farmland facilities, and improvement of soil quality based on the overall planning of rural collectives. The reform enables farmers to agree to the rural collectives to adjust farmland by administrative means because some promises (original area of farmland, original contracted relationship, and original managing model) and expectations (concentrated and contiguous farmlands, better farming conditions, and better-quality soil) are given to farmers, which improves the public benefits of rural collectives. From the results, the real rights are still greater than the creditor right in the control rights of farmland of farmers, but the rights start to shift from real rights to creditor rights, which means rural collectives have realized the adjustment of farmland based on certain conditions, and the adjustment of farmland is not an untouchable red line for rural collectives.

Based on the 'one household one plot' system reform, some rural collectives in Yuyang District tried to realize farmland shareholding cooperation by suppositional authentic right (farmers are only identified with the area of all their farmland, but not specific plots); they hoped to promote the shift of farmland rights from decentralization to centralization by market means. In these rural collectives, most members of rural collectives are less willing to manage farmland, and they have non-agricultural jobs and desire property income, so these rural collectives are suitable for farmland shareholding cooperation. These rural collectives promised the original area of farmland, original contracted relationship, and freedom to enter or exit, and these gave farmers the expectation of property income, more free time, and better jobs if the farmland shareholding cooperation could be agreed upon by members of rural collectives. These conditions set by these rural collectives are consistent with the needs of these members of rural collectives, so almost all members of rural collectives unify the proposal and join the newly established rural collective shareholding economic cooperative, according to the procedure, and formulate the cooperative charter. The cooperative charter stipulates that farmers will voluntarily use the area of farmland they hold as their original share in the cooperative. Meanwhile, it also stipulates that the farmland is planned and developed by the cooperative, and the collective members do not participate in specific business matters but have the right to supervise and make suggestions. In addition, if the collective members are dissatisfied with the cooperative's operation, they have the right to apply to the cooperative to withdraw their shares in the form of negotiation, and the cooperative will redistribute to them specific plots that meet their contracted area. It is not difficult to find that the shift in farmland rights from decentralization to centralization has been further realized after rural collectives complete the farmland shareholding cooperation by market means. Compared with the 'one household one plot' system reform, the degree of shift is more significant. According to the fact that farmers do not participate in the specific management of farmland, it can be seen that the control rights of the farmland of farmers have changed from being dominated by real rights to being dominated by creditor rights, but it is not an extreme set of creditor rights because farmers have the right to exit by negotiation.

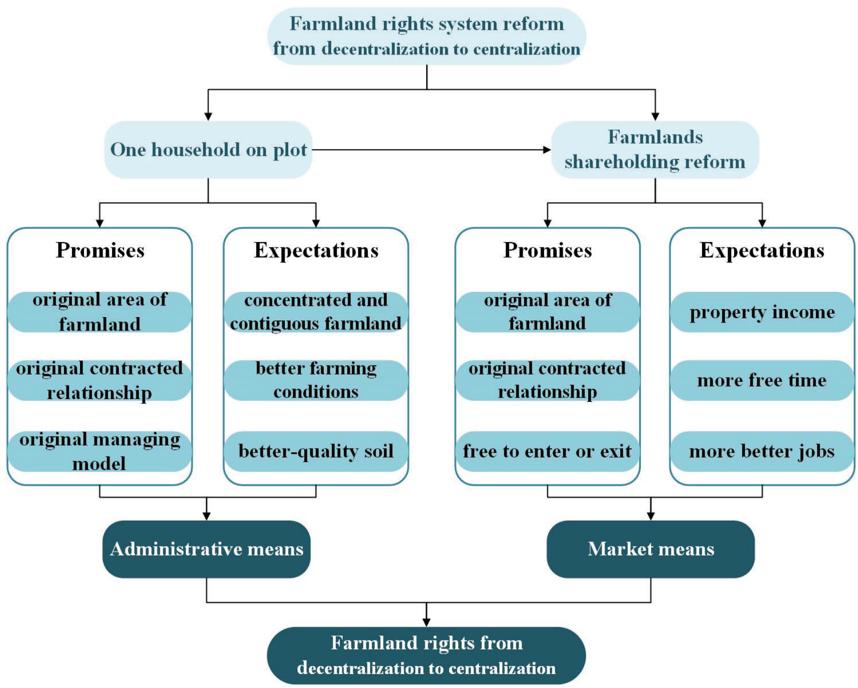

Figure 4. The farmland rights system reform in Yuyang District.

3.3. The Development of Agricultural Modernization in Yuyang District after Farmland Rights System Reform

When Yuyang District completed the farmland rights system reform from decentralization to centralization, these collectives circulated concentrated and contiguous farmlands to new agricultural business entities by the cooperative self-operation, introduction of social capital, and cooperation with social capital, which accelerates the development of appropriate scale management of farmland. According to data from seven rural collectives, compared with the past, the number of new agricultural business entities in the village has increased by 2.5 on average, and the farmland management area of them has increased by 50.9 mu.

When the appropriate scale management of farmland is achieved, these new agricultural business entities have a greater willingness to invest more production factors into the farmland. According to interviews with eight new agricultural business entities, all of them mention that the expansion of management scale decrease production cost of unit farmland, which makes it cost-effective to introduce new technologies and invest more production factors. They improve the farming efficiency and product quality by mechanized production, soil testing formulas, comprehensive water and fertilizer facilities, farmland management information systems, and innovation on technology and management of agriculture. This means the achievement of the intensification of elements on unit farmland. Meanwhile, these new agricultural business entities achieve the mechanization of all production links by purchasing agricultural machinery and provide mechanized production for local farmers by paid services, which promotes the improvement of the overall local agricultural production efficiency. Government officials in Yuyang District stated that all new agricultural business entities have realized mechanized operations, and they provide 80% of the agricultural mechanized services. Furthermore, the production behavior of the local new agricultural business entities also changes towards the direction of environmental friendliness with the expansion of the scale of farmland management. They believe that these changes can not only improve the quality of agricultural products to earn more profits, but also practice social responsibility by reducing the negative impact on the environment. Three new agricultural business entities said they stop farming a part of farmlands each year to restore fertility because other farmlands are enough to meet their needs of earning. Six new agricultural business entities said they purchase more high-quality fertilizers, which have less threats on farmlands, because their demands increase due to expansion of farmland area, and they can purchase these fertilizers for lower prices. According to interviews with government officials and village cadres, their words are also confirmed, and these situations are common in new agricultural business entities in Yuyang District.

Generally, the practice of Yuyang District proves that new agricultural business entities achieve high levels of yield, efficient production, and environment friendly agricultural development objectives by large-scale farmland management, intensive use of production factors, environmentally friendly production behavior, and agricultural mechanized production, thereby promoting the process of agricultural modernization. An important prerequisite for these changes is that rural collectives have obtained more real rights of farmland by the farmland rights system reform from decentralization to centralization, and the appropriate scale management of farmland has been achieved by their adjustments.

4. The Farmland Rights System Reform Performance of Yuyang District

According to field research, corn, potatoes, and pasture are the main crops planted by agricultural business entities (traditional farmers and new agricultural business entities) in Yuyang District. Among them, corn is the crop with the largest planting area, and it is widely planted by traditional farmers and new agricultural business entities. Therefore, this study will evaluate the promotion effect of Yuyang District's reform on agricultural modernization through the changes in the conditions of corn planting. Here, the data in 2016 are used as the data before the reform, and the data in 2021 are used after the reform, and the two are compared to explore the reform results.

4.1. High Level of Yield

Table 3 shows the changes of yield indicators before and after the reform. Obviously, the reform has significantly improved the farmland management conditions of all agricultural business entities. The average area of farmland per agricultural business entity has increased from 26.4 to 48.87 mu, and the average number of plots per agricultural business entity has decreased from 16 to 2.4. It should be noted that some agricultural business entities constantly circulate farmland from others, so the reform has realized the contracted farmland of each household, but some agricultural business entities still have more than one piece of farmland. In the new farmland management conditions, the average yield of unit farmland of corn also increased by 135.1 kg. Combined with the information obtained from different agricultural business entities, traditional farmers believe that the adjustment and consolidation of farmland facilitate agricultural production, so their actual cultivated area has increased after the reform. New agricultural business entities consider that the reform not only facilitates agricultural production by expanding the scale of farmland, but also that the increase in demand for agricultural materials supports them purchasing fertilizers and pesticides for lower prices, so they tend to purchase high-quality materials, and the change is conducive to increased production. The result proves that the reform has played a positive role in increasing the yield of unit farmland, which achieves the objective of high level of yield in agricultural production.

Table 3. Comparison of yield indicators before and after the farmland rights system reform.

		Before	After	Changes
High level of yield	Average area of farmland per agricultural business entity (mu)	26.4	48.87	+22.47
	Average number of plots per agricultural business entity (piece)	16	2.4	−13.6
	Average yield of unit farmland (kg)	729.8	864.9	+135.1

4.2. Efficient Production

Table 4 compares the changes of efficient production indicators for evaluating the impact of the reform on efficient production. It is not difficult to find that the agricultural mechanization rate has been significantly improved after the reform, from 63% in 2016 to 79.6% in 2022, which proves that the reform has lowered the cost of agricultural mechanization production by the adjustment. Labor productivity has grown dramatically, by nearly 50%. The popularization of agricultural mechanization, the improvement of agricultural socialization services, and the upgrading of agricultural technology and management technology have improved, so agricultural production does not require excessive labors and time. Meanwhile, the increase in the number of new agricultural business entities means that the number of high-quality labors in agriculture has increased. Moreover, the growth in output of unit farmland also increases the input-output ratio of unit farmland by 11.3% compared with before the reform. In traditional farmers' views, their production costs are higher than before, but the rise of their incomes is remarkably faster than costs. Therefore, the result is that the reform accelerates the objective of efficient production of agricultural production by improving the mechanization rate, labor productivity, and input-output ratio of unit farmland can be drawn.

Table 4. Comparison of efficiency indicators before and after the farmland rights system reform.

		Before	After	Changes
Efficient production	Mechanization rate (%)	63	79.6	+16.6
	Labor productivity (%)	65.7	114.5	+48.8
	Input-output ratio of unit farmland (%)	149.2	160.5	+11.3

4.3. Environmental Friendliness

Table 5 shows the changes of environmental friendliness indicators in order to evaluate the impact of reform on environmental friendliness of agricultural production. According to ESV calculations, the ESV of Yuyang District in 2022 increased by 43.1 compared to 2016, which is beneficial regarding the increase in the actual cultivated area. It means an increase wherein humans gain more from the ecosystem. In terms of carbon emissions, the total carbon emissions and carbon intensity of agricultural production have decreased slightly after the reform because of the increase in the amount of organic fertilizer used by new agricultural business entities. Generally, the reform has increased the benefits of agricultural production from ecology and promotes agricultural production gradually changing towards environmentally friendly.

Table 5. Comparison of environmental friendliness indicators before and after the farmland rights system reform.

		Before	After	Changes
Environmental friendliness	Ecological service value	101.7	144.8	+43.1
	Total carbon emissions (t)	46,926	45,400	−1562
	Carbon intensity (t/hm^2)	0.29	0.28	−0.01

5. Discussion and Implications

5.1. Discussion

As this study shows, the farmland rights system reform from decentralization to centralization effectively solves obstacles of farmland circulation, which facilitates concentrated and contiguous farmlands, which are circulated to new agricultural business entities from rural collectives [2,12,15,28–31]. These new agricultural business entities pursue the objectives of high levels of yield, efficient production, and environmental friendliness in agricultural production by scale of farmlands, intensification of factors, diversification of functions, and mechanization of production, and then indirectly promote the process of agricultural modernization [35–43]. In essence, this reform is a further extension of the land marketization reform, which is to realize the shift of farmland rights from decentralization to centralization by market means rather than administrative means. The control rights of farmland of farmers still retain considerable real rights, and they have shifted with the change in demand of farmers. They not only avoid the negative impact of land circulation by administrative means on farmers' enthusiasm for production, but also increase income growth channels for farmers, which is an effective mean to promote economic growth with market rules. The rights relationship of farmland was adjusted by administrative means in the early stage of reform, but its fundamental purpose is to clear the obstacles in order to complete the shift in farmland rights from decentralization to centralization by market means. Obviously, in farmland issues, the intervention of administrative means can effectively make up for the deficiency of market means because it can avoid market failure by modifying the rights relationship of farmland.

Yuyang's experiences show that the farmland issue is a complex one that cannot be solved by a theory based on a single type of property rights. The theory of property rights based on private ownership is still the main property rights theory, but it is still difficult to explain the issue of farmland without considering the public benefits. Therefore, it is necessary to explore agricultural land issues from the perspectives of public welfare and private benefits. Moreover, when considering the issue of farmland, administrative means are effective supplements to market means because it is difficult to achieve optimal allocation of farmland simply by relying on the market. The intervention of administrative means does not mean that it does not conform to the market rules, although it plays a key role in the process of the shift in farmland rights from decentralization to centralization. In Yuyang's practice, administrative means are used to remove obstacles that hinder the optimal allocation of farmland by market means, and the decision-making power of farmland allocation is still in the hands of the market. The reform has empowered rural collectives to participate in market activities, which is a way to facilitate the public benefits. Undoubtedly, the completion of the reform is a policy accelerator for the optimal allocation of farmland in the new development stage, which goes with the flow of change in social demand and promotes agricultural modernization.

5.2. Implications

As mentioned of this study, the reform is not an end, but a method to achieve the ultimate mission. Unlike previous studies, this study focuses on the contribution of reform to agricultural modernization and explores the impact mechanism of reforms on agricultural modernization. It innovatively links the farmland rights system reform with the three objectives of agricultural production, studies the impact mechanism of reform accelerating objectives of agricultural production, and evaluates the effect degree of reform promoting agricultural modernization based on the results. Meanwhile, this study constructs an indicators system to quantitatively analyze the impact of the reform on agricultural modernization, which overcomes the shortcomings of previous studies that excessively relied on the literature and documents to evaluate reform performance. Furthermore, this study sorts out the process of farmland rights system reform from decentralization to centralization in Yuyang District and summarizes the experiences of practice. It does note that the reform is an infant attempt in China, and rural collectives that have completed the shift in farmland rights from decentralization to centralization by market means are still in the minority, so the result of this study confirms the effectiveness of the reform design of the central government and provides some advanced experiences for other regions.

There are some limitations that are deserving of further study. Firstly, agricultural modernization has diverse demands on land use, including production, life, ecology, etc. [54], but this study only explores impact mechanism of farmland reform on agricultural modernization from the perspective of agricultural production, so the choice of study perspective is lack of diversity. Therefore, future studies should attempt to explore the impact mechanism of the reform on agricultural modernization in a comprehensive perspective, including all objectives of agricultural modernization. Secondly, the indicators system for evaluating reform performance constructed in this study is not perfect because of the single perspective of the study. It can only indirectly evaluate the effect of the reform on agricultural modernization by analyzing the impact of reform on agricultural production. Further studies should conduct a comprehensive indicators system based on diverse perspectives for evaluating reform performance. Finally, it is premature to evaluate the result of the reform on the example of one district, so further studies should consider how to explore this issue in a wider space.

6. Conclusions

In this study, it analyzes the process of promoting the optimal allocation of farmland from the farmland rights system reform from decentralization to centralization based on the shift theory of land rights and analyzes the methods of the new agricultural business entities to promote the agricultural modernization, then deduces the theoretical approach of farmland rights system reform from decentralization to centralization promoting agricultural modernization based on these analyses. Meanwhile, a multi-dimensional indicator system is established to evaluate reform performance. According to a theoretical approach and an indicator system, the reform practice of Yuyang District has been sorted out and evaluated, which proves that the practice is scientific and feasible. The study has shown that the farmland rights system reform from decentralization to centralization has alleviated the fragmentation of farmland and coordinated the new agricultural business entities to develop appropriate scale management of farmland, and it has assisted the pursuit of high level of yield, efficient production, and environment friendly objectives of agricultural production that promote the realization of agricultural modernization. Therefore, the farmland rights system reform from decentralization to centralization is an important prerequisite for agricultural modernization, which indirectly promotes the realization of agricultural modernization.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to management rules of research group.

Conflicts of Interest: The authors declare no conflict of interest.

Notes

1 Mu is a unit of area, which is equal to 0.0667 hectares.

2 Yuan refers to the currency unit of RMB.

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Article

The Scale and Revenue of the Land-Use Balance Quota in Zhejiang Province: Based on the Inverted U-Shaped Curve

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Abstract: The project-based construction land-use policy of 'increasing versus decreasing balance' (IVDB) is pivotal to easing the contradiction between urban and rural land in China. Understanding the relationship between the scale and revenue of the balanced quota is crucial for increasing the efficiency of quota-allocated, and further improving, IVDB performance. However, existing studies have rarely revealed the impact of the balanced quota's scale on its revenue, supported through empirical evidence. In this study, we analyzed the relationship between the scale and revenue of the balanced quota and used the quadratic econometric model to explore the inverted U-shaped impact of the scale of the balanced quota on the revenue of the 1907 IVDB projects in Zhejiang province. The results show that: (1) the relationship between the quota's scale and the revenue shows an inverted 'U' type in Zhejiang. On the premise of considering three control variable groups, the optimally balanced quota of Zhejiang province is 7.19 ha. (2) There is spatial heterogeneity in the optimal scale of the balanced quota in Zhejiang and the appreciated scale of the quota in northeast and southwest Zhejiang is 9.50 ha and 6.03 ha, respectively. Then we discussed problems associated with the scale and revenue of the project-based balanced quota under the implementation of the IVDB policy. The study enriches the performance analysis of IVDB policy from the point of view of economic perspective and tries to provide a scientific basis for the appropriate size quota for local government. Finally, comprehensive consideration of inputs to allocate the balanced quota, optimizing the rural resettlements spatial planning, and strengthening central-government supervision is put forward.

Keywords: increasing versus decreasing balance (IVDB); balanced quota; revenue; inverted U-shaped curve; Zhejiang province

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1. Introduction

Farmland and homesteads are associated with human settlement in rural areas, which provide space for production and for living [1]. However, with increasing industrialization, urbanization and population concentration towards the ever-growing cities, these two types of land use have been facing dilemmas [2–6].On the one hand, noteworthy farmland has been abandoned in many developed countries and some developing countries since the 1950s [7]. On the other hand, as massive numbers of rural migrant workers have flooded into urban areas to earn a living, many rural settlements remain unoccupied seasonally or permanently [8–11]. Traditionally, many countries around the world have long employed rural land consolidation and land reclamation to solve the above problems and revitalize rural development [12–15]. In particular, under its strict cultivated land protection and spatial planning system, China has implemented the increasing versus decreasing balance (IVDB) urban-rural construction land-use policy, which is similar to that of transferable development rights (TDR) in the United States [16].

Generally, the IVDB policy aims to balance the increases in urban construction land with a reduction in rural construction land [17] and this rural construction land will be reclaimed as cultivated land to ensure the dynamic balance of total arable land [18,19]. Since its initiation in 2000, and subsequently formally proposed in official documents in 2004, the IVDB policy has been implemented throughout China. The former Ministry of Land and Resources (MLR) [1] issued the policy document for IVDB in 2005, Proposals for regulating the pilot of increasing versus decreasing balance of urban-rural built land. The policy stipulates clearly that a balanced quota, which is used to control the scale of rural demolition and urban construction, is assigned by the central government in the form of projects and strictly restricted to the scope of counties. Under the guidance of the IVDB policy, the first round of experiments for IVDB was launched in 2006 and 183 projects with 4923 ha of balanced quotas were allocated to Tianjin, Shandong, Hubei, Sichuan and Jiangsu provinces. By 2019, 31 provinces in mainland China have adopted the IVDB policy, with approval of 681,670 ha of balanced quota to implement the pilot projects [20]. In practice, multiple implementations have been created to achieve a spatial equilibrium between urban and rural construction land, including the transfer of the farmland development rights program and flat-for-flat compensation formula in Zhejiang province [21,22] and the land coupon programs in Chongqing [23,24].

Meanwhile, the IVDB policy has kept pace with China's land management tools. For the past few years, the central government incorporated the IVDB policy into the country's poverty alleviation support system [25]. Specifically, poverty-stricken areas and counties were given the right to determine the quantity of the balance quota for as long as they needed to, and the quota could be transferred at the provincial or even national level according to relevant regulations. The CNY 1896 billion cross-provincial quota-transfer funds were channeled to poverty-stricken areas from 2018 to 2020 [26]. During the five-year transition period (2020–2025) of effectively combining achievements in poverty alleviation with rural vitalization, the above provisions continue to be implemented according to the 'Measures for transferring inter-provincial quota linked to the increasing versus decreasing balance of urban-rural built land during the transition period' in 2021. In the context of factors' marketization, the latest evolution of the IVDB policy is that the power to assign the balanced quota is devolved from the central government to the provincial government, as stipulated in the Notice of the Ministry of Natural Resources on the management of the 2020 Land Use Plan. As we all know, the revenue of the balanced quota is the key economic motivation for implementation of the IVDB policy and homesteads are referred to as 'sleeping' land assets figuratively. Therefore, under the background of project-based IVDB policy, what is the relationship between the scale and revenue of the balanced quota? Particularly, as the local government's demand for urban construction land is always enormous, the balanced quota's scale has carried the potential risk of being much too much when the IVDB policy is oriented by the provincial government. It is interesting as to whether there is an optimal scale of the balanced quota to obtain the maximum benefits with the implementation of the project-based IVDB policy. Even furthermore, are there differences in the optimal scale of the balance quota in different regions? The answers to the above questions could improve the efficiency of quota-allocation and provide a scientific basis for local governments to measure the appropriately balanced quota of each IVDB project, which will eventually enhance the overall welfare of the IVDB policy implementation.

Some studies have been conducted to analyze the determinants of a balanced quota and associated recommendations are provided under specific contexts in China. Peng and Huang (2021) suggest that the balanced quota be incorporated into municipal or county spatial planning indicators for unified management and use [27]. Cai and Liu (2021) insist that the scale and transferring scope of the balanced quota should be determined and adjusted by the market [28]. Combined with a case study of IVDB policy implementation, Zheng (2020) recommends that collective organizations and farmers participate in determining the quantity of quotas to consolidate the achievements of poverty alleviation [29]. In a case study of Huantai county in Shandong province, Long, et al. (2012) argue that the IVDB policy implementation with a top-down decision-making mechanism should incorporate elements of bottom-up planning [17]. In fact, the deep involvement of local villagers is a common feature of most successful IVDB cases [30]. Additionally, focusing on the revenue of the balanced quota, scholars analyze cases of measurement and distribution [31,32] and the direct or indirect effects on economic growth. However, few studies have revealed the appropriate scale of the balanced quota in the process of the project based IVDB implementation. There is also a lack of research on the relationship between the quota's scale and revenue supported by empirical data. The existing scattered case analyses are not enough to show the overall situation of the IVDB policy implementation within a region, which means that it is difficult to effectively guide the further improvement of the IVDB policy. As such, knowledge of the relationship between the balanced quota's scale and revenue based on the IVDB projects is still rare. What is more, the knowledge gap, if filled, could provide the support of economic theory and method for the decision-making of local government, which has been leading the IVDB implementation since 2020. Meanwhile, the moderate scale quota plays a crucial role in improving the performance of IVDB policies.

By 2019, 31 provinces in China (excepting Taiwan, Hong Kong and Macao) have adopted the IVDB policy [20]. Among them, Zhejiang is the first province to explore the transferring quota in an urban setting, through construction land replacement, rural land consolidation and reclamation and so on [2]. After being integrated in the IVDB policy, the province has taken the lead in carrying out a county-level comprehensive land consolidation project [3]. In addition, Zhejiang province, with rapid economic development, is faced with many problems such as limited land space, insufficient reserve cultivated land resources, high population density and a large gap in the urban construction land index. There is no doubt that the IVDB policy has become a long-term mechanism to relieve land shortage in Zhejiang. Therefore, we took Zhejiang as a representative case area to explore the relationship between the scale and the revenue of the project-based balanced quota.

The rest of this article is organized as follows. Section 2 analyzes the theory of the relationship between the balanced quota's scale and revenue. Then we put forward the research hypothesis. Section 3 explains the methodology and data sources used and provides insight into the descriptive statistics. Section 4 provides the empirical results, followed by discussion and key policy implications in Section 5. The final section summarizes the main findings and points out deficiencies.

2. Theoretical Analysis and Hypotheses

According to the Economies of Scale Theory, as the output of the enterprise increases, the marginal cost gradually decreases, which can realize the benefit of scale. However, if the scale continues to expand, the cost will increase due to factors such as uneconomical management. Then the Theory of Moderate Scale is derived. Further, the moderate scale operation refers to the practice of moderately expanding the scale of production and operation units under the existing conditions, so that the allocation of various production factors tends to be reasonable and the best operating benefits can be achieved. In the field of land management, whether it is agricultural land or urban land, there is an inverted 'U' curve relationship between input and output. For example, the scale of farmland and agricultural efficiency and/or farmers' income shows an inverted 'U' curve relationship [33,34] and there are moderate scale boundaries in land transfer and land trusteeship [35].Similar research studies the optimal scale of towns and urban construction land, etc. Based on the above theories and research results, we try to make general logical inferences concerning the implementation of the project-based IVDB policy; as the scale of the balanced quota increases, the capital, labor and other factors of production input in each process, such as demolition, resettlement and new construction, will gradually approach the optimal combination ratio, which shows an increasing trend of marginal revenue; when the whole inputs reach the best combination, the marginal earnings of the IVDB project achieves the peak and the optimal scale of the balanced quota is realized. With the expansion of the quota's scale, the ratio of production factors gradually deviates from the optimal combination ratio, showing a trend of diminishing marginal income. In general, there may exist an inverted 'U' curve relationship between the scale and revenue of the balanced quota (Figure 1).

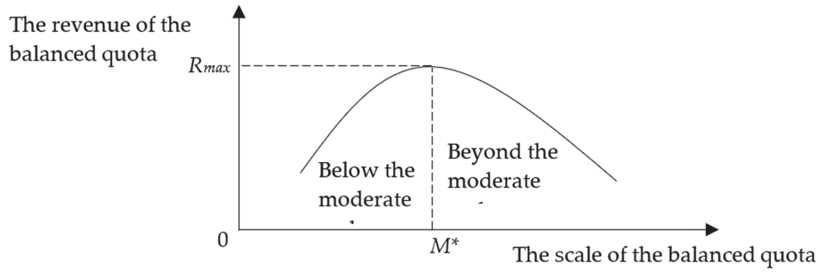

Figure 1. The inverted u-shaped curve diagram of balanced quota's scale and revenue.

Specifically, when the project-based balanced quota is within the moderate scale (0 to M^* in Figure 1), the quota will promote revenue mainly through an incremental and cost-saving mechanism. In terms of the incremental mechanism, the larger the balanced quota, the larger the scale of demolition in rural areas and new construction in urban areas. After deducting part of the resettlement land of farmers in the demolition areas, the scale of surplus land that can be transferred to urban construction is relatively large. Under the premise of a certain unit price of the quota, the larger the scale of the saving, the higher the total income. Taking five IVDB projects in Dongbao District of Hubei province as an example, under the control of the balanced quota, the scale of the demolition areas is 100.71, 64.20, 30, 20, and 18.91 ha, respectively, and the area of residential land for resettlement farmers is 21.91, 12.72, 5.36, 4.03, and 3.00 ha, respectively. Therefore, the new construction land quota that can be transferred to cities and towns is 80.06, 51.55, 24.64, 16.39, and 17.19 ha, respectively [32] [4]. Through the analysis of this case, we can intuitively find that the scale of the balanced quota is directly proportional to the revenue of the savings indicator that can bring economic benefits. In terms of the cost-saving mechanism, the input costs involved in the implementation of the IVDB policy mainly include the demolition and compensation of farmers' homesteads, land reclamation, infrastructure construction and resettlement housing construction. On the one hand, a certain scale of demolition and reclamation is convenient for mechanized operations and can surely reduce labor costs [5]. On the other hand, the average total cost of infrastructure construction such as for water and electricity will decrease along with the increase in supply.

When the quota exceeds the moderate scale (the right side of M^* in Figure 1), it will inhibit the return of the quota. This phenomenon is mainly caused by the law of increasing marginal costs and diminishing marginal returns. Firstly, transaction costs can be more expensive if the scale of the balanced quota is too large. The large scale means that the number of farmers involved is huge and the government needs to spend too much time and funds on mobilizing demolition, determining compensation and resettlement methods and coordinating disputes over ownerships. All these lead to higher transaction costs for demolition and resettlement. Secondly, the unit return will be lower. On the premise that the urban construction land will not expand indefinitely, the larger the balanced quota, the more the new urban construction scale can be transferred, which is likely to cause a buyer's market because of the oversupplying. An extreme example is that, according to China's rate of urbanization (the population urbanization rate will be 75% to 80%), there will be nearly 200 million farmers moving to cities or towns in the next two decades; at the same time, about 2 million ha of newly added urban construction land is needed, on the condition of an urban construction land planning standard of 100 square meters per person. However, the current rural homestead area is as high as 13 million ha. So, under the circumstance that the scale of rural homesteads is huge while the demand for newly constructed urban land is limited, the benefit of the saving quota formed by the reclamation of homesteads can only be determined by the lowest price of many quota-sellers. The price will be close to the cost of demolition. Additionally, the inputs will be inefficiently allocated. There is a certain investment combination ratio between land input and other production inputs such as capital and labor. If the balance quota exceeds an appropriate scale, it will not be able to effectively cooperate with other factors to form economies of scale. This will cause low efficiency and even inefficient allocation of production factors.

Based on the above analysis, the core hypothesis of this study is put forward as follows: there may exist an inverted U-shaped curve relationship between the scale and the revenue of the project-based balanced quota, and there is an appropriate quota scale that maximizes the revenue.

3. Materials and Methods

3.1. Econometric Model

The discussion above provides the theoretical analysis for the scale and revenue of the balanced quota in the IVDB policy implement. Based on this, referring to [33,35], we establish the following quadratic econometric model, with the project as the research unit in this study:

$$R_i = \alpha_0 + \alpha_1 Area_i + \alpha_2 Area_i^2 + \sum\nolimits_{j=1}^{2} \beta_j Con_{ij} + \sum\nolimits_{j=1}^{6} \gamma_j Eco_{ij} + Reg_k + \varepsilon_i \quad (1)$$

where R_i is the revenue of the i project; $Area_i$, $Area_i^2$ respectively are the scale and squared scale of the balanced quota in project i; Con_{ij}, Eco_{ij} and Reg_k are three types of control variables, with Con_{ij} used to control the characteristics of the balanced quota, Eco_{ij} and Reg_k respectively, control the socioeconomic and regional characteristics of the county where the project is located; α, β and γ represent the parameters to be estimated of explanatory variables; ε_i represents the random error term.

3.2. Variables and Definition

(1) Explained variable. In order to measure the revenue of the balanced quota as comprehensively as possible, the total income of the quota (*R*) is selected as the explained variable. *R* refers to the benefits obtained by transferring the balanced quota which is approved for urban construction, after deducting the scale for resettlement in each project area.

(2) Explanatory variable. The quotas related to the scale of the project based IVDB include the following three main types: the scale of the project area, the balanced quota and the saving quota. Generally, the scale of the project area is approximately twice the size of the balanced quota, and the scale of the saving quota is the amount transferred to the urban construction on the condition of subtracting the rural resettlement space from the balanced quota. Considering that the balanced quota is closely related to other scales, this study chose the balanced quota as the core explanatory variable (*Area*).

(3) Control variables. In order to avoid the problem of reducing the reliability of the model due to missing variables, we draw on the related research methods of [34], and select three control variable groups to control other factors that may affect the revenue of the balanced quota. The first group is the utilization characteristics of the balanced quota in each project after they are transferred to cities and towns (*Con*). Since the amount and specific uses of the balanced quota transferred to urban areas can affect the explained variable, the proportion of urban construction scale in the balanced quota and the proportion of commercial and residential construction land in the urban construction area are selected as control variables. The second group is the characteristics of social and economic conditions at the county level in which the project is located (*Eco*). Considering that the unit price of the quota will change due to the level of socio-economic development in different regions, the total population, GDP growth rate, urbanization rate, proportion of the service industry, fiscal revenue versus expenditure ratio and per capita disposable income ratio of urban versus

rural residents are included in the control variables. The third group is the regional characteristic control variables (*Reg*). Our study selects municipal administrative units as dummy variables to further control external environmental factors, such as natural environment, resource endowment and other social or economic conditions in different project areas. Except for the municipal-level dummy variable, all other variable definitions and descriptive statistics are shown in Table 1.

Table 1. Variable definitions and descriptive statistics.

Variable		Name	Definition (Unit)	Mean	Standard Deviation
Dependent variable		Revenue of the balanced quota	Revenue from the transfer of balanced quota to urban use (CNY10 thousand)	415.46	1481.01
Independent variable		Scale of the balanced quota	The scale of the project-based balanced quota approved by the superior government (ha)	162.44	159.05
Control variables	Project features	Proportion of new construction in urban	Actual land supply scale for new construction in urban/the approved balanced quota (%)	0.66	0.42
		Proportion of commercial and residential land	Sum of commercial and residential land for new construction/actual land scale for new construction in urban (%)	0.25	0.38
	Socio-economic characteristics	Total population	Total resident population in 2019 (10 thousand people)	77.67	41.75
		GDP growth rate	(GDP in 2019-GDP in 2018)/GDP in 2018 (%)	0.08	0.05
		Urbanization rate	Urban population/total population in 2020 (%)	0.66	0.09
		Proportion of the service production	GDP of tertiary industry/GDP in 2019 (%)	0.47	0.07
		Fiscal revenue vs. expenditure ratio	Total fiscal revenue/general public budget expenditure in 2019	1.11	0.39
		Per capita disposable income of urban vs. rural	Per capita disposable income in urban/per capita disposable income in rural in 2019	1.77	0.18

3.3. Data Resource and Description

Data in this paper include two main categories: the project data of IVDB and the socioeconomic data. The former was obtained from the 'Online supervision system for increasing versus decreasing balance of urban-rural built land' by the MNR. The data includes the approval, establishment, implementation process and acceptance inspection of each project. The statistical indicators include the scale of the balanced quota and reclamation, the newly added scale of rural and urban construction land, the total project investment and the revenue of the quota, number of farmers and per capita annual income before and/or after the implementation of the project, etc. Due to the projects that have not yet been completed, the inspection cannot obtain key information such as the revenue of the balanced quota, so our research object deals with 1907 projects of the IVDB in Zhejiang province, which had completed the acceptance inspection by the end of 2018 and could clearly locate the county administrative units of every project [6], so that 1097 projects are distributed in 62 counties of 11 cities in Zhejiang (Figure 2).

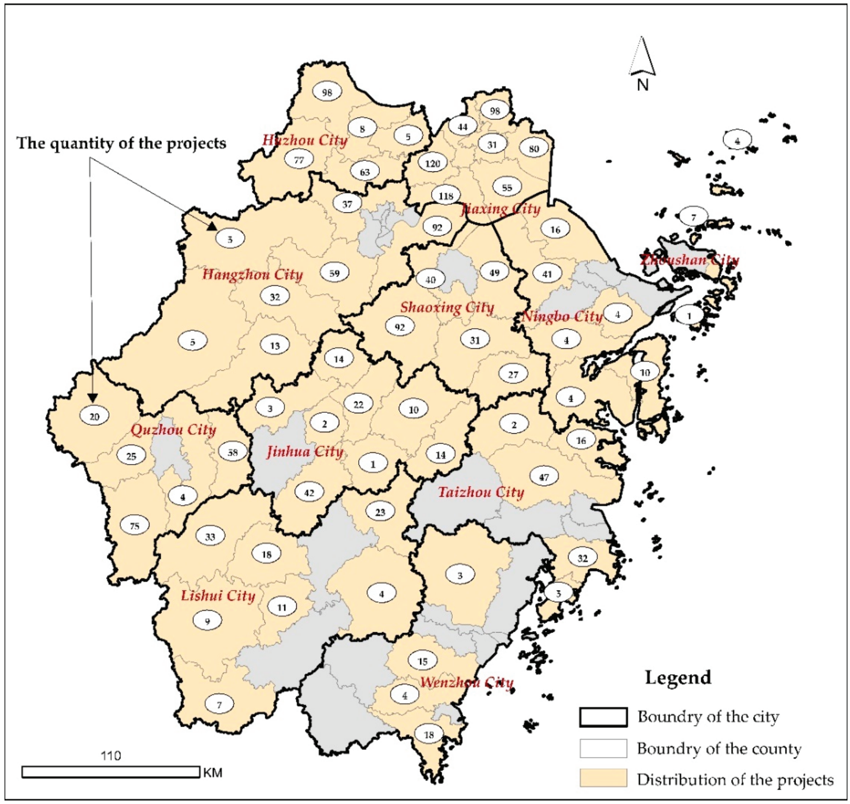

Figure 2. Distribution area and quantity of the increasing versus decreasing balance projects in Zhejiang province.

As far as a single project is concerned, the largest scale of the balanced quota was approved during the second batch of IVDB projects in Jiande county, Hangzhou city in 2012, reaching 67.30 ha; while the smallest project was the civil aviation navigation station program in Nanxun District, Huzhou City in 2006, with a scale of only 0.01 ha. In 2012, the comprehensive improvement project of rural land in Beitangtou & Highland in Qinmin Village of Haining prefecture obtained 3revenue of CNY 302.22 million and the approved balanced quota was 23.65 ha. The comparison of the scale of the balanced quota with benefits for 11 cities in Zhejiang province is plotted in Figure 3. The above intuitive statistics show that the scale of the quota and the revenue are not completely positively correlated and the relationship between the two needs to be further demonstrated.

In addition, the total population, GDP, output value of tertiary industry, total fiscal revenue and general public budget expenditure per capita disposable income of urban and rural residents and other social-economic data of the 62 counties were extracted from the statistical yearbooks and statistical bulletin. The urbanization rate was calculated according to China's Seventh Census. Meanwhile, in order to maintain consistency with the IVDB projects statistical time node as far as possible, most social and economic data are from the year of 2019. The mean and standard deviation of each index are shown in Table 1.

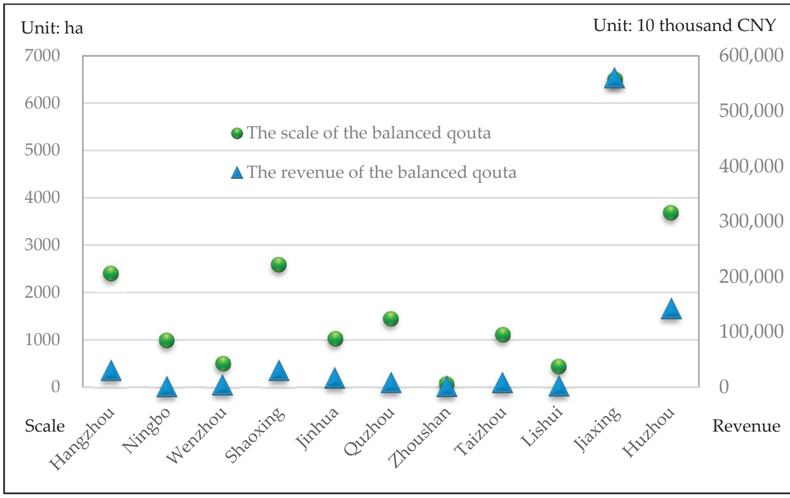

Figure 3. The comparing of the scale of the balanced quota with the benefits of 11 cities in Zhejiang province.

4. Results

4.1. Comparison of Returns under Different Quota Scales

In order to clarify the scale of the balanced quota and the characteristics of revenue in different projects, all objects are divided into below 3.33 ha (50 mu), 3.33–6.66 ha (50–100 mu), 6.66–13.33 ha (100–200 mu), 13.33–33.33 ha (200–500 mu), and more than 33.33 ha (500 mu) for group descriptive statistics (Table 2). From the perspective of scale characteristics, the scale of the balanced quota generally does not exceed 33.33 ha, and the number of projects with 3.33, 6.66, and 13.33 ha as grouping intervals is relatively evenly distributed. From the perspective of revenue characteristics, when the scale of the balanced quota is within 33.33 ha, the revenue increases with the expansion of the quota scale while, when the scale exceeds 33.33 ha, the revenue shows a declining situation. In general, the change trend and fluctuation characteristics of the quota scale and revenue provide evidence for the existence of the optimal balanced quota scale. On this basis, the following will use the econometric model to further explore the quantitative relationship between the scale of the quota and the revenue.

Table 2. Comparison of the scale and revenue of the balanced quota in different projects.

Balanced Quota Scale/ha	Number of Project	Quota Revenue/10 Thousand	
		Mean	Standard Deviation
[0, 3.33]	555	61.556	209.317
(3.33, 6.66]	356	265.860	600.845
(6.66, 13.33]	430	618.132	1510.287
(13.33, 33.33]	482	731.467	2371.445
(33.33, 67.33]	84	536.909	1552.598

4.2. The Influence of Turnover Index Scale on Index Return

Before estimating the nonlinear model, the variables such as the balanced quota scale, income and population, with large standard deviations, were logarithmically processed, for the purpose of eliminating heteroscedasticity [7]. At the same time, all independent variables were multicollinearity tested by variance inflation factor method [8]. The results show that the VIF values of all variables are less than 10, which means that there is no collinearity problem. Then, based on OLS, Stata 16.0 software is used to estimate the impact of the scale of the balanced quota on revenue. In the process of estimating, considering that the sample data has mixed cross-sectional characteristics, the robust standard error regression method is used. The results are shown in Table 3, where model 1 is the estimated result without adding control variables and model 2 is the result of adding other control variables.

Table 3. Estimated results of the impact of the scale of project-based balanced quota on revenue.

Variable	Model 1		Model 2	
	Coefficient	Robust Standard Error	Coefficient	Robust Standard Error
Balanced quota scale	1.197 ***	0.187	0.556 ***	0.153
Balanced quota scale squared	−0.119 ***	0.025	−0.0594 ***	0.021
Proportion of new construction in urban			−0.633 ***	0.161
Proportion of commercial and residential land			0.177	0.158
Total population			−0.864 ***	0.218
Urbanization rate			−12.29 ***	0.865
GDP growth rate			−10.97 ***	1.541
Proportion of the service production			−3.257 ***	1.223
Fiscal revenue vs. expenditure ratio			5.472 ***	0.406
Per capita disposable income of urban vs. rural			0.122	0.562
Constant term	−1.064 ***	0.311	7.430 ***	1.492
municipal-level dummy variable	controlled		controlled	
sample size	1907		1907	
R^2	0.022		0.269	

Note: *** denotes a significance level of 10%.

According to Table 3, no matter whether control variables are added or not, when the revenue of the balanced quota is taken as the explained variable, the regression coefficients of the first and second terms of the quota scale are positive and negative, respectively, and both are significant at the level of 1%. This measurement result verifies the theoretical hypothesis of this paper, that is, there is an inverted U-shaped relationship between the scale of the balanced quota and the revenue in the project based IVDB implementation. Specifically, the inverted u-shaped relationship means that the revenue gradually increases and then decreases with the expansion of the quota scale. The gradually expanding scale makes all kinds of inputs close to the optimal combination ratio step by step, along with the increase in the revenue. When the scale and other factors of production such as labor and capital reach the optimal ratio, the maximum revenue is achieved, and the quota scale reaches the optimal size. If the scale exceeds the optimal size, the whole input will be faced with deviation from the optimal production state and this will lead to a decrease in revenue eventually. Moreover, the optimal scale of the balanced quota can be calculated from the regression coefficients of the first and second terms of the independent variable in the model estimation results. According to model 2 of Table 3, the logarithm of the appropriate scale of the balanced quota is 0.31 ha in Zhejiang province and the corresponding moderate scale is 7.19 ha. Combined with the 1907 IVDB projects completing inspection in Zhejiang, 22.44% of the approved balanced quota exceeds the appropriate scale, which means that the quota is inefficiently allocated.

Among the first group of control variables, the proportion of new construction in urban areas has a significant negative impact on the revenue of the balanced quota. Although this seems unexpected, it is actually reasonable. In this respect, our explanation is that, although the larger the scale urban new construction means a higher the demand for quota and makes it easier to increase the economic benefits theoretically, in reality the benefits are also limited by such factors as an underdeveloped economy and weak financial strength in some projects, resulting in the low transaction unit price of the balanced quota and low revenue. In the second group of control variables, fiscal revenue vs. expenditure ratio is positively correlated with the revenue of the balanced quota. The main reason for this is that a higher ratio represents a bigger surplus, meaning local governments have the financial capacity to pay for the balanced quota. Urbanization rate, GDP growth rate and proportion of the service production are negatively correlated with the revenue. A possible explanation is that the former three variables are key standards to measure the level of economic development, and the higher the level of economic development, the better the rural economic situation. Therefore, the time and cost of the demolition, transaction, resettlement and other aspects will be longer and more expensive. Further, the 1907 projects in this paper are counted according to the acceptance inspection data, which may lead to fewer projects not only being approved but also accepted in developed areas. All this can cause negative correlation. In addition, per capita disposable income, urban vs. rural, does not pass the significance level.

4.3. Spatial Heterogeneity Analysis

Due to the differences in resource endowment, economic development and implementation cycle of IVDB projects in different regions, the optimal quota scale for maximizing revenue contains distinctions. Zhejiang province is divided into the northeast and southwest region according to the urban spatial pattern of 'one bay, two cores, four poles and multiple clusters' in Zhejiang [9]. OLS estimation is performed on the two sub-samples, respectively, in this study. The regression results of spatial heterogeneity are shown in Table 4.

Table 4. Estimated results of the spatial heterogeneity of the scale and revenue in Zhejiang IVDB projects.

Variable	Northeast Zhejiang		Southwest Zhejiang	
	Coefficient	**Robust Standard Error**	**Coefficient**	**Robust Standard Error**
Balanced quota scale	1.091 ***	0.207	0.973 ***	0.202
Balanced quota scale squared	−0.110 ***	0.028	−0.108 ***	0.028
Proportion of new construction in urban	−1.338 ***	0.205	−0.118	0.183
Proportion of commercial and residential land	0.0106	0.210	0.515 **	0.254
Total population	−0.624 **	0.271	−1.361 ***	0.301
Urbanization rate	−15.01 ***	1.263	−3.015 ***	1.115
GDP growth rate	−10.00 ***	2.051	−8.999 ***	1.645
Proportion of the service production	−6.758 ***	1.217	−2.676 *	1.476
Fiscal revenue vs. expenditure ratio	5.344 ***	0.539	3.567 ***	0.569
Per capita disposable income of urban vs. rural	−5.175 ***	0.821	2.719 ***	1.025
Constant term	19.11 ***	1.857	0.241	2.412
sample size	1370		537	
R^2	0.188		0.224	

Note: *, ** and *** denote a significance level of 1%, 5% and 10%, respectively.

In the two sub-sample models of Table 4, the coefficient of the first term of the balanced quota scale variable is significantly positive and the secondary term is significantly negative, indicating that the scale has a significant inverted 'U' impact on the revenue of the balanced quota in different regions, which is consistent with the baseline regression results of Table 3. Furthermore, combined with the regression coefficient of core explanatory variable, the optimal scale of the balanced quota in northeast and southwest Zhejiang is 9.50 ha and 6.03 ha, respectively [10]. The former scale is larger than that of the latter, which is closely related to the geomorphological factors of Hang-Jia-Hu Plain and Ning-Shao Plain distributed in the Hangzhou Bay area. In addition, there are two pivotal problems that need to be specially explained in the regression results to distinguish spatial heterogeneity. Firstly, the slope of the inverted 'U'-shaped curve in the northeastern Zhejiang is greater than that of southwestern Zhejiang, indicating that the marginal return of the balanced quota in northeastern Zhejiang is higher. This result is in line with the general rule that the more developed the region is, the higher the unit price of the quota. Secondly, the control variable of proportion of commercial and residential land has a significant positive correlation with revenue in southwest Zhejiang. This is consistent with the normal expectation that the transfer income of urban construction and the revenue of the balanced quota is positively correlated.

4.4. Robustness Test

(1) Change the selected model. Usually, different models may obtain different regression results. Considering the numerical feature that the dependent variable (R) is not less than 0, we choose the Tobit model, which can handle the tail-broken data to re-regression. The estimate results are shown in Table 5 for model 3. It can be found that, regardless of the direction or significance, the influence of the scale of the balanced quota and its square term on the revenue is consistent with the results in Table 3, indicating that the inverted U-shaped relationship between the scale of the quota and the revenue is robust.

Table 5. Robustness test of model estimation results.

Variable	Model 3		Model 4	
	Coefficient	**Robust Standard Error**	**Coefficient**	**Robust Standard Error**
Balanced quota scale	3.692 ***	1.053	0.030 *	0.017
Balanced quota scale squared	−0.428 ***	0.121	−0.005 **	0.003
Constant term	22.04 ***	7.750	12.48 ***	0.103
control variables	control		control	
sample size	1907		1907	
R^2			0.015	
LR	702.87			
Prob > chi2	0.0000			

Note: *, ** and *** denote a significance level of 1%, 5% and 10%, respectively.

(2) Replace the explained variable. The revenue of the balanced quota is replaced by the profit of the quota and the impact of the index scale and net income is estimated as robustness test. The profit of the quota is obtained by subtracting the actual total investment [11] from the revenue and the OLS regression is performed after the negative number is turned to the positive and the logarithm is processed. The results are shown in Table 5 for model 4. Similarly, the primary item of the balanced quota scale is negative and the secondary item is positive, with the significance tests of 10% and 5%, respectively, being passed to verify the existence of an appropriate scale of the project-based balanced quota.

5. Discussion and Policy Implication

5.1. Problems Associated with the Scale and Revenue of the Balanced Quota

In the context of spatial planning with tight constraints, as the incremental quota becomes less and less, the balanced quota will be more pivotal for local governments in acquiring urban construction land. At the same time, the revenue of the balanced quota provides indispensable capital for the revitalization of rural regions. The spatial relocation under the IVDB implication conforms to the development of urban-rural coordination [20]. Therefore, though the IVDB implicating process may impose on the welfare of vulnerable groups such as peasants [17], the quality of reclaimed farmland land may be poorer than the occupied land, and the hidden debt of local government may be at greater risk, we can still safely deduce that the IVDB policy will be implemented persistently in China over years and decades. Therefore, there are two pivotal issues to be further concerned combined with our theoretical analysis and empirical results on the relationship between balanced quota's scale and revenue.

The first issue is how to determine the optimal scale of the balanced quota under the project-based IVDB policy? As the 1907 projects of Zhejiang province show, there is an inverted 'U' curve relationship between the scale of the balanced quota and its revenue. In other words, the quota's scale follows the rule that 'the more is not the better'. Three perspectives need to be considered to achieve the optimal scale to maximize returns. One is the factor of natural perspective. The implementation of IVDB policy is strongly dependent on the regional location, topographic features, soil quality, irrigation conditions and other natural factors. From the perspectives of ecological benefit, requisition-compensation, balance of cultivated land and farmers' use of cultivated land, Yang, et al. (2015) analyzed the rationality of the project of IVDB in the China Mountain Area [36]. If local governments pursue land indicators excessively and promote rural demolition arbitrarily, without considering the objective limitations of natural conditions, the IVDB policy will be out of control and the overall interests will be damaged. The other is the production perspective. As the theory of Economies of Moderate Scale says, as a kind of production factors, land should be considered in relation to labor, capital and other inputs. Only when the proportion of all kinds of production factors are close to the optimal combination can the revenue of the balanced quota be maximized. Then the local governments' financial burden will be reduced and the economic incentive mechanism of the IVDB policy will be brought into full play. In addition, the market perspective is an indispensable consideration. According to some Chinese cases, building high-rise buildings can save 90% of the balanced quota to transfer to urban-supporting construction, while building 'small villas' can only transfer 60% of the total quota. In the process of the IVDB's implementation, the prefectural government also tends to save more transferable quota. Contrary to most humans' intuitive prediction, our measurement results of both the whole region and the spatial heterogeneity of Zhejiang province show that, the larger the scale of urban construction is, the lesser the quota's income. Essentially, this is a reflection of market behavior. When the quota supply exceeds the demand, the earnings will naturally decline. Therefore, rather than trying to reduce the living space of farmers to obtain a bigger urban construction quota, it is better to find ways to turn to a seller's market for the balanced quota.

The second issue is to what extent the provincial government can orient the project based IVDB policy. In China's vertical land management system, there exist three levels of government: central, provincial and prefectural [37,38]. In fact, in 2004 has clarified the division of land management powers between central and local government. That is, the power and responsibility to regulate the total amount of newly added land for construction belongs to the central government, while the power to revitalize existing land for construction belong to local government. The responsibility for protecting a rational use of land rests with the local government at all levels, with the provincial government bearing the primary responsibility. As the implication of the IVDB policy almost has no effect on incremental construction land, relevant power for the policy rests with provincial and prefectural government according to the above document. However, considering the possibility of overuse of land resources by local government, the central government has been controlling the balanced quota before 2020. Under the new system of spatial planning, provincial government has the right to arrange the implication of the IVDB policy, in line with the tight constraints of resource utilization. The provincial government's role is shifting from that of a hub [37] to a decider, and neither the top-down [39–41] nor bottom-up [42–44] theories of the process of IVDB can explain well the administrative discretion of the role. Particularly, the provincial government and prefecture may have the possibility of engaging in collusive behaviors because of common economic interests [45]. Experience and lessons from "centralization-decentralization-recentralization" [46] may be conductive to understanding the function of the provincial government in the IVDB policy implementation.

5.2. Policy Implication

For the purpose of coordinating the relationship between the scale and revenue of the balanced quota and improving the performance of the IVDB policy, this paper offers the following three suggestions.

Firstly, the scale of the balanced quota should be determined through comprehensive consideration of inputs. In the process of implementing the project based IVDB policy, in addition to the quota quantity, such factors as the coordination and governance capacity of local government, fund raising for demolition, reclamation and resettlement, and the unavoidable transaction costs can affect the returns of the quota. Only when the whole inputs are coupled and coordinated can the benefits be maximized. Therefore, when the provincial government approves the balanced quota or the county government applies for it to the superior government, the first step is to assess how well each input matches up. Then the optimal balanced quota of every project can be determined comprehensively. The optimal scale determined based on these comprehensive factors can realize the maximization of the revenue, theoretically. Based on the revenue of the balanced quota, the incremental benefits returning to the demolished areas will also be increased accordingly, and the economic situation of farmers will be significantly improved.

Secondly, the spatial planning of rural resettlements needs to be optimized. Rural spatial plans and project design are highly significant for IVDB policy implementation. In the whole process of planning and designing, it is pivotal to listen to the farmers' thinking and respect their willingness. In particular, when the rural resettlement program is launched, planners should consider suitable distance for cultivation, space for storing goods such as farm tools, stable cost of living, etc. In this case, farmers' enthusiasm for cooperation can be motivated greatly in the implementation of demolition and reclamation, which will improve the efficiency of the balanced quota's producing and trading eventually. Additionally, the quota for the integration of tertiary industries in rural areas should be reserved if it is necessary and the countryside has a sound industrial base. Then farmers can obtain sustainable income in this way. The above measures are necessary supplements to determine the optimal scale of the balanced quota, so are in line with the inherent requirements of rural revitalization. In particular, the layout of rural residential areas based on spatial planning is conducive to improving the living environment of farmers and creating an ecologically livable production and living space.

Thirdly, central-government supervision should be strengthened in the process of the provincial-oriented IVDB implementation. While the provincial government leads the IVDB policy, there is also a risk of over-expanding the scale of the balanced quota, driven by government performance assessment and land finance. The 'merging villages and living together' policy in Shandong province is typical evidence. Then the central government, the paramount decision-maker at the top of governmental hierarchy in China, scan supervise and regulate the implement of IVDB directly and design policies to make provincial government more accountable [37]. To some extent, the strong supervision of central government provides the most solid backing to protect the interests of farmers. Any local government behavior at the expense of farmers' interests will be sanctioned severely by central government.

6. Conclusions

Under the background of IVDB implementation power moving down to the provincial government, this paper verified the inverted U-shaped impact of the scale of the balanced quota on the revenue at both theoretical and empirical levels and obtains the appropriate quota scale corresponding to the maximization of the earnings. Based on 1907 IVDB projects in Zhejiang province, the conclusions are as follows. First, with the quantity increase of the balanced quota, the revenue of the quota climbs and then declines. In other words, the relationship between the quota's scale and the revenue shows an inverted 'U' type. On the premise of controlling the characteristics of the projects and the socio-economic development of the county in which the IVDB project is located, the optimal balanced quota of Zhejiang province is 7.19 ha. When the quota exceeds this critical point, the revenue will decrease constantly. Second, there is spatial heterogeneity in the optimal scale of the balanced quota in Zhejiang. Specifically, the optimal scale of the quota in northeast and southwest Zhejiang is 9.50 ha and 6.03 ha, respectively, and the marginal return of the quota in the former is higher than the latter, which is consistent with the general rule that the more developed the region is, the higher the unit price of the quota. In the context of increasing the efficiency of quota-allocation and further improving the IVDB performance, we suggest that: (1) the scale of the balanced quota should be determined through comprehensive consideration of inputs, (2) the spatial planning of rural resettlements need to be optimized, and (3) central-government supervision should be strengthened in the process of the provincial-oriented IVDB implementation.

However, despite our study being carefully conducted, there are still several crucial limitations. On the one hand, considering that the prefectural government plays a pivotal role in adopting the IVDB and the early characteristics of the policy, we use a county-level project as the basic research unit along with the advantages of data acquisition. With the evolution and development of the IVDB policy, the balanced quota will be transferred across prefectures or even across provinces around China with high probability. These phenomena mean that the project based IVDB beyond the county is much different from the within, which may lead to quite different relationship between the scale and the revenue of the balanced quota. In short, more attention should be paid to the cross-regional implement of the IVDB to explore the optimal scale of the balanced quota. On the other hand, due to the inseparability of the capital invested in demolition and reclamation of the IVDB project, the appropriate scale oriented to the maximization of revenue mainly adopts the gross profit index. The net profit after deducting the actual invested capital amount is not analyzed as a dependent variable, which is involved only in the robustness test. Future research needs to find a more scientific way to deal with profits.

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Notes

[1] The Ministry of Land and Resources was reorganized and renamed as Ministry of Natural Resources (MNR) in March 2018.

[2] In June 1998, the Governmental Office of the Zhejiang Province issued the No.91 document 'Circular on encouraging rural land consolidation', proposing that 'After the completion of the rural land consolidation program, the urban construction land target shall be assigned to 70% of the actual increase of the effective arable land area on the condition of offsetting the pre-arranged building quota'.

[3] For more details, see the No.4 document 'Implementation opinions of General Office of Hangzhou Municipal Party Committee and General Office of Hangzhou Municipal Government on promoting pilot work for comprehensive consolidation of rural land in townships and towns' in 2013, the No.80 document of 'The General Office of the Zhejiang Provincial People's Government on the Implementation of Comprehensive Land Consolidation and Ecological Opinions on Restoration Projects' in 2018, etc.

[4] In the research by Chen et al. (2016), the total area of demolition and the new-construction area are not exactly equal, and the newly added construction land quota is calculated from the area of the new construction area minus the area of the resettlement area, so it is slightly different from the results presented in this paper.

[5] This paper focuses on the relationship between the revenue of the construction land quota saved in the demolition area and the scale of the demolition area, without considering the land acquisition compensation and the fee for the newly added construction land when the quota is transferred to urban areas.

[6] In order to ensure the integrity of the data, this paper does not exclude the land remediation, construction land reclamation and other project types that are related to the IVDB in the Online supervision system. At the same time, considering the location requirements of control variables, the 361 projects in the acceptance inspection table that cannot be located in the county-level administrative units (such as 'The Implementation Plan for Increase Versus Decrease Balancing (V)-3 of Hangzhou City in 2010', 'The Increasing Versus Decreasing Balance of Urban-R333333000ural Built Land Implementation Plan (II) of Jiaxing City In 2012') are excluded.

[7] There is 0 value in the original data of the revenue. For this reason, we add 1 to all the data before taking the logarithm.

[8] Quadratic terms are not included in the collinearity test.

[9] For details, see the 'Zhejiang Provincial Land and Space Master Plan (2021–2035) (draft for comments) in April 2021.

[10] Specifically, according to the coefficient of balanced quota scale (1.091 of northeast Zhejiang. 0.973 of southwest Zhejiang) and balanced quota scale squared (−0.110 of northeast Zhejiang. −0.108 of southwest Zhejiang) in Table 4, we can calculate the optimal scale when the revenue is maximized (1.091/(−2*(−0.110) = 4.949, 0.973/(−2*(−0.108) = 4.505). Furthermore, the variable of the balanced quota scale was logarithmic processed (see 4.2. For the influence of turnover index scale on index return), we need to take the natural logarithm E as the base of 4.949, 4.505 power function, respectively, i.e., 9.50 ha and 6.03 ha, respectively.

[11] The actual total investment data comes from the 'Online supervision system for increasing versus decreasing balance of urban-rural built land' by the MNR.

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Eco-Environmental Effects of Changes in Territorial Spatial Pattern and Their Driving Forces in Qinghai, China (1980–2020)

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Abstract: As urbanization and industrialization have advanced in leaps and bounds, the territorial spatial pattern of Qinghai has experienced profound transformation and reconstruction, which has been directly reflected in land-use changes and affected the eco-environment. In this context, we constructed a functional classification system of "production-living-ecological" (PLE), used remote sensing data for six periods from 1980 to 2020, and employed the land transfer matrix, eco-environmental quality index, ecological contribution rate of land-use transformation and geographical detectors to analyze the changes in the territorial spatial patterns, eco-environmental effects and driving forces of eco-environmental quality. The results revealed that (1) the spatial distribution of the province was characterized by the relative agglomeration of the production and living spaces and the absolute dominance of ecological spaces; (2) The eco-environmental quality of the region portrayed a steady improvement, with a significant reduction in the medium–low and low-quality areas; and (3) the annual average precipitation, proportion of non-agricultural area, and socio-economic factors had a significant impact on the eco-environmental quality of the region, meanwhile, national economy and ecological policies are important indirect driving forces of eco-environmental quality. Our findings will provide guidelines for territorial spatial management and serve as a reference for eco-environmental protection in Qinghai.

Keywords: territorial space; production–living–ecological space; spatio-temporal variation; eco-environment effect; driving force; territorial spatial pattern; eco-environmental quality

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1. Introduction

Territorial space is an important foundation for national survival and social and economic development, which is the carrier and place for human production and life. It is a composite dynamic system composed of natural ecological and socio-economic elements [1,2]. Changes in territorial spatial pa-terns are manifested as changes in the interaction and functional connections between different land use types in the region [3,4]. This, in turn, affects changes in the society, economy, and ecology of the region and is also an important link in studying regional systems of human–natural coupling relationships [5,6].

Notably, the concept of land use form was introduced by British geographer Alan Grainger in 1995 [7], Since then, scholars have studied the territorial spatial pattern, based on land use, while considering systematization, hierarchy, and diversification [8–12]. An increasing number of studies are analyzing the spatial patterns of land under the influence of land use change from different perspectives [13,14], while analyzing the evolution of different land types [14–16] and influencing factors and effect methods [17,18].

The land-use changes in the territorial spatial pattern of a region are affected by the natural background conditions and socio-economic development of the region [19,20]. Simultaneously, the changes also affect the regional climate and ecological environment. Foley [21] concluded that changing land use strategies can effectively improve the negative effects of food production, freshwater resources, forest resources, regional climate, and air quality (especially the spread of infectious diseases). Peters [22] analyzed the comprehensive effects of climate and land use on the biodiversity and eco-system functions in Kilimanjaro. Notably, previous studies have indicated that climate can regulate the impact of land use on biodiversity and ecosystem function. Disordered transition and irrational utilization will lead to a series of problems such as ecological environment deterioration and ecosystem service function decline [23,24]. To study the effect of land use on ecosystem service function, scholars have focused more on the areas where the national development strategy has high importance, or the ecological environment is fragile [18,25,26]. The eco-environmental effect of territorial spatial pattern change, and its driving force analysis, are one of the important ways to optimize environmental protection, ensure food security, and promote the economical and intensive utilization of land and resources [27–29].

Since 1978, China has experienced a reform; the rapid development of its economy has accompanied a series of issues related to sustainable development between the production and living activities in territorial spatial patterns and between human settlements and natural ecosystems [30–33]. Solving problems related to the rapid development and transformation of the social economy, such as those regarding land development order and the heavy costs associated with resources and the environment, has always been an important scientific aspect of the study of the human-natural coupling relationship in the field of regional sustainable development [34,35]. Qinghai is the 'Asian water tower' and contains the Three Rivers Source, which plays a very important role in the global ecological development. With the rapid development of urbanization and industrialization, the spatial form of land and the spatial pattern of production, life, and ecology in the Qinghai province are also changing [36,37]. In this context, through the construction of the functional classification system of production-living-ecological (PLE) space, it is used to analyze the relationship between macro spatial pattern and micro land use. Meanwhile, it will be helpful to explore the characteristics of territorial spatial pattern change at the macro scale and study the eco-environment quality and its driving factors caused by land use at the micro scale [37–39].

In the context of sustainable development, eco-environment quality changes based on territorial spatial patterns and factors affecting the changes have attracted much attention. It will be of great theoretical and practical significance to study the spatio-temporal pattern change of territorial spatial patterns, eco-environmental quality and its driving forces in the process of social and economic development. Specifically, our objectives were to (1) from the perspective of PLE land use function, quantify the spatio-temporal changes of Qinghai's territorial space pattern from 1980 to 2020; (2) employing the eco-environmental quality index and the ecological contribution rate method of land use transformation, the dynamic change of eco-environmental quality and ecological contribution of land use transformation were analyzed; and (3) The driving factors affecting the change of ecological environment quality were analyzed and the driving mechanism was discussed in order to provide reference strategies for Qinghai Province to realize the rational utilization of land resources and spatial planning, and to formulate differentiated ecological protection policies for regions.

2. Materials and Methods

2.1. Study Area

Qinghai Province is located in the northeast of the Qinghai-Tibet Plateau (36°31′–39°19′ N latitude, 89°35′–103°04′ E longitude) (Figure 1). The region has a plateau continental climate, with an average annual temperature of 2–9 °C and an annual rainfall of 250–550 mm. Qinghai is the birthplace of the Yellow, Yangtze, and Lancang rivers and one of the most important ecological protection barriers in China. At present, due to the fragile ecological environment restricted by topography and resources, the exploitable land resources in Qinghai province are scarce and the land use structure is simple [40]. The above situation has led to the imbalance of population distribution and economic development layout in the province at different degrees, and the issues related to ecological environment protection have also become prominent.

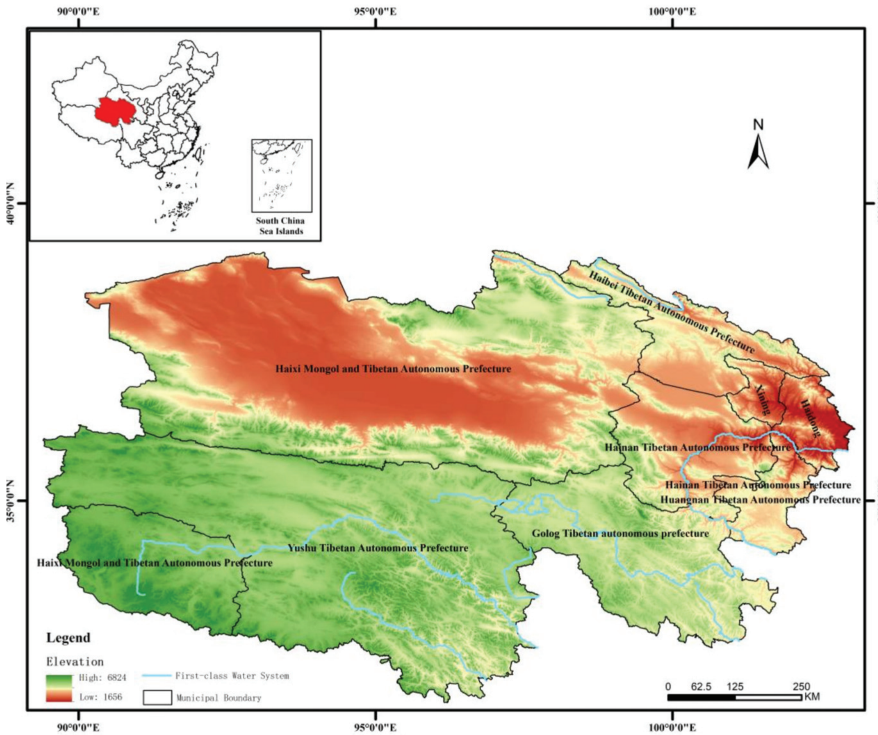

Figure 1. Location of Qinghai Province, China.

2.2. Methods

2.2.1. Construction of Production–Living–Ecological (PLE) Land Classification System

Territorial spatial classification uses the differences in land use types to integrate various elements in the whole area, and then coordinate the layout and utilization of various spatial resources [11,41]. Based on the obtained land type data (including six first-level types of cultivated land, woodland, grassland, water area, construction land, and unused land, and 25 second-level types, such as paddy field and dry land), from the perspective of PLE space, we analyzed the processes of land resources in terms of their quantity and space reallocation among the production, living, and ecological function. The dynamic economic and social development and transformation of the studied territorial space at each stage can be understood, using PLE space as a reference [42,43]. We considered the high ecological and environmental resolution of the secondary classification of land use, results of different global ecosystem services, measured by scholars from various countries, such as Costanza et al. [44], and the actual situation of ecosystem services in China (such as the distinction between paddy field and dry land). Then we employed the eco-environmental quality index obtained by Li et al. [45]. Meanwhile, because this index system is widely used in China and better conforms to the actual situation of ecological service function in China, we directly adopted this index as the background value of the eco-environmental quality index [46,47]. The area weighting method was used to assign the eco-environmental quality index values to various land categories in the PLE space. Finally, we calculated the eco-environmental quality index of land use types for the production, living and ecological functions (Table 1).

Table 1. PLE land classification system and eco-environmental quality index of land use types in Qinghai province.

Territorial Land Space Classification Based on PLE Space		Corresponding Land Type		Eco-Environmental Quality Index (Land Use Types)
1st Level Classes	**Subclasses**	**1st Level Classes**	**Background Value of Eco-Environmental Quality Index**	
PS	APS	Cultivated land	Dry cultivated land (0.25) paddy field (0.3)	0.250
	IPS	Urban and rural, industrial and mining, residential Land	Other construction land (0.15)	0.150
LS	ULS		Urban land (0.2)	0.200
	RLS		Rural residential land (0.2)	0.200
ES	GES	Grassland	High covered grassland (0.75) Medium coverage grassland (0.45) Low cover grassland (0.2)	0.334
	FES	Wood Land	Forest land (0.95) Shrub land (0.65) Sparse woodland (0.45) Other woodlands (0.4)	0.647
	WES	Water Area	Canal (0.55) Lake (0.75) Pond (0.55) Permanent glacier snow land (0.9) Tidal flat (0.45) Beach land (0.55)	0.659
	OES	Unused Land	Sand (0.01) Gobi (0.01) Saline alkali land (0.05) Swamp land (0.65) Bare land (0.05) Bare rock gravel (0.01)	0.056

PS: Production space; LS: Living space; ES: Ecological space; APS: Agricultural production space; IPS: Industrial and mining production space; ULS: Urban living space; RLS: Rural living space; FES: Forest ecological space; GES: Grass ecological space; WES: Water ecological space; OES: Other ecological space.

2.2.2. Territorial Spatial Transfer Matrix

The territorial space transfer matrix is an application of the Markov model commonly used to analyze land use change. In this method, according to the change relationship of land cover in different time and direction, two-dimensional matrix is used to analyze the specific situation of mutual transformation between different land use types, through quantitative data, e.g., the change of location and area and the initial and final land class transfer. Thus, the overall trend of land use change and the change of land use structure can be understood [48]. The mathematical formula of the transition matrix is as follows:

$$S_{ij} = \begin{bmatrix} S_{11} & S_{12} & \cdots S_{1n} \\ S_{21} & S_{22} & \cdots S_{2n} \\ \cdots & \cdots & \cdots \\ S_{n1} & S_{n2} & \cdots S_{nn} \end{bmatrix} \quad (1)$$

In Equation (1), S_{ij} is the total area of the territorial space of type i at the beginning of the study to type j at the end of the study. n is the number of land use types of territorial space utilization. The data of land use types in different periods were analyzed using ArcGIS 10.2 software, and the transfer matrix of the land types in each period was established.

2.2.3. Eco-Environmental Effect

1. Unit eco-environmental quality index

The distribution law of territorial space is strongly dependent on the spatial scale, and the study of scale selection will greatly affect the conclusions obtained. To obtain the most appropriate scale, based on the results of Chen et al. [43,49], we adjusted the image of the study area. Finally, a 4 × 4 km scale was used to sample the study area, with equal spacing, and nearly 46,000 sample areas were generated. Comprehensively considering the proportion of the PLE space area in each ecological grid cell and the background value of the eco-environmental quality index, the eco-environmental quality status of each ecological grid cell in the study area was quantitatively expressed. The mathematical formula used for this analysis is shown below:

$$EV_i = \sum_{i=1}^{N} A_{ki}/A_k R_i \tag{2}$$

In Equation (2), EV_i is the eco-environmental quality index of i ecological units. R_i is the eco-environmental quality index of class i land use type. A_{ki} is the area of land use type i in the kth ecological unit. A_k is the area of the kth ecological unit. n is the number of land use types. Simultaneously, we applied the Kriging method to carry out spatial interpolation on the eco-environmental quality index of the study area, and it was divided into five levels (Table 2).

Table 2. Eco-environmental quality index level.

Level	Low-Quality Area	Medium-Low-Quality Area	Medium-Quality Area	Medium-High-Quality Area	High-Quality Area
Value	$EV \leq 0.15$	$0.15 < EV \leq 0.25$	$0.25 < EV \leq 0.35$	$0.35 < EV \leq 0.45$	$EV > 0.45$

2. Ecological contribution rate of land use function transformation

The ecological contribution rate of land use function transformation refers to a certain type of land use change resulting from the change in the regional ecological quality. By calculating the ecological contribution rate of land use transformation, we can demonstrate the main type of the land ues transformation, which causes the increase or decrease [50], which can be expressed as follows:

$$LEI = (LE_{t+1} - LE_t) LA/TA \tag{3}$$

In Equation (3), LEI is the ecological contribution rate of land use function transformation. LE_{t+1} and LE_t are the ecological quality index of the land use types at the beginning and end of the change, respectively, reflected by a certain land use change type. LA is the area of the change type; TA is the total area of the region.

2.2.4. Geographical Detector

Geographical detectors are a statistical tool that is used to detect the spatial differentiation of geographical phenomena and explain their driving forces [51]. The term was proposed by Wang Jingfeng [52]. In this study, we used the factor and interaction detection modules of a geographic detector to identify the main driving forces that affect the regional eco-environmental quality, and at the same time, try to explore the driving mechanism that affects the eco-environmental quality of Qinghai Province.

2.3. Data Sources and Pre-Processing

2.3.1. Data Sources

In this study, we used the six periods land use data of Qinghai Province for the years 1980, 1990, 2000, 2010, 2015, and 2020 at 30 m × 30 m spatial resolution. The digital elevation model (DEM) image data at 30 m spatial resolution and the datasets of the spatial differences of the precipitation and mean temperature of Qinghai were obtained from the Data Centre for Resources and Environmental Sciences, Chinese Academy of Sciences (https://www.resdc.cn, accessed on 3 March 2022). We used the human–computer interactive visual interpretation method, which was based on the data from Landsat multispectral scanner system (MSS), thematic mapper/enhanced thematic mapper (TM/ETM), and Landsat8, which was used to interpret the data. The comprehensive interpretation accuracy of the method was not less than 90% and could thus meet the needs of this study. We used ArcGIS to extract the elevation, slope, and relief from the DEM data. The socio-economic data were collected from the Qinghai Statistical Yearbook and National Economic and Social Development Statistical Bulletin of each city, county, and district.

2.3.2. Selection of Indexes

The evolution of regional ecological environmental governance is determined by several factors. Natural conditions determine the basis of eco-environmental quality, but socio-economic factors are also important to change the regional eco-environmental quality [16,53]. To explore the driving forces and evolutionary mechanism of the eco-environmental quality in Qinghai Province, we selected 10 indicators on the basis of the natural conditions and socio-economic influences of the region (Table 3).

Table 3. The serial number and name of each factor.

Number	X_1	X_2	X_3	X_4	X_5
Name	Altitude	Slope direction	Relief amplitude	Annual average temperature	Annual average precipitation
Number	X_6	X_7	X_8	X_9	X_{10}
Name	Year-end total population	Population density	GDP	Non-Agricultural proportion	Road network density

GDP: gross domestic product.

3. Results

3.1. Overall Characteristics of Changes in Territorial Spatial Pattern

3.1.1. Horizontal Regional Differentiation of Territorial Spatial Pattern

Qinghai Province has obvious regional differentiation in territorial space level, portraying a strong agglomeration of the production and living spaces and the dominance of ecological spaces. In 2020, the proportion of production, living, and ecological spaces in the total area of Qinghai Province was 1.29, 0.13, and 98.57%, respectively. The production and living spaces are mainly concentrated in the eastern part of Qinghai (Xining City, Haidong City, south-eastern part of the Haibei Tibetan autonomous prefecture, Hainan Tibetan autonomous prefecture, and south-eastern part of the Haixi Mongolian Tibetan autonomous prefecture) having the largest proportion of ecological spaces that are mainly distributed in central and western Qinghai.

From the perspective of the spatial distribution of second-class places, the urban living spaces (ULS) and rural living spaces (RLS) in Qinghai Province are small and concentrated, and their spatial distribution is similar to those of agricultural production space (APS) and industrial production space (IPS). Grassland ecology space (GES) and other ecology space (OES) were the most widely distributed spaces. Notably, the GES were mainly distributed in the Haidong region and Qinghai-Tibet Plateau. The OES were mainly distributed in the Qaidam basin. The forestland ecological space (FES) is mainly distributed in the eastern margin of the Qinghai and Kunlun Mountains. The water ecological space (WES) is distributed in the whole region, but more concentrated in the western Qinghai-Tibet Plateau (upstream of the Three-River Headwaters region).

3.1.2. Difference in Vertical Gradient of Territorial Spatial Pattern

The vertical gradient differentiation of territorial space in Qinghai Province was obvious (Figure 2). The widest and narrowest areas of the territorial space were located in areas having altitudes of 4500–5000 m and >5000 m, respectively. The area of the production and living spaces was inversely proportional to the altitude. There was no distribution of the production and living spaces above the altitude of 5000 m. The maximum area of the production and living spaces was at altitudes above 3000 m (5670.01 km^2 and 689.23 km^2, respectively). The ecological spaces fluctuated with the increase in the altitude; the maximum area of ecological spaces (205,502.94 km^2) occurred at the altitude of 4500–5000 m above sea level.

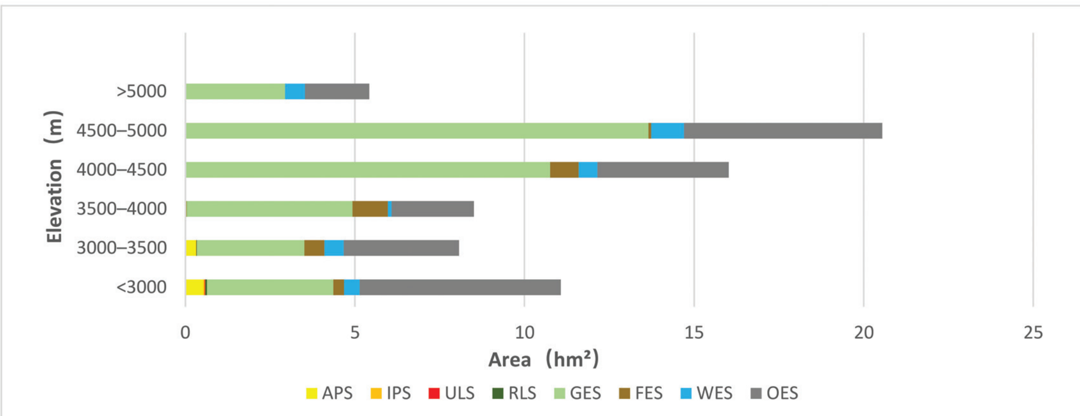

Figure 2. Distribution of PLE space at different altitudes in Qinghai Province, China.

In terms of the spatial distribution of second-level land classes, the land areas of the APS, IPS, ULS, and RLS portrayed a decreasing trend with increasing altitude. Notably, the maximum numbers of APS, IPS, ULS, and RLS all appeared in the areas having altitude less than 3000 m. The areas of GES and OES portrayed a trend of initial decrease, followed by an increase. This was followed by a decrease with increasing elevation; notably, the maximum numbers of GES and OES appeared at altitudes of 4500–5000 m and <3000 m, respectively. The FES portrayed an initial increasing trend with increasing elevation, followed by a decreasing trend; the maximum number appeared at an elevation of 3500–4000 m above the sea level. The WES area portrayed a trend of fluctuation; the maximum number of WES occurred at an altitude of 4500–5000 m.

3.2. Characteristics of Changes in Spatio-Temporal Patterns of Territorial Space

From 1980 to 2020, the territorial space of Qinghai Province in the horizontal region portrayed the pattern characteristics of increasing production and living spaces and shrinking ecological spaces (Table 4). The area of production spaces increased from 8051.18 km^2 in 1980 to 9262.22 km^2 in 2020. The area of living spaces increased from 650.16 km^2 in 1980 to 948.06 km^2 in 2020. However, the area of ecological land decreased from 687,965.40 km^2 in 1980 to 686,457.57 km^2 in 2020.

Table 4. Structural changes of production-living-ecological space types in Qinghai Province from 1980–2020 (km^2/%).

Space Type	Secondary Space Type	1980		1990		2000		2010		2015		2020	
		Area	Scale	Area	Scale	Area	Scale	Area	Scale	Area	Scale	Area	Scale
PS	APS	7849.59	1.12	7982.88	1.14	8245.08	1.18	8571.28	1.23	8523.68	1.22	8604.42	1.24
	IPS	201.59	0.03	265.75	0.04	308.19	0.04	762.41	0.11	1065.99	0.15	657.80	0.09
LS	ULS	106.39	0.02	111.64	0.02	129.43	0.02	178.79	0.03	193.70	0.03	262.41	0.04
	RLS	543.77	0.08	544.59	0.08	569.82	0.08	614.85	0.09	681.54	0.10	685.65	0.10
ES	GES	373,144.71	53.56	372,763.25	53.51	372,329.20	53.44	392,372.13	56.32	392,205.73	56.30	391,414.40	56.18
	FES	28,718.82	4.12	28,724.06	4.12	28,709.43	4.12	28,563.01	4.10	28,585.00	4.10	28,540.55	4.10
	WES	27,436.21	3.94	27,434.20	3.94	27,292.10	3.92	29,749.50	4.27	30,055.67	4.32	32,700.94	4.69
	OES	258,665.66	37.13	258,840.37	37.15	259,083.43	37.20	235,855.88	33.85	235,356.54	33.78	233,801.68	33.56
Space Type	**Secondary Space Type**	**1980–1990**		**1990–2000**		**2000–2010**		**2010–2015**		**2015–2020**		**1980–2020**	
		Area Change	**Change Rate**	**Area Change**	**Change Rate**	**Area Change**	**Change Rate**	**Area Change**	**Change Rate**	**Area Change**	**Change Rate**	**Area Change**	**Change Rate**
PS	APS	133.29	0.17	262.20	0.33	326.20	0.40	−47.60	−0.11	80.74	−0.19	754.83	0.24
	IPS	64.16	3.18	42.44	1.60	454.22	14.74	303.58	7.96	−408.19	7.66	456.21	5.66
LS	ULS	5.25	0.49	17.79	1.59	49.36	3.81	14.91	1.67	68.71	−7.09	156.02	3.67
	RLS	0.82	0.02	25.23	0.46	45.03	0.79	66.69	2.17	4.11	−0.12	141.88	0.65
ES	GES	−381.46	−0.01	−434.05	−0.01	20,042.93	0.54	−166.40	−0.01	−791.33	0.04	18,269.69	0.12
	FES	5.24	0.002	−14.63	−0.01	−146.42	−0.05	21.99	0.02	−44.45	0.03	−178.27	−0.02
	WES	−2.01	−0.001	−142.10	−0.05	2457.40	0.90	306.17	0.21	2645.27	−1.76	5264.73	0.48
	OES	174.71	0.01	243.06	0.01	−23,227.55	−0.90	−499.34	−0.04	−1554.86	0.13	−24,863.98	−0.24

From the perspective of the change degree of the secondary spatial structure (Figure 3), the proportion of the secondary spatial area in Qinghai Province in 2020 (from large to small) was: GES > OES > WES > FES > APS > RLS > IPS > ULS. In addition to the decrease in the FES and OES ratio (the areas decreased by 178.27 and 24863.98 km^2, respectively), the APS, IPS, ULS, RLS, GES, and WES increased significantly (754.83, 456.21, 156.02, 141.88, 18269.69, and 5264.73 km^2, respectively). The ULS and RLS areas portrayed an increasing trend; the GES and WES portrayed an initially increasing trend followed by a decreasing trend. The APS area portrayed a trend of fluctuation, IPS and OES portrayed an initial increasing followed by a decreasing trend, and FES portrayed a trend of a small drop.

Based on the change rate of the secondary spatial structure in Qinghai Province, we could deduce that, during 1980–2020, the growth rates of the areas of the IPS, ULS, and RLS were 5.66, 3.67, and 0.65%, respectively, while those of the FES and OES portrayed a decreasing trend (−0.02 and −0.24%, respectively).

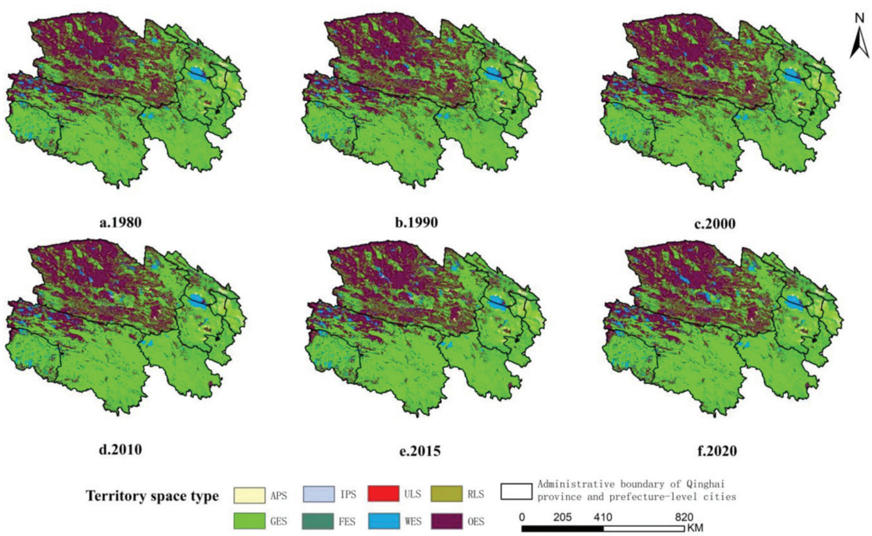

Figure 3. Territorial spatial pattern from the perspective of Production-Living-Ecological space for the years (**a**) 1980; (**b**) 1990; (**c**) 2000; (**d**) 2010; (**e**) 2015; (**f**) 2020.

3.3. Spatial-Temporal Transformation Characteristics of Land Use Types in Territorial Space in Qinghai

During 1980–1990, the area transformed from GES was the largest (453.49 km^2), accounting for 39.62% of the total area transformed (Figure 4a), among which 42.32% was converted into APS, 38.39% into OES, and 19.12% into other spaces. The total area of all the types of spaces converted to GES was only 72.03 km^2, and thus the total area of GES decreased.

From 1990 to 2000, the number of GES areas transferred to other spaces was the largest (which was 897.11 km^2), accounting for 49.46% of the total converted area (Figure 4b), among which 40.46% was converted to OES, 31.85% to APS, and 27.68% to other spaces. However, the area of various spaces converted to GES was only 463.08 km^2, and thus, the total area of GES continued to decline.

From 2000 to 2010, the area of OES converted to other spaces was the largest (28,669.66 km^2), accounting for 79.09% of the total amount (Figure 4c), among which 90.57% was converted into GES, 8.14% into WES, and 1.29% into other spaces. The area of all the types of space converted to OES was only 5441.88 km^2. Notably, compared with the previous 20 years, the total area of the OES decreased, whereas that of GES increased.

During 2010–2015, the area of OES converted to other spaces was 1585.31 km^2, accounting for 43.20% of the total amount (Figure 4d), among which 44.28% of OES was converted to WES, 38.37% to GES, and 16.85% to other spaces. The area of all types of space was converted to 1085.79 km^2, and the total area of OES continued to decrease.

From 2015 to 2020, the area of OES converted to other spaces was 3407.57 km^2, accounting for 41.19% of the total amount (Figure 4e), of which 62.58% was converted to WES, 31.28% to GES, and 6.15% to other spaces. The total area converted to OES was only 1866.97 km^2; notably, the total area of OES continued to decrease during this period.

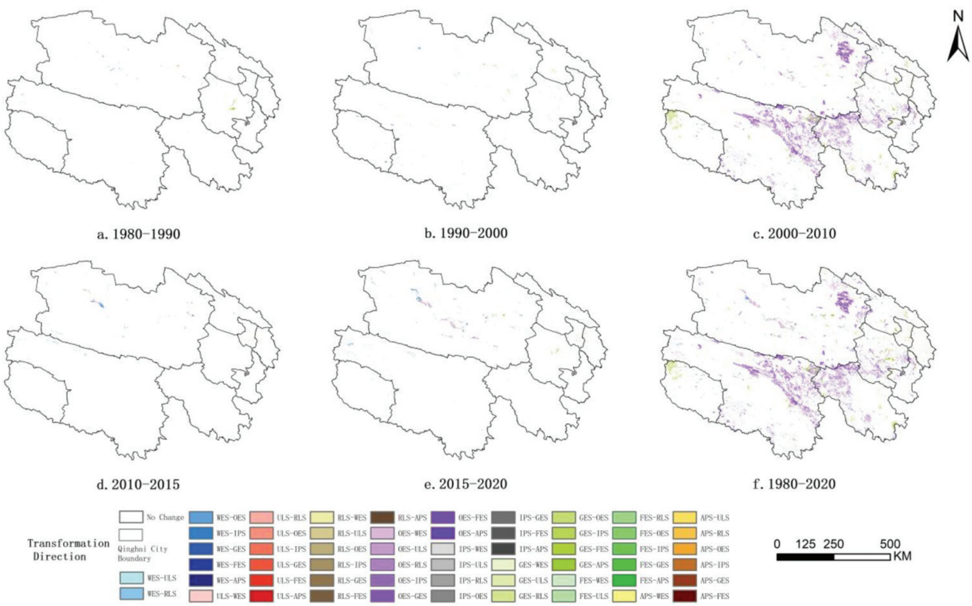

Figure 4. Spatial distribution of territorial space changes in Qinghai Province from 1980 to 2020.

3.4. Comprehensive Quality of the Ecological Environment

3.4.1. Spatial-Temporal Evolution Characteristics of Ecological Environment Comprehensive Quality

The overall eco-environmental quality index of Qinghai province for 1980, 1990, 2000, 2010, 2015, and 2020 was 0.2557, 0.2562, 0.2561, 0.2653, 0.2655, and 0.2667, respectively. Except for a slight decrease in 2000, the overall ecological environment portrayed a significant improvement. Additionally, there were significant differences in the ecological and environmental quality grades (Figure 5). The area of high-quality regions continued to increase, whereas that of medium high-quality regions portrayed an initial decrease followed by an increase. The area of high-quality regions was the smallest in each period, accounting for less than 20% of the total area of the study area. Notably, the changes in the medium-quality and low-quality areas portrayed a wave-state potential. The area of medium low-quality regions portrayed an initial increase followed by a decrease, and the area of medium–low- and low-quality regions exceeded 55% of the total area, constituting the main body of eco-environmental quality (Table 5). As shown in Figure 5, the high-quality and the medium–high-quality areas were mainly distributed in the east and northwest of Qinghai. The medium-quality regions were distributed in the south and east of Qinghai and gradually expanded to the north; the low and medium–low-quality areas were distributed in most parts of the north and central Qinghai, but portrayed a decreasing trend.

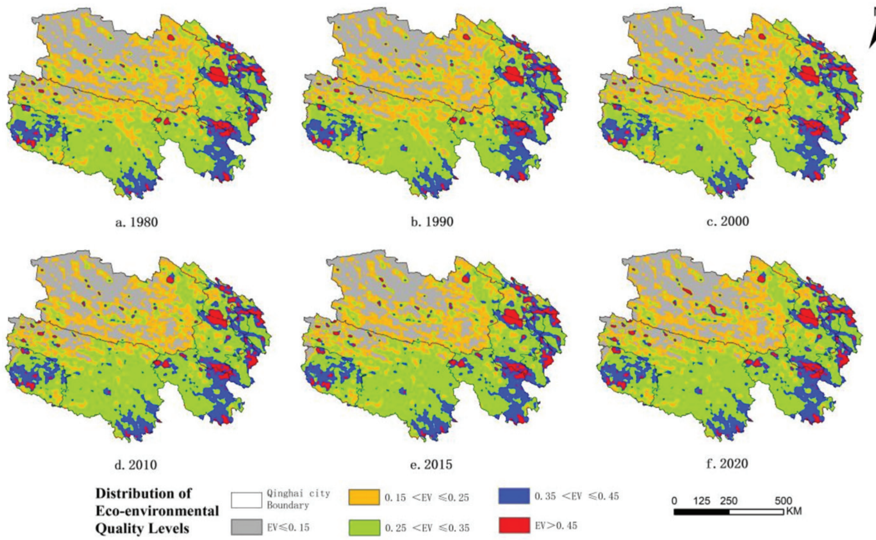

Figure 5. Distribution of eco-environmental quality levels in Qinghai Province from 1980 to 2020.

Table 5. Distribution of ecological environment quality grades of Qinghai (km^2/%).

Level	1980		1990		2000	
	Area	Scale	Area	Scale	Area	Scale
<0.15	165,996	23.83	166,254.66	23.86	166,456.17	23.89
0.15–0.25	15,4681.38	22.20	154,807.65	22.22	155,386.63	22.30
0.25–0.35	255,745.53	36.71	255,276.09	36.64	254,679.48	36.56
0.35–0.45	80,180.28	11.51	80,118.64	11.50	79,888.23	11.47
>0.45	40,067.91	5.75	40,214.16	5.77	40,260.96	5.78
Level	**2010**		**2015**		**2020**	
	Area	**Scale**	**Area**	**Scale**	**Area**	**Scale**
<0.15	156,510.63	22.47	156,629.88	22.48	153,724.32	22.07
0.15–0.25	133,162.01	19.11	132,982.11	19.09	132,836.13	19.07
0.25–0.35	276,066.81	39.63	275,342.31	39.52	275,437.8	39.54
0.35–0.45	88,509.33	12.70	88,748.46	12.74	89,530.61	12.85
>0.45	42,422.76	6.09	42,969.06	6.17	45,142.75	6.48

3.4.2. Main Land Use Conversion Affecting Eco-Environmental Quality

We observed two types of ecological quality trends, namely, improvement and deterioration, which offset each other, ensuring stability. From 1980 to 2020, the trend of ecological environment improvement in Qinghai Province was much higher than that of ecological environment deterioration; notably, the degree of ecological environment improvement continued to increase. As shown in Table 6, the conversion of OES into GES and WES and that of GES into WES and FES were the main factors for environment improvement. The conversion of GES into OES, APS, and IPS, and that of WES into OES and GES, were the main factors for environmental deterioration. The land function types that led to the improvement of the ecological environment were relatively concentrated, and the first seven land function transformations that contributed to the improvement/deterioration of ecological quality accounted for 99.34% and 97.56%, respectively.

Table 6. Major land use transformations influencing ecological environment quality and contribution rates.

1980–2020			
Change Trend	**Land Use Function Transformation**	**Index Movement**	**Contribution Proportion (%)**
Improvement of Eco-environment	OES-GES	0.010699	67.13
	OES-WES	0.003989	25.03
	GES-WES	0.000724	4.54
	GES-FES	0.000260	1.63
	APS-WES	0.000074	0.47
	OES-FES	0.000054	0.34
	IPS-WES	0.000032	0.20
Deterioration of Eco-environment	GES-OES	−0.002535	62.87
	WES-OES	−0.000635	15.75
	FES-GES	−0.000304	7.54
	WES-GES	−0.000183	4.54
	GES-APS	−0.000140	3.47
	GES-IPS	−0.000073	1.82
	FES-OES	−0.000063	1.56

3.5. Driving Force Analysis of Eco-Environmental Quality

The results indicated that the eco-environmental quality of Qinghai province was jointly affected by multiple factors, and different influencing factors had varied effects on the eco-environmental quality of the region (Figure 6). All factors passed the significance test at the 0.05 level, and the factor contribution rate q value was used to measure the impact degree of each factor on the spatial differentiation of the eco-environmental quality of the region ($q \geq 0.100$ was the factor, with a great impact on the eco-environmental quality of the study area). From 1980 to 2020, X5 (0.294), X4 (0.074) and X1 (0.061) contributed more to the natural factors, and X9 (0.223), X10 (0.199), and X8 (0.195) contributed more to the socio-economic factors. In general, socio-economic factors had a greater impact on the quality of the ecological environment.

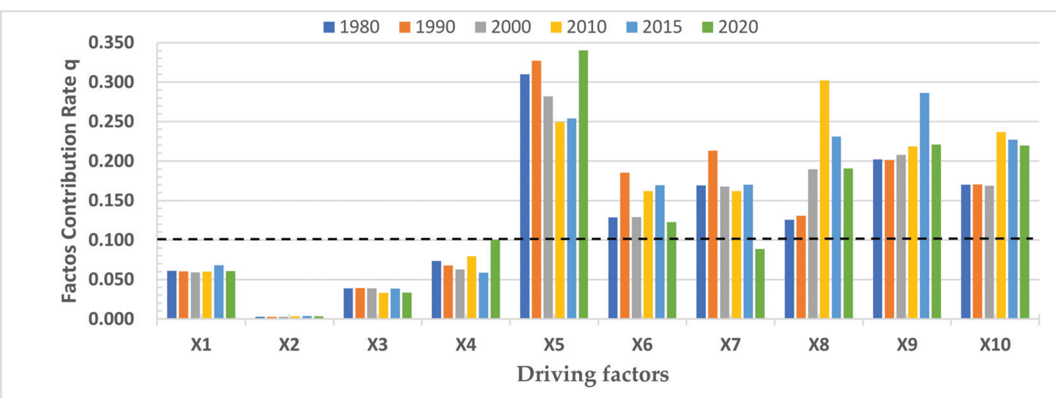

Figure 6. Contribution rates of driving factors for spatial differentiation of eco-environmental quality in Qinghai from 1980 to 2020.

3.5.1. Analysis of Natural Factors

From the perspective of factor interpretation, we analyzed the trends for the following factors: X1 (altitude), X2 (slope direction), X3 (relief amplitude), X4 (annual average temperature) and X5 (annual average precipitation). X1, X2, and X3 had little influence on the eco-environmental quality, and the changes were relatively stable. However, the q values of X1 and X3 in 1980 decreased slightly compared with those in 2020, indicating that the influence of X1 and X3 on the eco-environmental quality of the study area weakened. Compared with 1980, the advantage of q value of X2 in 2020 increased, indicating that the influence of X2 on the eco-environmental quality of the study area gradually enhanced, but its overall influence was less, compared to that of other factors. The influence of the q value of X4 on the ecological and environmental quality fluctuated in different years, but it had a greater impact on the ecological and environmental quality in 2020 (up to 0.1), indicating that the influence on ecological and environmental quality in 2020 strengthened. Finally, X5 had a great impact on the ecological and environmental quality. Although we observed a trend of fluctuation, the q value in each year was greater than 0.25, which indicated that X5 was the main driving force of the ecological and environmental quality. The q value increased from 0.31 to 0.34 from 1980 to 2020, indicating that the influence of X5 on the ecological and environmental quality of the study area increased significantly.

3.5.2. Analysis of Socio-Economic Factors

Additionally, we analyzed the following factors: X6 (year-end total population), X7 (population density), X8 (gross domestic product, GDP), X9 (non-agricultural proportion), and X10 (road network density). From the perspective of factor interpretation, X6–X10 had a great impact on the eco-environmental quality of the study area, which was the main driving force. The impact of X6 and X7 on the ecological environment of the study area fluctuated, but the overall level remained above 0.100, indicating that X6 and X7 had a great impact on the ecological environment of the study area. However, the q value of X7 decreased to 0.089 in 2020, indicating that the influence of X7 on the ecological and environmental quality weakened in 2020. Notably, X8, X9, and X10 portrayed an initial increasing trend, followed by a decreasing trend from 1980 to 2020; however, the values increased to different degrees, compared with 1980, indicating that the influence of X8–X10 on the eco-environmental quality of the study area was increasing.

3.5.3. Human–Natural Coupling Interaction Detection Results

Different factors have different effects on ecological and environmental quality; notably, there are complex interaction relationships among these factors, leading to differences in the magnitude, intensity, and direction of their effects. The interaction between factors may increase the impact on the ecological and environmental quality. From 1980 to 2020, the interaction between the natural and human factors in Qinghai portrayed two modes of non-linear and double factor enhancements; notably, there was no independent or weakening relationship, indicating that the influence of the interaction between the two factors was greater than the influence of each single factor. According to the results of factor detection and interaction detection, X5 and X1 (among natural factors) and X8 and X10 (among socio-economic factors) were the factors that portrayed the greatest influence on human-natural coupling interaction and factor detection (Table 7).

Table 7. The interaction of natural and human factors on the driving force of eco-environmental quality evolution in Qinghai Province.

Year			**1980**					**1990**					**2000**		
Interactive Items and Interaction Value	$X_1 \cap X_6$	$X_1 \cap X_7$	$X_1 \cap X_8$	$X_1 \cap X_9$	$X_1 \cap X_{10}$	$X_1 \cap X_6$	$X_1 \cap X_7$	$X_1 \cap X_8$	$X_1 \cap X_9$	$X_1 \cap X_{10}$	$X_1 \cap X_6$	$X_1 \cap X_7$	$X_1 \cap X_8$	$X_1 \cap X_9$	X1∩X10
	0.215	0.304	0.221	0.314	0.301	0.243	0.332	0.225	0.318	0.300	0.214	0.288	0.309	0.311	0.297
	$X_2 \cap X_6$	$X_2 \cap X_7$	$X_2 \cap X_8$	$X_2 \cap X_9$	$X_2 \cap X_{10}$	$X_2 \cap X_6$	$X_2 \cap X_7$	$X_2 \cap X_8$	X2∩X9	$X_2 \cap X_{10}$	$X_2 \cap X_6$	$X_2 \cap X_7$	$X_2 \cap X_8$	$X_2 \cap X_9$	X2∩X10
	0.132	0.172	0.130	0.205	0.173	0.187	0.216	0.135	0.205	0.173	0.132	0.171	0.193	0.211	0.172
	$X_3 \cap X_6$	$X_3 \cap X_7$	$X_3 \cap X_8$	$X_3 \cap X_9$	$X_3 \cap X_{10}$	$X_3 \cap X_6$	$X_3 \cap X_7$	$X_3 \cap X_8$	X3∩X9	$X_3 \cap X_{10}$	$X_3 \cap X_6$	$X_3 \cap X_7$	$X_3 \cap X_8$	$X_3 \cap X_9$	X3∩X10
	0.153	0.192	0.161	0.234	0.192	0.217	0.249	0.165	0.235	0.192	0.155	0.190	0.221	0.236	0.190
	$X_4 \cap X_6$	$X_4 \cap X_7$	$X_4 \cap X_8$	$X_4 \cap X_9$	$X_4 \cap X_{10}$	$X_4 \cap X_6$	$X_4 \cap X_7$	$X_4 \cap X_8$	X4∩X9	$X_4 \cap X_{10}$	$X_4 \cap X_6$	$X_4 \cap X_7$	$X_4 \cap X_8$	$X_4 \cap X_9$	X4∩X10
	0.212	0.268	0.230	0.331	0.268	0.249	0.349	0.233	0.329	0.265	0.202	0.255	0.317	0.326	0.259
	$X_5 \cap X_6$	$X_5 \cap X_7$	$X_5 \cap X_8$	$X_5 \cap X_9$	$X_5 \cap X_{10}$	$X_5 \cap X_6$	$X_5 \cap X_7$	$X_5 \cap X_8$	X5∩X9	$X_5 \cap X_{10}$	$X_5 \cap X_6$	$X_5 \cap X_7$	$X_5 \cap X_8$	$X_5 \cap X_9$	X5∩X10
	0.363	0.389	0.349	0.364	0.386	0.377	0.351	0.348	0.355	0.361	0.347	0.361	0.350	0.358	0.362
Year			**2010**					**2015**					**2020**		
Interactive Items and Interaction Value	$X_1 \cap X_6$	$X_1 \cap X_7$	$X_1 \cap X_8$	$X_1 \cap$X9	X1$\cap X_{10}$	X1$\cap X_6$	$X_1 \cap X_7$	$X_1 \cap X_8$	$X_1 \cap X_9$	$X_1 \cap X_{10}$	$X_1 \cap X_6$	$X_1 \cap X_7$	$X_1 \cap X_8$	$X_1 \cap X_9$	X1∩X10
	0.286	0.286	0.360	0.311	0.328	0.310	0.302	0.345	0.337	0.344	0.219	0.245	0.290	0.315	0.333
	$X_2 \cap X_6$	$X_2 \cap X_7$	$X_2 \cap X_8$	$X_2 \cap X_9$	$X_2 \cap X_{10}$	$X_2 \cap X_6$	$X_2 \cap X_7$	$X_2 \cap X_8$	$X_2 \cap X_9$	$X_2 \cap X_{10}$	$X_2 \cap X_6$	$X_2 \cap X_7$	$X_2 \cap X_8$	$X_2 \cap X_9$	X2∩X10
	0.166	0.166	0.304	0.223	0.240	0.173	0.174	0.235	0.289	0.231	0.127	0.093	0.195	0.225	0.223
	$X_3 \cap X_6$	$X_3 \cap X_7$	$X_3 \cap X_8$	$X_3 \cap X_9$	$X_3 \cap X_{10}$	$X_3 \cap X_6$	$X_3 \cap X_7$	X3$\cap X_8$	$X_3 \cap X_9$	$X_3 \cap X_{10}$	$X_3 \cap X_6$	$X_3 \cap X_7$	$X_3 \cap X_8$	$X_3 \cap X_9$	X3∩X10
	0.180	0.181	0.323	0.240	0.261	0.191	0.194	0.255	0.315	0.252	0.146	0.118	0.212	0.244	0.243
	$X_4 \cap X_6$	$X_4 \cap X_7$	$X_4 \cap X_8$	$X_4 \cap X_9$	$X_4 \cap X_{10}$	$X_4 \cap X_6$	$X_4 \cap X_7$	X4$\cap X_8$	$X_4 \cap X_9$	$X_4 \cap X_{10}$	$X_4 \cap X_6$	$X_4 \cap X_7$	$X_4 \cap X_8$	$X_4 \cap X_9$	X4∩X10
	0.255	0.256	0.384	0.328	0.356	0.275	0.272	0.346	0.360	0.335	0.221	0.227	0.295	0.326	0.339
	$X_5 \cap X_6$	$X_5 \cap X_7$	$X_5 \cap X_8$	$X_5 \cap X_9$	$X_5 \cap X_{10}$	$X_5 \cap X_6$	$X_5 \cap X_7$	$X_5 \cap X_8$	$X_5 \cap X_9$	$X_5 \cap X_{10}$	$X_5 \cap X_6$	$X_5 \cap X_7$	$X_5 \cap X_8$	$X_5 \cap X_9$	X5∩X10
	0.323	0.324	0.354	0.322	0.335	0.302	0.296	0.327	0.388	0.332	0.360	0.359	0.357	0.367	0.358

4. Discussion

Territorial space is an important carrier of regional human activities and ecological environments. The interaction between people and the natural environment in territorial space changes the function of regional territorial spaces and shapes the production, activity, and ecological spaces through the changes in the land use types in a region [32,54]. In 1999, the European Spatial Development Perspective (ESDP) clearly stated that spatial planning can promote sustainable and balanced development among regions [55]. As an effective means for the construction of ecological civilization and spatial planning, PLE space is classified on the basis of different utilization functions of territorial space to optimize the development pattern, control the development intensity, and adjust the spatial structure of territorial space [39,56]. In this study, we used the PLE functional space classification to merge and classify the land use spatial data, which accounted for the lack of the consideration of the ecological function in land use classification, and realized the connection between land function and land use classifications. Therefore, this method is widely used in land function regulation, determining the eco–environment effects, and other related fields [57–59].

According to relevant studies, the rapid development of social economy and urbanization is accompanied by the deterioration of eco-environmental quality to a certain extent [25,60,61]. This degradation is usually caused by the change of territorial spatial patterns due to land use transformation (Figure 7). Qinghai Province is located inland of north-west China, and most of its areas are restricted development zones (areas with weak resource and environment carrying capacities, with poor conditions for large-scale ag-glomeration of economy and population, but related to ecological security in a large area of the country) [62,63]. The causes of eco-environmental quality changes in Qinghai Province are consistent with those in regions and cities with rapid economic development and high urbanization rate in China, such as Yellow River Delta, Beijing-Tianjin-Hebei region, Yangtze River delta economic zone, etc. It is mainly due to economic expansion and urban occupation of ecological space that APS and ecological land are converted into ULS and RLS in territorial space. However, because most of the area in Qinghai is a restricted development zone, it also has a certain comprehensiveness and complexity, for example, unfavourable ecological space maintenance leads to grassland and forestland degradation and wetland atrophy.

The change of ecological environment quality reflects the interaction between natural environment and human society in territorial space, and its change is complex and dynamic. Such changes are caused by the natural constraints force provided by natural factors, the human driving force provided by socioeconomic factors, and the coupling interaction force between humans and nature. The effect of natural factors on the change of eco-environment quality is smaller than that of socioeconomic factors, but it creates the basic conditions of ecological environment quality. Socioeconomic factors have a more direct impact on eco-environmental quality and play a leading role in the change of it. The human-nature coupling interaction force has a strengthening effect on the eco-environment quality, which is often accompanied by a guiding and decision-making power. Guiding and decision-making power refer to the influence of local political environment [25]. The direction and speed of the evolution of territorial spatial pattern and eco-environment quality are determined by the joint participation of these forces.

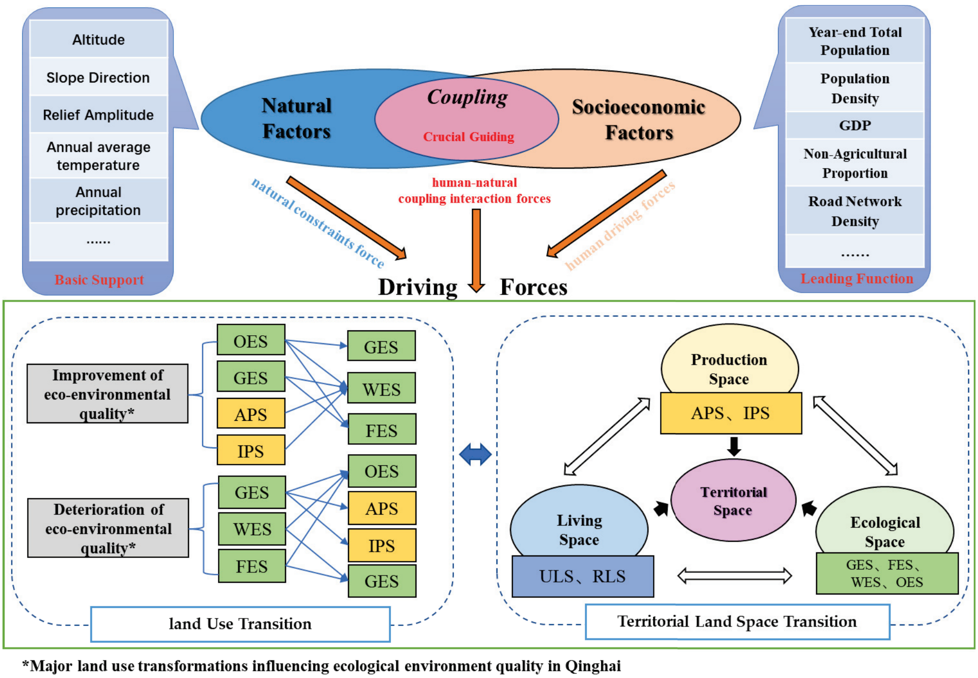

Figure 7. Mechanism of eco-environmental quality change under territorial spatial evolution in Qinghai.

4.1. Natural Factors Are the Natural Constraints Force Affecting the Eco-Environment Quality

Due to the characteristics of natural environments, the territorial space of Qinghai Province portrayed significant horizontal regional differentiation and vertical gradient differences. Simultaneously, due to the characteristics of small population density and the relatively concentrated population, the territorial spatial pattern indicated the characteristics of relative agglomeration of the production and living spaces and absolute dominance of ecological spaces. The production and living spaces portrayed significant convergences and were mainly distributed in Qinghai city (prefecture) in the county administrative centre. The eco-environmental quality of Qinghai Province portrayed an overall steady increase, but due to the fragile ecological environment, although the high-quality areas expanded, the overall area remained small. The low-quality area and the low-medium quality area continued to shrink, but the proportion of the areas were still large, indicating that the eco-environmental quality needed to be improved further.

4.2. Socioeconomic Factors Are the Human Driving Forces Affecting Eco-Environment Quality

From 1980 to 2020, the living space continued to expand due to urbanization and population growth, and the growth range and speed of the ULS was much greater than that of RLS in Qinghai. Both the production and ecological spaces portrayed fluctuations. The former space increased, while the latter slightly decreased. The eco-environmental quality of Qinghai Province portrayed an overall steady increase, albeit a slight decrease in 2000; this was partly because the eco-logical civilization concept was in its infancy stage in China and because in 1992, China officially proposed to establish the goal of the socialist market economy, which resulted from the people expecting high economic benefits, with little consideration for the protection of the ecological environment.

4.3. Human-Nature Coupling Interaction Force Are the Crucial Guiding Forces Affecting Eco-Environment Quality

At the national level, in terms of the vast spatial areas of Qinghai Province, the topography is generally complex; notably, the region is also one of the multi-ethnic populated provinces in mainland China and has a unique natural geographic and socio-economic structure. Relevant national policies, such as Western development, returning farmland to forest (grass-land), ecological civilization construction and high-quality development of the Yellow River Basin, all have a significant impact on socioeconomic factors by combining the characteristics of regional natural environment and form a crucial guiding force for the change of eco-environment quality. The increase in the production space from 1980 to 2000 was mainly caused by crowding out the GES, which led to the continuous decline of GES during this period. At the beginning of the 21st century, China put forward the construction of ecological civilization, and with the vigorous promotion of ecological civilization construction, the ecological spaces of grassland, woodland, and water area improved to different degrees, through the conversion of other ecological spaces (unused land). Qinghai Province is located in the upper reaches of the Yellow River, and its location has important political, ecological, economic and social significance. The implementation of relevant regional policies makes Qinghai's overall environmental quality portray a continuous upward trend. Additionally, we observed non-linear enhancement and double enhancement effects among the factors, indicating that human-nature coupling interaction force are the crucial guiding forces affecting eco-environment quality.

5. Conclusions

Based on the "PLE" spatial classification, we employed the land transfer matrix, eco-environmental quality index, and ecological contribution rate of land use transformation to quantitatively analyze the changes of territorial spatial pattern and eco-environmental effects in Qinghai Province, and used geographic detectors to explain the driving forces of eco-environmental quality evolution. (1) the spatial distribution of the province was characterized by the relative agglomeration of the production and living spaces and the absolute dominance of ecological spaces. It shows that there is a trend of expansion of production and living space and contraction of ecological space. (2) The eco-environmental quality of the region portrayed a steady improvement, with a significant reduction in the medium–low and low-quality areas. Spatially, the medium quality areas are mainly distributed in most of Haixi Prefecture, while the high-quality and medium-high-quality Area areas are mainly distributed in the eastern part of Qinghai and the southern part of Three Rivers Source region. (3) The annual average precipitation, proportion of non-agricultural area, and socio-economic factors had a significant impact on the eco-environmental quality of the region; meanwhile, national economy and ecological policies are important indirect driving forces of eco-environmental quality. Although the influence of natural factors on the eco-environmental quality of Qinghai Province is less than that of human factors, the support and constraint of natural geographical basis on the ecological environment cannot be ignored. Additionally, we observed non-linear enhancement and double enhancement effects among the factors, indicating that the human-nature coupling interaction force had a strengthening effect on the changes in the eco-environmental quality.

In the future development of Qinghai province, the key to the continuous improvement of ecological environment quality in the area are to optimize the layout of the PLE spaces, construct a reasonable territorial space protection pattern, and promote the sustainable development of human-natural coupling.

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Article

The Analysis of Family Farm Efficiency and Its Influencing Factors: Evidence from Rural China

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Abstract: Improving the efficiency of family farms is of great significance to rural revitalization and agricultural modernization in China. In order to find out the development status and shortcomings of family farms in China, and put forward targeted policy recommendations to improve the efficiency of various family farms, this paper applies the DEA model to measure the efficiency of family farms from a micro perspective by using the field survey data of the national family farm demonstration bases of Wuhan and Langxi, China. In addition, the Tobit model is further applied to explore the factors that affect the efficiency of full sample family farms, as well as to compare and analyze the differences in the efficiency in different regions and of different operation types. The results show that the efficiency of family farms is low, the efficiency of family farms in Wuhan is higher than that in Langxi, and the efficiency of breeding family farms is higher than that of planting family farms and mixed family farms. Capital input, farmers' education level, market channels, brand registration, fertilizer usage and financial credit have positively affected the efficiency of family farms, while government subsidies and natural disasters have had negative effects on it. Specially, the land operating area shows a U-shaped relationship with farm efficiency. The efficiency of planting family farms is positively affected by labor input, while that of breeding and mixed family farms rely more on capital input and financial credit instead.

Keywords: family farm; efficiency; DEA model; Tobit model; farm operation; influencing factors

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1. Introduction

The traditional production of small farmers in rural China has led to low agricultural production efficiency. In order to improve the efficiency of agricultural production, boost rural economy and achieve agricultural modernization in China, the Chinese government has been attaching great importance to encouraging the development of new agricultural operating entities, such as family farms. The Ministry of Agriculture issued the "Guiding Opinions on Promoting the Development of Family Farms" document in 2014, stating that the family farm mode is conducive to form moderate scale operations, which has played an important role in developing modern agriculture; therefore, it is of great importance to develop family farms in China. Subsequently, the No. 1 Central Documents, from 2015 to 2017, stipulated a series of measures to support the development of new agricultural operating entities, which created a nice social environment for the founding and developing of family farms. In 2019, the General Office of the State Council issued the "Opinions on Promoting the Organic Connection of Small Farmers and Modern Agriculture Development", which clearly proposed and clarified a family farm cultivation plan. The "High-Quality Development Plan for New Types of Agricultural Entities and Service Entities (2020–2022)", compiled by the Ministry of Agriculture and Rural Affairs in 2020, set the goal that the number of family farms in China will reach 1 million by 2022.

Under the guidance and support of government policies, the family farms in China have gained initial achievements, the number of which has been increasing every year.

According to data from the Ministry of Agriculture and Rural Affairs of China, the number of family farms in China over quadrupled from about 139,000 in 2014 to 600,000 in 2018. However, although the number of family farms increased by 461,000 households, the growth rate declined year by year after 2015. The chain growth rate of family farms was initially 146.8% in 2015, followed by 29.7% in 2016, further decreased to 23.4% in 2017, and eventually fell to 9.29% in 2018. Another characteristic that should not be ignored is that most family farms in China are in a single type of planting or breeding operation. Among all family farms existing in any year between 2014–2018, the planting family farms account for the largest proportion, followed by breeding family farms. For example, in 2018, the planting, breeding, fishery, planting and breeding, and other types of family farms accounted for 62.7%, 17.8%, 5.3%, 11.6% and 2.6%, respectively, and similar distributions can be observed in other years.

Although we have witnessed an initial development of family farms in China, we have to admit that the total number of family farms is still minor. According to the data of the third agricultural census for China, the number of family farms only accounts for 0.2% of China's agricultural total households. In comparison to the traditional Chinese small farms, family farms have the characteristics of family-based production unit and scale operation [1], and they have been proved to be the most efficient mode in current agricultural production [2,3]. Therefore, it is of great significance to figure out how to improve the efficiency of family farms so as to maximize their functions in driving agricultural economic development. In order to promote the development of family farms, we have to answer the following questions: what is the actual operating efficiency of family farms in China? What are the factors that affect the efficiency of family farms? What are the differences in the efficiency and the influencing factors of family farms in different regions and different operation types?

1.1. Literature Review and Research Hypothesis

1.1.1. Family Farm Efficiency

Scholars have conducted a great amount of research on the efficiency of family farms. Many scholars confirmed that, through empirical analysis, the efficiency of family farms in China is not high [4–7], and the conclusions drawn from the decomposition of pure technical efficiency and scale efficiency varies. Qian and Li [4] conducted a DEA measurement and analysis of the efficiency of different types of family farms in Songjiang, Shanghai; they found that the efficiency of family farms is not high at 0.3841, and planting-and-breeding family farms have the highest efficiency compared to pure-grain-planting family farms and machine-farming family farms. Han et al. [5] argued that there are many DEA ineffectiveness units in 62 households of fruit-and-vegetable family farms in Zhejiang Province, and the average pure technical efficiency is greater than their scale efficiency. Li et al. [6] calculated that the technical efficiency of 234 family farms in Shandong Province was only 0.170, and the low value was attributed to the relatively insufficient pure technical efficiency rather than scale efficiency. The planting-and-breeding family farms had the highest efficiency, while pure-planting family farms were the least efficient. The research of Gao et al. [8] proved that the technical efficiency of family farms depends more on scale efficiency, while the pure technical efficiency is low.

Hypothesis 1 (H1). *The efficiency of family farms in China is low.*

1.1.2. Factors Affecting the Efficiency of Family Farms

Regarding the factors that affect the efficiency of family farms, various scholars have asserted that agricultural factor inputs, farmers' characteristics, family farm operation characteristics and external factors may all affect the efficiency of family farms. Agricultural factor inputs refer to those basic elements that must be put into agriculture production to produce agricultural products, such as land, labor and capital. Farmers' characteristics are the farmers' personal characteristics, for example, the farmer's age, education level, training skills and farming experience. Family farm operation characteristics include family farm internal operating situations, for example, the regulations, market channels, technology adoption and brand registration. External factors refer to those environmental factors, such as the policy, credit support and disasters.

Zhang and Liu [9] believed that problems, such as over-scale, lack of labor, high production costs and single operating structure, lead to the lack of family farm efficiency. In Bangladesh, Peru and Thailand, farm scale and agricultural productivity are positively correlated [10]. However, some scholars concluded that the land operation area of family farms being overlarge can reduce their efficiencies [11,12], while others found that there seems to be an inverted U-shaped relationship between family farm efficiency and its land scale [4,13]. The inverted U-shaped relationship implies that the relationship between the land scale and the efficiency of family farms is not linearly correlated, either positively or negatively. With the expansion of land scale, the efficiency of family farms first increased because the full utilization of machines could create economics of scale, and then decreased after an optimal scale, forming an inverted U-shape. The education and skill level of the farmers [14–16], investment scale, agricultural machinery subsidies and agricultural insurance positively affect the operating efficiency of family farms, while the number of laborers, the cost of land transfer, agricultural machinery and credit funds show a negative correlation with it [8]. Kong and Zheng [17] asserted that agricultural subsidies can bring stable income expectations to farmers, thus positively affecting the efficiency of family farms, in contrast to researches by Zhu and Lansink [18] and Chen [19], which pointed out that agricultural subsidies would cause efficiency lost. It is also concluded that a fair external information environment and a perfect credit system [20] can promote the development of family farms, and the improvement of family farm efficiency requires external support from credit funds [21].

Hypothesis 2 (H2). *Factors that influence the efficiency of family farms vary by types and regions.*

In summary, most of the research objects in existing literatures are family farms in a certain area or of a certain type; comparative researches on family farms in different regions and of different operating types still need to be supplemented. Furthermore, most articles about the measurement and analysis of family farm efficiency focus on the comprehensive technical efficiency, which seldom decompose it and analyze its influencing factors. Based on the analysis of the literature reviews and their limitations, this paper uses the field survey data of two family farm demonstration bases in China as the research sample, and divides them into three categories, pure planting, pure breeding and mixed family farms, according to the type of operation, so that the family farms in different regions and of different operation types can be compared. In addition, this paper measures and decomposes the efficiency of family farms and analyzes its influencing factors. Through comparisons and analysis, this paper aims to find out the shortcomings of family farms in different regions and types, and put forward targeted policy recommendations to promote the efficiency of various family farms.

1.2. Contributions and Limitations

The contributions of this paper are as follows:

1. We conducted a field investigation of all family farms registered in Hubei Wuhan and Anhui Langxi family farm demonstration bases, and obtained full samples of those family farms in 2016 as our research samples, which not only reflects the actual operating situation of family farms in two areas, but also avoids information loss and bias that may exist in sampling surveys.
2. Unlike many papers that only use single dimensional economic indicators, such as the income or profit of family farms to evaluate the development situation of family farms, we measured the efficiency of family farms through a DEA model, the result of which reflects family farms' operating status more accurately and comprehensively,

for it covers as many input and output variables as possible that actually occurred in their agricultural production and operation in 2016.

3. In our paper, we not only analyze the possible influencing factors on full sample family farms' efficiency, but also compare the effect differences on family farms in different regions and of different operation types, which would be very helpful to promote the development of various family farms by applying targeted policies.

However, we admit that this paper has the following limitations:

1. We use a cross-sectional field survey data from 2016, which can only present the development status of family farms at that time, but cannot reflect the dynamic changes of family farms, especially after the COVID-19 pandemic, whereby the development situation of the local family farms may have changed.
2. There are a total of five family farm demonstration bases in China, namely, Shanghai Songjiang, Zhejiang Ningbo, Hubei Wuhan, Jilin Yanbian, and Anhui Langxi, but we only conduct a field investigation of two of them, which fails to compare all family farms in China more comprehensively.

2. Research Sample and Methods

2.1. Research Data

In order to guide the orderly development of local family farms, the Ministry of Agriculture summarized five development modes—Shanghai Songjiang, Zhejiang Ningbo, Hubei Wuhan, Jilin Yanbian, and Anhui Langxi—as typical modes for promotion, among which, the "Hubei Wuhan mode" is the typical example of suburban agriculture serving urban development under the background of the cities' industrialization and urbanization, and the "Anhui Langxi mode" is the representative of agricultural scale transformation in underdeveloped areas after the outflow of laborers, so that they have strong representation across China [22].

The emergence and development of family farms in Hubei Wuhan is closely related to the development of the agricultural product market. As a mega city, Wuhan has had a great and stable demand for agricultural products, resulting in the rise in suburban agriculture. Since the 1990s, under the context of Wuhan's accelerated industrialization and urbanization, some suburban farmers in Wuhan abandoned their farmland and intended to seek well-paid jobs in the urban city. Other farmers took the opportunity to rent contracted land from those farmers who had abandoned farmland, and engaged in vegetable planting and aquaculture; thus, a group of large professional planting and breeding households gradually formed, which is also the prototype of family farms. On the basis of the farms' self-development in the suburbs of Wuhan, the government became involved in time to promote the standardization of the land transfer market. In 2009, the Wuhan government launched a pilot project of developing family farms, and five municipal-level family farms were established. After that, a series of policies were introduced to support the development of family farms, contributing to the formation of the mature Hubei Wuhan family farm development mode. The biggest feature of the Hubei Wuhan mode is that the operating scope of family farms is in line with the needs of urban residents, including vegetables, aquatic products, melons and fruits, livestock and poultry, and other agricultural products, and there is a trend of diversification as people's consumption increases.

The generation of family farms in Anhui Langxi is closely related to industrialization and urbanization. In the early 1990s, with the accelerated development of some industrial cities in the Yangtze River Delta, a growing number of farmers in Langxi chose to work in these cities, leaving their farm land abandoned or for their relatives and friends for farming. In 2001, a farmer in Langxi took the opportunity to rent in more than 100 mu (Mu, a unit of area in China $\approx$ 0.1647 acre) of abandoned farmland, and established the first family farm in Langxi: "Lvfeng Family Farm". By engaging in the large-scale planting of rice and wheat, "Lvfeng Family Farm" obtained a higher income than traditional farmers, which played an exemplary role for other farmers, and many other farmers started to follow. The Langxi government also played an important role in the development of family farms; it not only actively guided farmers to transfer their farmland, but also arranged for the availability of special support funds worth CNY 10 million for the development of family farms in the annual budget, and evaluated 15–20 model family farms every year for awards or subsidies. The Family Farm Association is another important driving force for family farms in Langxi. In 2009, some family farms in Langxi with strong representation and obvious radiating effects established the "Langxi Family Farm Association", which is the first family farm association in China, and it has contributed to serving the local family farms as a nongovernmental organization, for example, to coordinate bank loans and organize farmer training. As Langxi is at a distance from big cities, limited by the market capacity and preservation ability, it is unlikely for family farms in Langxi to produce vegetables, aquatic products and other agricultural products with higher economic value on a large scale, so that the most significant feature of the family farms in Langxi is that they maintain the operating pattern dominated by crops.

From July to August 2017, we conducted an on-site investigation of the development situation of all the registered family farms in Wuhan City, Hubei Province, and Langxi County, Anhui Province by using the same set of questionnaires and obtained samples in 2016. The investigation method was face-to-face interviews, and every question was asked by the investigator and answered by the farmer. Then, every answer was recorded by the investigator and immediately confirmed by the farmer, which guaranteed the authenticity and accuracy of the data. The data covered the basic characteristics of the family farms and farmers, land circulation and utilization, fixed assets and investments, farm industry and scale, employment, production and sales, income and expenditure, agricultural technology application, farm operation and management, natural and market risks, agricultural cooperatives and financial support, and a total of 629 questionnaires were distributed. After deleting the questionable questionnaires, such as those that were missing or inconsistent, 584 final samples were obtained and divided by region: 273 in Wuhan and 311 in Langxi. In terms of the operating type, among the final samples, there were 294 for planting family farms, 127 for breeding family farms, and 163 for mixed family farms (the fishery family farms only account for a very small proportion of the total sample and are thus included in the category of breeding (as aquaculture) family farms in this paper). Planting family farms are the family farms that only operate and obtain income from the planting industry, for example, they grow grains, such as rice, wheat, vegetables and fruits. Breeding family farms refer to the family farms that only operate and obtain an income from the breeding industry, for example, they raise livestock, poultry and aquatic products. Mixed family farms are family farms that operate both planting and breeding industries and gain an income from them.

2.2. Empirical Model Setting

2.2.1. DEA Model

Efficiency usually refers to the relative value of the input and output in production activities. Therefore, the efficiency of family farms can be regarded as the maximum output ratio that can be achieved under certain input constraints [23]. The DEA (Data Envelopment Analysis) method is a common performance evaluation tool in the field of decision analysis. By comparing the distance between the decision-making unit and its production frontier, the production efficiency of the multi-input and multi-output decision-making unit is calculated [24]. If the observation value of the decision-making unit is on the production frontier, the efficiency value of the decision-making unit is the optimal value of 1. If the efficiency value is less than 1, it means that the decision-making unit is inefficient, and the gap between 1 and its efficiency value reflects the inefficiency degree of the decision unit. In this paper, A DEA model that considers multiple inputs and multiple outputs was applied to measure and decompose the operating efficiency of all family farms, as well as to compare the efficiency of family farms in different regions and of different types.

The traditional DEA mainly includes two models: the CCR model and BCC model. Among them, the CCR model was initially proposed by Charnes et al. [24] to obtain the technical efficiency value of the decision-making unit under the premise of constant return to scale by calculating multiple input and output variables, while the BCC model was put forward by Banker et al. [25]. Under the condition of variable returns to scale, it can not only obtain technical efficiency, but can also decompose the technical efficiency (TE) into pure technical efficiency (PTE) and scale efficiency (SE). Considering that family farms are only able to control and adjust the amount of input rather than the output during the production process, and they follow the premise of variable scale, this paper chose the input-oriented DEA-BCC model [26] as follows:

Suppose there are n decision-making units $DMU_j(j = 1, 2, 3 \cdots n)$, m input indicators, and s output indicators. Assume X_{ij} represents the i-th input of the j-th decision-making unit, Y_{rj} represents the r-th output of the j-th decision-making unit $(1 \leq i \leq m, 1 \leq r \leq s)$, S^- is the surplus variable, and S^+ is the insufficient variable. The CCR model is:

$$\left\{ \begin{array}{c} \min\theta \\ s.t \sum_{j=1}^{n} \lambda_j x_{ij} + s_i^- = \theta x_{i0} \\ \sum_{j=1}^{n} \lambda_j y_{rj} - s_i^+ = y_{i0} \\ \lambda_j \geq 0, (j = 1, 2, \cdots, n) \\ s_i^- \geq 0, s_i^+ \geq 0 \end{array} \right. \quad (\theta\ unconstrained) \tag{1}$$

The BCC model considers that the return to scale of the decision-making unit is variable, so it is modified on the basis of the CCR model and shown as follows:

$$\left\{ \begin{array}{c} \min\theta \\ s.t \sum_{j=1}^{n} \lambda_j X_j + S^- = \theta X_0 \\ \sum_{j=1}^{n} \lambda_j Y_j - S^+ = Y_0 \\ \sum_{j=1}^{n} \lambda_i = 1 \\ \lambda_j \geq 0, (j = 1, 2, \cdots, n) \\ S^+ \geq 0, S^- \geq 0 \end{array} \right. \quad (\theta\ unconstrained) \tag{2}$$

2.2.2. Tobit Model

Considering that the family farm efficiency values that were calculated by the DEA model range from 0 to 1, which are censored data, the Tobit model with limited dependent variables should be applied for regression. Furthermore, in order to reduce the impact of heteroscedasticity, some agricultural factor input variables with large values are taken to logarithms [27], and a semi-logarithmic model is set as follows:

$$Y_i = \alpha + \sum \beta_1 \ln(X_i) + \sum \beta_2 Z_i + \varepsilon_i \tag{3}$$

In the formula (3), Y_i is the efficiency of the i-th family farm, X_i are the variables affecting the efficiency of the family farm that need to take logarithm, Z_i stands for other factors that affect the efficiency of the family farm, β is the coefficient to be estimated, ε_i is the random error term, and the subscript i represents every individual family farm.

2.3. Variables Selection

2.3.1. DEA Variables

Referring to the method of Qian and Li [4], and considering the actual situation of family farms in Wuhan and Langxi, from the perspective of considering the land, labor, and capital, this paper selected land input, labor input, and capital input as the input variables, and selected family farm operating income, which includes plantation income, livestock income, agricultural service income, and government subsidies, as the output indicators.

The land input refers to the actual land area operated by the family farm, including the area of self-owned land and circulation land. The question in the questionnaire is: "How much is the total area of the land operated by the family farm in 2016?", and the actual area filled in by the farmer is the land input indicator. The labor input refers to the total number of household laborers and hired laborers in the family farm's production activities, which is calculated according to the number of household laborers and the number of long-term employees of the family farms in 2016. The capital input refers to the operating expenditures of the family farm in 2016, including the expenditures on fertilizers, agricultural (livestock) medicines, seedlings, feeds, vaccines; expenditures on water, electricity, oil, gas, and coal; small mechanical tools, equipment and infrastructure maintenance expenses; specialized agricultural services expenditures; interest, housing rent, transportation and other productive expenses.

The family farm output indicator is measured by the operating income of the family farm, including the income from planting-and-breeding industries, agricultural service income and government subsidies. The descriptive statistics of the input and output indicators of the family farm are shown in Table 1.

Table 1. Descriptive statistics of the input and output indicators of family farms.

Variable Type	Variable Name	Unit	All Family Farm		Planting Family Farm		Breeding Family Farm		Mixed Family Farm	
			Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.
Land Input	Land operating area	Hectare	20.85	26.84	21.10	23.38	15.35	26.59	24.71	31.89
Labor Input	Household Laborer	Person	2.59	1.12	2.49	1.10	2.68	1.17	2.69	1.09
	Hired Laborer	Person	2.54	5.07	2.64	6.14	2.09	3.21	2.73	4.03
Capital Input	Expenditures on fertilizers, agricultural (livestock) medicines, seedlings, feeds, vaccines	CNY 10,000 (the average exchange rate of USD/CNY in 2016 was 1 USD = 6.6423 CNY)	43.63	157.15	17.17	33.46	77.18	108.71	65.19	273.93
	Expenditures on water, electricity, oil, gas, and coal	CNY 10,000	2.40	4.59	1.78	2.68	3.21	5.57	2.91	6.09
	Small mechanical tools, equipment and infrastructure maintenance expenses	CNY 10,000	1.38	4.86	0.88	2.62	2.09	8.47	1.72	3.97
	Specialized agricultural services expenditures	CNY 10,000	1.07	4.74	1.37	6.04	0.45	1.48	1.01	3.54
	Interest, housing rent, transportation and other productive expenses	CNY 10,000	3.15	9.02	2.55	7.20	3.98	10.02	3.57	10.93
Output	Planting industry income	CNY 10,000	55.78	136.93	74.85	111.24	-	-	64.85	204.73
	Breeding industry income	CNY 10,000	57.02	222.80	-	-	127.88	166.52	104.66	380.73
	Agricultural service income	CNY 10,000	0.35	1.90	0.32	1.45	0.33	2.46	0.43	2.12
	Government subsidies	CNY 10,000	1.89	6.18	1.33	4.03	1.12	5.55	3.50	8.98
	Total income	CNY 10,000	115.04	314.02	76.49	112.19	129.34	167.60	173.44	551.34

As shown in Table 1, the average land operating area of all family farms is 20.85 hectares, indicating that the scale operation among family farms has been initially achieved. The average land area operated by mixed-type family farms is 24.71 hectares, higher than that of all the family farms, while the average land area operated by breeding family farms is 15.35 hectares, lower than that of all the family farms. Meanwhile, the standard deviation of the land operating area for all types of family farms is relatively large, indicating that the land area operated by family farms varies. From the perspective of considering the labor input, the number of household laborers is similar to that of hired laborers, which is 2.59 and 2.54 people, respectively. The labor input of all types of family farms is similar, and the average of the household laborers and employed laborers for mixed family farms is slightly higher than that of the other types. From the perspective of considering the capital input, the average input of breeding and mixed family farms in most aspects is higher than that of all family farms, except in the expenditures for specialized agricultural services, in contrast to the input of planting family farms. As for the total income, the average income of all family farms is CNY 1.1504 million, and the income for the planting industry is similar to that for the breeding industry (CNY 557.8 thousand and CNY 570.2 thousand, respectively). Relatively speaking, mixed family farms have the highest income, followed by breeding family farms, and planting family farms receive the lowest income.

2.3.2. Tobit Variables

Table 2 shows the Tobit regression variables and their descriptive statistics. The variables include four aspects:

1. Agricultural input variables. Agricultural input variables include family farms' land input, labor input and capital input. Since the combination of different agricultural factors may lead to different efficiencies [28], the impact direction of agricultural factors is uncertain. Some scholars agree with the principle of optimal scale operation of land area, that is, as the scale of the family farms expands, the production materials, such as mechanized equipment, can be fully utilized, so that the production cost of the unit agricultural products can be reduced, and the scale benefits can be increased. However, when the scale of operation is too large, it leads to an increase in the management and production costs; when the marginal cost is greater than the marginal benefit, the benefit of scale diminishes. Therefore, there may be an inverted U relationship between the land operating area and the efficiency of the family farms [27,29]. However, there are also numerous studies showing that, in low-income developing countries, the agricultural productivity of farms has a U-curve relationship with the farm size, that is, productivity decreases as the farm size increases from its smallest unit, and then rises as the farm size increases after a threshold [30–32]. Therefore, the direction between the land input and the efficiency of family farms is uncertain. As China is a developing country, the present study assumes that they may present a U relationship. Generally speaking, if the family farm has a sufficient labor force and capital funds, it can have a better start-up condition and stronger operating ability. Therefore, it is expected that the labor input and capital input will positively affect the efficiency of the family farms.
2. Farmers' characteristic variables. The characteristic variables of farmers include gender, age, education level, and years of farming. Some scholars believe that the older the farmer is, the more experienced he or she is, which is helpful to improve the efficiency of family farms [33]. However, some scholars pointed out that older farmers usually have poorer health conditions, and are unlikely to accept new things, so they may not be able to undertake the task of family farms [34]. Therefore, the impact of family farmers' age on family farm efficiency is uncertain. From a gender perspective, men are usually physically more powerful than women, and they tend to be more aggressive and adventurous, while women may be better at detail management [35], so gender has an uncertain effect on the efficiency of family farms. The higher the education level of the farmer, the easier it is for him or her to master new knowledge, as well as apply new technology [15]. Therefore, the education level of the farmer is expected to have a positive impact on the efficiency of the family farm. Since the farmer who has longer farming years usually has a richer experience in agricultural production, it is inferred that the farmer's farming years are positively correlated with the efficiency of the family farm.
3. The family farm characteristic variables. Family farm characteristic variables mainly include the family farm's regulations, market channels, the brand trademark registration, the new technology adoption, and the use of fertilizer. Family farms that have good regulations have better internal management mechanisms, so it is expected that the family farms with perfect regulations have higher efficiency. Smooth market channels enable family farms to sell more products and obtain more profits, hence market channels are expected to have a positive impact on the efficiency of family farms. Registering a brand trademark helps to publicize the popularity and reputation of agricultural products to expand the market for family farms. Therefore, it is expected that the brand trademark registration is positively correlated with the efficiency of

family farms. Similarly, using new agricultural technologies can not only improve the productivity of family farms [36], but also increase the intellectual content of agricultural products and their derivatives, thus it is expected to positively influence family farm efficiency. Additionally, as the use of fertilizers is conducive to cultivating land fertility and increasing yields; it is projected to have a positive impact on the efficiency of family farms.

4. Environmental factors. The environmental factors mainly include government subsidies, financial credit, and natural disasters. Government subsidies may encourage family farms to invest in production, but they may also enable farmers to form the idea of "getting something for nothing" and reduce their production enthusiasm [13]. Therefore, the impact of government subsidies on family farm efficiency is uncertain. Financial credit is conducive to the production expansion of family farms, thus it is expected to be positively correlated with the performance of the family farm. Family farms that suffer from natural disasters face the plights of reduced or no harvest, so it is predicted that natural disasters negatively affect the performance of family farms.

Table 2. Tobit regression variables and descriptive statistics.

Variable Types	Variable Names	Variable Definitions	Total Samples		Wuhan		Langxi		Expected Direction
			Mean	Std.	Mean	Std.	Mean	Std.	
Agricultural Input Variables	Land input (land)	Land operating scale (hectares)	20.85	26.85	19.21	20.48	22.30	31.36	+/−
	Labor input (labor)	Number of laborers (people)	5.13	5.23	6.42	6.77	3.99	2.91	+
	Capital input (cap)	CNY 10,000	51.63	166.56	59.32	217.20	44.87	103.36	+
Farmers' Characteristic Variables	Gender (gender)	Female = 0, male = 1	0.89	0.31	0.85	0.35	0.93	0.26	+/−
	Age (age)	Years	46.48	7.51	46.38	8.03	46.57	7.03	+/−
	Education level (edu)	Never went to school = 1, primary school = 2, junior high school = 3, high school, secondary vocational and technical college = 4, junior college, higher vocational and technical college = 5, undergraduate and above = 6	3.45	0.96	3.86	0.81	3.08	0.93	+
	Years of farming (exp)	Years	20.70	11.69	20.17	11.32	21.16	11.99	+
Family Farm Characteristic Variables	Regulations (regu)	None = 1, yes but not standard = 2, yes = 3	1.95	0.88	1.97	0.87	1.93	0.89	+
	Market channels (market)	None = 0, yes = 1	0.64	0.48	0.64	0.48	0.65	0.48	+
	Brand (brand)	None = 1, registering = 2, yes = 3	1.38	0.74	1.32	0.69	1.43	0.78	+
	New technology (tec)	No = 0, Yes = 1	0.72	0.45	0.70	0.46	0.74	0.44	+
	Fertilizer (fer)	Never use = 1, use occasionally = 2, use often = 3	2.09	0.86	2.36	0.81	1.86	0.84	+
Environmental Factors	Government subsidies (aid)	No = 0, yes = 1	0.17	0.37	0.14	0.35	0.19	0.39	+/−
	Financial credit (credit)	Amount of credit funds obtained from financial institutions (CNY 10,000)	24.46	56.06	24.68	71.72	24.27	37.38	+
	Suffer from natural disasters (dis)	No = 0, yes = 1	0.89	0.31	0.89	0.31	0.89	0.31	−

Note: the total sample size is 584, 273 from the Wuhan area, and 311 from the Langxi area.

3. Results and Analysis

3.1. Efficiency Measurement of Family Farms: Based on the DEA Model

Table 3 presents the results of the variance inflation factor (VIF) of the input indicators and the results of the Pearson test on the input and output indicators. The results show that the VIF values of the input indicators are all less than 10, indicating no multicollinearity, and the Pearson correlation coefficients of the input and output indicators are significantly positive at the level of over 5%, indicating that the land input, labor input and capital input are all positively correlated with the output indicator, with the significant coefficients at 0.9078, 1.9938 and 1.6773, respectively. Therefore, the input and output indicators selected for this study satisfy the assumption of the same direction, so that the DEA model can be used for the analysis.

Table 3. Multicollinearity and Pearson test results.

Input Indicator	VIF	Pearson
Land input	1.10	0.9078 ***
Labor input	1.09	1.9938 **
Capital input	1.06	1.6773 ***

Note: ***, ** are their significance at the levels of 1% and 5%, respectively.

Table 4 shows the results of the efficiency value of the family farms. The average value of the technical efficiency (TE) of all the family farms is low (0.3058), verifying that H1 is true. From the decomposition of the technical efficiency (TE) into pure technical efficiency (PTE) and scale efficiency (SE), it is shown that the average value of the family farms either in SE or PTE is not high (0.5779 and 0.5213, respectively), contributing to the low TE. Although the PTE is slightly higher than the SE, both of them still have much room for improvement. Therefore, family farms should further improve their technical skills, while focusing on scale operations. A further analysis of the returns to scale shows that, among all the family farm samples, as many as 516 family farms are in a state of increasing their returns to scale, only 31 are in a state of decreasing their returns to scale, and the other 37 family farms are in a state of constant returns to scale.

Table 4. The efficiency of all the family farms of different types and in different regions.

Type	Households	Technical Efficiency (TE)	Pure Technical Efficiency (PTE)	Scale Efficiency (SE)	Increasing Returns to Scale	Diminishing Returns to Scale	Constant Returns to Scale
All family farms	584	0.3058	0.5779	0.5213	516	31	37
Planting family farms	294	0.2605	0.4997	0.5256	270	11	13
Breeding family farms	127	0.4104	0.7102	0.5547	96	17	14
Mixed family farms	163	0.3060	0.6160	0.4874	150	3	10
Wuhan district	273	0.3734	0.5994	0.5994	235	14	24
Langxi district	311	0.2464	0.5590	0.4527	281	17	13

Note: the efficiency values of the technical efficiency (TE), pure technical efficiency (PTE), and scale efficiency (SE) are the calculated average efficiencies; TE = PTE $\times$ SE.

Table 4 also presents the results of the efficiency values of the family farms of different types and in different regions. In terms of family farms of different types, the TE, PTE and SE of breeding family farms are the highest, with values reaching 0.4104, 0.7102, and 0.5547, respectively, while the efficiency values of the planting family farms and mixed family farms are relatively lower. The SE of the mixed family farms is the lowest (0.4874), and it is also confirmed by the fact that among the 163 mixed family farms, 150 households are in a state of increasing returns to scale. Hence, the mixed family farms need to pay more attention to adjusting the scale of operation to improve their TE. The PTE of the planting family farms is lower than their SE, indicating that the planting family farms should focus more on the improvement of technology and management skills.

From a regional perspective, the TE of the family farms in Wuhan is higher than that of Langxi (0.3734 and 0.2464, respectively). A similar pattern can be observed in the figure for the PTE and SE in Wuhan and Langxi, indicating that the family farms in Wuhan have more advantages in technology, management and scale operation, which contributes to a TE that is relatively higher.

3.2. Factors Affecting the Efficiency of the Family Farms: Based on the Tobit Model

This paper used stata11 to process and analyze the data. On the basis of estimating the total sample, regression estimations were also carried out by region and operation type, and the estimated value of each variable coefficient and its significance were obtained. The results are shown in Table 5.

Table 5. Tobit regression results of the variables affecting family farm efficiency.

Variable Types	Variable Names	Model 1-1 Total	Model 1-2 Total	Model 2 Planting	Model 3 Breeding	Model 4 Mixed	Model 5 Wuhan	Model 6 Langxi
Agricultural Input Variables	Ln(land)	−0.1601 *** (−5.77)	−0.1592 *** (−5.78)	−0.0766 * (−1.88)	−0.2049 *** (−4.06)	−0.2088 ** (−2.20)	−0.1182 * (−1.91)	−0.1665 *** (−5.78)
	$[Ln(land)]^2$	0.0119 ** (2.10)	0.0127 ** (2.28)	0.0010 (0.11)	0.0264 ** (2.31)	0.0216 (1.35)	−0.0024 (−0.20)	0.0203 *** (3.55)
	Labor	0.0028 (1.26)		0.0049 ** (2.22)	−0.0050 (−0.49)	−0.0001 (−0.01)	0.0033 (1.08)	−0.0033 (−0.79)
	Ln(cap)	0.0333 *** (3.50)	0.0373 *** (3.99)	−0.0122 (−0.75)	0.0679 *** (2.72)	0.0459 ** (2.58)	0.0367 ** (2.35)	0.0198 * (1.65)
Farmers' Characteristic Variables	Gender	−0.0144 (−0.42)		−0.0425 (−1.02)	−0.0214 (−0.20)	0.0081 (0.14)	−0.0107 (−0.22)	0.0205 (0.46)
	Age	−0.0008 (−0.45)		−0.0024 (−1.07)	−0.0016 (−0.39)	0.0031 (1.15)	−0.0021 (−0.78)	0.0003 (0.14)
	Edu	0.0156 (1.34)	0.0235 ** (2.11)	0.0319 ** (2.24)	−0.0135 (−0.48)	−0.0279 (−1.21)	0.0055 (0.25)	−0.0150 (−1.16)
	Exp	−0.0007 (−0.61)		−0.0007 (−0.49)	−0.0001 (−0.04)	−0.0011 (−0.62)	0.0008 (0.44)	−0.0021 * (−1.75)
Family Farm Characteristic Variables	Regu	0.0154 (1.19)		0.0143 (0.89)	0.0394 (1.18)	0.0158 (0.72)	0.0033 (0.16)	0.0361 ** (2.48)
	Market	0.0644 *** (2.89)	0.0645 *** (2.91)	0.0340 (1.29)	0.0278 (0.43)	0.0992 ** (2.53)	0.0882 ** (2.39)	0.0467 * (1.93)
	Brand	0.0392 *** (2.57)	0.0453 *** (3.02)	0.0553 *** (2.74)	−0.0769 ** (−2.11)	0.0986 *** (3.84)	0.0223 (0.81)	0.0655 *** (3.97)
	Tec	0.0190 (0.81)		−0.0008 (−0.02)	0.2101 *** (3.73)	−0.0940 ** (−2.25)	0.0203 (0.53)	0.0400 (1.49)
	Fer	0.0371 *** (2.94)	0.0402 *** (3.20)	0.0400 ** (2.44)	0.0280 (0.91)	0.0303 (1.30)	−0.0092 (−0.43)	0.0449 *** (3.08)
Environmental Factors	Aid	−0.0675 ** (−2.35)	−0.0644 ** (−2.25)	−0.0490 (−1.37)	−0.1281 (−1.54)	−0.0578 (−1.21)	−0.0563 (−1.13)	−0.0502 (−1.61)
	Credit	0.0009 *** (3.34)	0.0009 *** (3.38)	0.0003 (0.54)	0.0013 * (1.81)	0.0015 *** (2.69)	0.0016 *** (3.26)	0.0001 (0.34)
	Dis	−0.0744 ** (−2.15)	−0.0720 ** (−2.09)	−0.1745 *** (−3.19)	−0.0272 (−0.40)	−0.0130 (−0.22)	0.0079 (0.14)	−0.1699 *** (−4.34)
Constant Term	c	0.3643 *** (3.50)	0.2939 *** (4.74)	0.4861 *** (3.38)	0.4460 * (1.82)	0.2797 (1.23)	0.5112 *** (2.77)	0.3863 *** (3.31)
Sample Size		584	584	294	127	163	273	311

Note: *t*-values are in brackets, ***, **, and * are their significance at the levels of 1%, 5%, and 10%, respectively.

Model 1-1 and 1-2 show the results of the efficiency influencing factors of all the family farm samples and those obtained after gradually eliminating the insignificant variables, respectively. From the perspective of considering the agricultural input variables, land input [ln(land)] is negatively correlated with the family farms' efficiency at the 1% level, while its square term shows an opposite trend, forming a U-shaped relationship between the farm efficiency and land operating area. In fact, there is an almost globally inverse relationship between the farm size and productivity within developing countries [37], including India, the Philippines, Latin America [38–41], China, Nigeria, Mexico, and Bangladesh [30]. In other words, in these developing countries, both small and large farmers are more productive than the intermediate-sized farmers, and this can be explained by the more efficient hiring labor utilization of small farmers and the machine scale economies of large farmers [30]. To be more specific, intermediate-sized farmers are most likely to employ part-time workers, which proves to be costly and less efficient than small farmers, while the full mechanization in large farms saves on labor-related costs [42], of which the increase in the scale capacity can explain for the upper tail of the U shape. The capital input (ln(cap)) of the family farm is significantly positive at the level of 1%, indicating that the efficiency of the family farms increases with the input of capital. To our knowledge, the more capital invested in the family farm, the easier it is for the family farms to purchase equipment, achieve mechanized production and economies of scale, which can promote the productivity of family farms. Among the farmers' characteristic variables, only the farmers' education level (Edu) has a significant impact on the efficiency of the family farm at a 5% level, proving that the farmers with a higher education degree have better skills relating to farming operations, which is beneficial in the making of smart decisions and enhancing the productivity of the farm. In terms of the family farm characteristic variables, the market channels (Market), brand trademark registration (Brand), and use of fertilizer (Fer) are all significantly positively correlated with the family farms' efficiency at a 1% level. Unblocked market channels contribute to the increase in product sales, registered brand trademarks enable the family farms to achieve a better publicity effect, and the use of fertilizer increases the fertility of the land and improves the unit output. Therefore, the three variables are conducive to the improvement of family farm efficiency. From the perspective of environmental factors, government subsidies (Aid) negatively affect the efficiency of the family farms at a 5% level; a possible explanation for this is that government subsidies may induce farmers to form the idea of "getting something for nothing", thereby reducing their enthusiasm for production. Financial credit (Credit) shows a positive correlation with family farm efficiency at the level of 1%. External credits can expand the budget constraint of the family farms and allow them to invest more funds for production, thus improving the efficiency of the family farms. When family farms suffer as a consequence of natural disasters (Dis), this significantly influences the efficiency of the family farm, because the natural disasters directly result in plights, such as a reduction in or no harvest, which poses a threat to the efficiency of the family farms.

Models 2, 3, and 4 present the results of the efficiency influencing factors of family farms of different operation types, while Models 5 and 6 show this for different regions. The heterogeneity of the results verify that H2 is true, and the analyses of each model are as follows:

Model 2 presents the result of regression on the factors affecting the efficiency of planting family farms. The land scale (ln(land)) shows a significantly negative correlation with the efficiency at a 10% level, with which the labor input (labor) is significantly positively correlated at the level of 5%, indicating that, for a planting type family farm, a smaller operating scale and a greater labor force can improve the production efficiency of the family farms. The education level (Edu) of the farmer positively affects the efficiency of the family farms at the level of 5%, proving that the higher the education level of the family farmer, the more possible it is for them to make decisions that are beneficial to the development of the planting family farm. The brand trademark registration (Brand) and use of fertilizer (Fer) both significantly and positively influence the efficiency of the family farm, indicating that brand promotion is conducive to the sale of planting products, and the use of fertilizer can boost the yield of agricultural products, thereby improving the efficiency of the family farms. As a consequence of suffering from natural disasters (Dis), the efficiency of family farms can lower, as the planting agricultural operations are weak and high risk, and therefore suffering from natural disasters may result in family farms having no income for the entire year.

Model 3 presents the result of regression on the factors affecting the efficiency of the breeding family farms. The land scale (ln(land)) and its square term show a U-shaped relationship with the efficiency of the family farm, where their coefficient values are significantly at −0.2049 and 0.0264, respectively, verifying that the smallest and largest breeding family farms are more efficient than the intermediated-sized farms. Capital input (ln(cap)) and new technology application (Tec) are both significantly positively correlated with efficiency at the 1% level; similarly, financial credit (Credit) presents a positive correlation with breeding family farms' efficiency at a 10% level, as the capital input and financial credit they obtain make it possible for breeding family farms to purchase advanced machinery and apply new technologies, such as cultivating new varieties and applying assembly lines, which contributes to the improvement of farm productivity. Brand trademark registration (Brand) is negatively related to the efficiency of the family farm at a 10% level. A possible explanation for this is that the breeding industry already has well-known brands, such as Hairy Crab of a famous Lake or Local Pork of a Mountain. Brands registered by single family farms find it difficult to compete with the more well-known trademarks in the market with a higher price, and, as a result, agricultural products with family farms' registered trademark brands may not be as popular as the original sales.

Model 4 shows the result of the factors that affect the efficiency of the mixed family farms. The land scale (ln(land)) negatively affects the family farm efficiency at the level of 5%, while the capital input (ln(cap)) presents an opposite influencing direction, indicating that the mixed family farms are not suitable for an excessively large scale of operation, and the capital input is proved to be helpful in building a good circular agricultural mixed model, such as the recycling of pig manure and urine, and rice–duck symbiosis, so as to improve the efficiency of the farm. In addition, the market channels (Market) and brand trademark registration (Brand) are significantly positively correlated with the farm efficiency at the levels of 5% and 1%, respectively, indicating that the smooth market channels and brand promotion can improve the efficiency of the mixed family farms by broadening the market. The adoption of new technology (Tec) shows a significantly negative correlation with farm efficiency at the 5% level, and it is probably because the new technologies are not yet mature in this field, which leads to a lower efficiency at this stage. Financial credit (Credit) positively influences the efficiency of the farm, since it can provide a sufficient source of external funds for the mixed family farms, which is conducive to their expansion in terms of production.

Models 5 and 6 are the regression results of the factors affecting the efficiency of the family farms in Wuhan and Langxi, respectively. From the perspective of the common points, firstly, among the agricultural input variables, the land operating area (ln(land)) in two regions is significantly negatively correlated with the family farm efficiency, while the capital input (ln(cap)) in the two regions is significantly positively correlated with this at a 5% level, showing that the family farms in both regions are more efficient at a smaller scale and with more capital investment. Capital investment contributes to the expansion of the production of the family farms, thereby increasing the productivity and efficiency of the family farms, and since family farms in Wuhan are located in the provincial capital city, the efficiency improvement affected by the capital input is better than that in Langxi. Secondly, among the other influencing factors, the market channels (Market) both in Wuhan and Langxi have positive impacts on the efficiency of the family farms. This is due to the fact that unblocked sales channels can increase the choice of markets at which family farms can sell more goods.

From the perspective of differences, in Langxi, the square term of the land operating area $[\ln(\text{land})]^2$ shows a positive relationship with the efficiency of the farm, thus the U-shaped relationship between the land area and farm efficiency is obvious in Langxi. The farmer's years of farming (Exp) shows a significantly negative relationship with the efficiency of the farm at the 10% level. Farmers who have spent more years in the practice of farming may have a richer farming experience, but they are also less likely to accept new technology and modernized methods, which is not conducive to improving the efficiency of the family farms. The regulation (Regu), the brand trademark registration (Brand), and the use of fertilizer (Fer) in the family farms in Langxi are all significantly positively correlated with the farms' efficiency, indicating that a complete internal regulation system, brand publicity, and fertilizer use will improve the farms' operating efficiency through an improvement of the management efficiency, the sale of more products, and the increase in yields, respectively. Among the environmental factors, financial credit (Credit) in Wuhan presents a significantly positive impact on farm efficiency, while that in Langxi is nonsignificant. This situation may be due to the relatively standardized development of the financial market in Wuhan, as Wuhan is a provincial capital city, so financial credit enables the family farms to expand their production and improve productivity through financing, while the development of the financial market in Langxi is relatively lagged. The efficiency of the family farms in the Langxi area is negatively affected at a 1% level, as a consequence of suffering from natural disasters (Dis). Since many family farms in the Langxi area suffered from natural disasters in 2016, they were affected by the disaster and their income was reduced. Therefore, this has a significantly negative impact on the efficiency of the local family farms.

4. Discussion

4.1. Discussion about the Efficiency of the Family Farms

In order to present family farm efficiency more specifically and elaborate on the discussion, this paper presents the decomposition of the DEA results of the family farms, according to the level of their ineffectiveness by types in Table 6.

Table 6. The decomposition of the efficiency of the family farms measured by the DEA.

Type		Mean	DEA Effectiveness ($\theta = 1$)		Low Level of Ineffectiveness ($0.7 \leq \theta < 1$)		Medium Level of Ineffectiveness ($0.4 \leq \theta < 0.7$)		High Level of Ineffectiveness ($0 \leq \theta < 0.4$)	
			Mean	Percentage (%)	Mean	Percentage(%)	Mean	Percentage(%)	Mean	Percentage (%)
TE	All family farms	0.3058	1.0000	5.99	0.8374	5.14	0.5367	14.21	0.1695	74.66
	Planting family farms	0.2605	1.0000	4.76	0.8798	1.70	0.5368	11.22	0.1672	82.31
	Breeding family farms	0.4104	1.0000	8.66	0.8378	14.17	0.5286	22.83	0.1552	54.33
	Mixed family farms	0.3060	1.0000	6.13	0.8064	4.29	0.5478	12.88	0.1818	76.69
	Wuhan district	0.3734	1.0000	8.06	0.8348	5.86	0.5444	23.08	0.1877	63.00
	Langxi district	0.2464	1.0000	4.18	0.8406	4.50	0.5124	6.43	0.1577	84.89
PTE	All family farms	0.5779	1.0000	19.52	0.8232	11.99	0.5449	35.10	0.2778	33.39
	Planting family farms	0.4997	1.0000	12.59	0.8028	6.80	0.5411	37.07	0.2724	43.54
	Breeding family farms	0.7102	1.0000	31.50	0.8411	21.26	0.5539	30.71	0.2802	16.54
	Mixed family farms	0.6160	1.0000	22.70	0.8199	14.11	0.5458	34.97	0.2920	28.22
	Wuhan district	0.5994	1.0000	20.88	0.8276	15.02	0.5536	31.87	0.2790	32.23
	Langxi district	0.5590	1.0000	18.33	0.8171	9.32	0.5384	37.94	0.2769	34.41
SE	All family farms	0.5213	1.0000	6.68	0.8707	24.49	0.5451	28.25	0.2151	40.58
	Planting family farms	0.5256	1.0000	4.76	0.8756	24.83	0.5438	31.63	0.2284	38.78
	Breeding family farms	0.5547	1.0000	11.02	0.8835	30.71	0.5361	20.47	0.1677	37.80
	Mixed family farms	0.4874	1.0000	6.75	0.8428	19.02	0.5530	28.22	0.2252	46.01
	Wuhan district	0.5994	1.0000	9.52	0.8853	30.40	0.5549	31.14	0.2151	28.94
	Langxi district	0.4527	1.0000	4.18	0.8505	19.29	0.5348	25.72	0.2151	50.80

Note: the inefficiency of the DEA is divided into three levels: low, medium and high; θ is the efficiency value; TE = PTE $\times$ SE.

4.1.1. Full Sample Discussion

The results show that the TE (technical efficiency), PTE (pure technical efficiency) and SE (scale efficiency) of the family farms are low. The mean value of the TE of all the family farms is as low as 0.3058, and among all the family farms, only 5.99% have the status of DEA effectiveness, while up to 75.66% are at a high level of ineffectiveness. The TE reflects the distance between the actual output of each decision-making unit (family farm) and the optimal output (production frontier) under the premise that the inputs of the production factors, such as labor, capital, and land, remain unchanged. The higher the TE, the better the production capacity. The result implies that the TE of family farms is low, indicating that the resources have not been used reasonably and effectively by the family farms, so the family farms are still in the primary stage of development and have much room for improvement.

By decomposing the TE into PTE and SE, it can be observed that the PTE value of all family farms is similar to that of the SE (0.5779 and 0.5213, respectively). Although the PTE and SE values of all the family farms are both higher than the TE, only 19.52% and 6.68% of family farms are in an effective status in terms of the PTE and SE, respectively. According to the equation of "TE = PTE × SE", the values of the PTE and SE that are not high enough resulted in the low value of the TE. As the PTE refers to the management ability and technical level of the family farms when other conditions remain unchanged, and the SE reflects the effectiveness of farm specialization and moderate scale operation, in order to improve the TE of family farms, it is not only necessary for family farms to improve the PTE by improving their management ability and technical level, but also to improve the SE by forming a moderate operation scale.

4.1.2. Discussion of the Family Farm Efficiency in Different Regions and of Different Types

From the perspective that considers the different regions, the TE of family farms in Wuhan (0.3734) is slightly higher than that in Langxi (0.2464), and it is mainly attributed to the relatively higher SE in Wuhan (0.5994) than that in Langxi (0.4527), since the PTE values of Wuhan (0.5994) and Langxi (0.5590) are similar. Additionally, there are up to 50.8% of family farms in Langxi that are highly inefficient in terms of the SE, while the proportion for that in Wuhan is 28.94%, verifying that family farms in Wuhan are better at performing moderate scale operations to achieve higher efficiency.

From the perspective of different operation types, the TE of breeding family farms (0.4104) is higher than that of planting family farms (0.2605) and mixed family farms (0.3060). A possible explanation for this is that, given the similar SEs of the three types of family farms (0.5256, 0.5547 and 0.4874), breeding family farms have a higher PTE at 0.7102, while the PTE of planting and mixed family farms are 0.4997 and 0.6160, respectively. The values imply that the planting, breeding and mixed family farms all experience a similar condition of scale operation, whereas the breeding family farms benefit more from technical improvements rather than the expansion of scale, for breeding family farms do not require a scale as large as planting or mixed family farms, but rather require new technology to achieve intensive production.

4.2. Discussion about the U-Shaped Relationship between Farm Efficiency and Land Scale

The results of this paper show that the land scale has a U-shaped relationship with family farm efficiency. With the expansion of land scale, the efficiency of family farms first decreased then increased after a threshold, forming a U-shape.

However, many people are convinced that the land scale of family farms ought to have an inverted U relationship with their efficiency because of the achievement of optimal scale. In fact, the two views are not contradictory, because the U-shaped relationship between the land scale and farm efficiency is mostly observed in low-income developing countries, while the inverted U relationship is usually found in high-income developed countries.

Foster and Rosenzweig [30] explained the U-curve relationship very thoroughly. The U-curve relationship between land scale and farm efficiency is driven by two factors: the cost of hiring laborers and the scale economies of machine capacities. In low-income countries, such as India, Indonesia and China, family farms are, on average, much smaller than those in developed countries, such as the U.S. For very small family farms in low-income countries, limited by the land scale, it is unlikely to implement mechanized production, and only family members work the land and operate their own farms efficiently. As the farm size increases, the family members work harder until they are unable to afford operating larger farmland by themselves and begin to hire additional labor, which comes with additional transaction costs and thus lowers their net income. The family continues to work the land as the farm size increases until the point that the benefit of hiring additional laborers outweighs the cost, and productivity starts to increase—which is where we observed the bottom of the curve. After this point, productivity rises with the farm size, as larger farms can take advantage of machines that have a greater capacity at larger scales and lower labor use, mirroring the economies of scale that are well-observed in developed countries. The inverted U-shaped relationship that many other scholars observed appears after the optimal scale achieved by the larger family farms, as after this optimal size point, the overlarge scale of family farms may exceed the management ability of family farmers and lead to diminishing farm efficiency. Hence, small farms in developing countries are more productive than those that are slightly bigger, but far less productive than the larger farms observed in high-income countries, as shown in Figure 1.

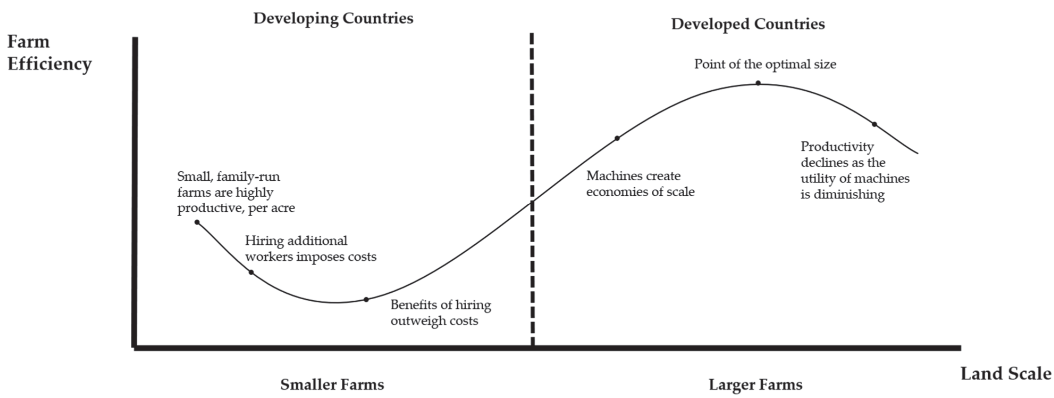

Figure 1. Relationship between farm efficiency and land scale.

The result of the U-shaped relationship between farm efficiency and land scale addressed in this paper indicates the left side of Figure 1, as the farm land scale is too small in China compared to that in developed countries, and family farms in China have to experience initial decreasing returns to increasing farm size to acquire a higher efficiency.

5. Research Conclusions and Suggestions

In recent years, in order to realize agriculture modernization and rural revitalization, the Chinese government has been focusing on the cultivation of new types of agricultural operating entities, among which family farms are promoted as typical representatives. Therefore, it is of great significance to study the efficiency of family farms and their influencing factors. This paper used the field survey data of 584 family farms in 2 national family farm demonstration bases in Wuhan City, Hubei Province and Langxi County, Anhui Province in 2016, and applied the DEA model to measure the efficiency of family farms. Then, the Tobit model was used to examine the key factors affecting the efficiency of family farms from four perspectives, agricultural factor input, characteristics of farmers, characteristics of family farms, and environmental factors, and further compared the family farms in different regions and of different types.

The research results show that the TE of all family farms is not high, and both the PTE and SE obtained by decomposing the efficiency can be improved. Breeding family farms have the highest efficiency, while planting family farms and mixed family farms have relatively lower efficiencies. The SE of mixed family farms is lower than their PTE, and it is the lowest among all types of family farms. The TE, PTE and SE of family farms in Wuhan are higher than that in Langxi.

Among the factors affecting the efficiency of family farms, capital input, farmer's education level, market channels, brand registration, the use of fertilizer and financial credit have positive impacts on the efficiency of family farms, while government subsidies and natural disasters negatively affect the efficiency of family farms. More specifically, the land operating area shows a U-shaped relationship with farm efficiency.

For planting family farms, labor input, farmer's education level, brand registration, and the use of fertilizer positively affect their efficiency, while land operating scale and natural disasters negatively affect it. For breeding family farms, capital input, new technology, and financial credit positively affect their efficiency, while brand registration negatively affects it. More specifically, the land operating area shows a U-shaped relationship with farm efficiency. As for the mixed family farms, capital input, market channels, brand registration, and financial credit positively affect their efficiency, while land operating scale and new technology negatively affect their efficiency.

From a regional perspective, the key factors affecting the efficiency of family farms in Wuhan mainly include the land operating scale, capital input, market channels and financial credit, and the key factors that affect the efficiency of family farms in Langxi include the land operating scale, capital input, farmer's years of farming, regulations, market channels, brand registration, fertilizer use, financial credit and natural disasters. More specifically, the land operating area negatively influences the farm efficiency in Wuhan, while it shows an obvious U-shaped relationship with farm efficiency in Langxi.

According to the research conclusions, it can be seen that although the family farms in the Wuhan and Langxi regions have been supported by the government for many years, the efficiencies of family farms in the two regions are still low, so it is of great significance to improve the family farms' efficiency. The factors affecting the efficiency of family farms in different types and regions vary. Therefore, family farms in each region and of different types needs to choose appropriate measures based on the actual situation and different types of local family farms, paying particular attention to the following points:

First, the local government should attach importance to the accumulation of agricultural input factors on family farms, especially encouraging the labor input of planting family farms and capital input of breeding and mixed family farms, to help improve the efficiency of family farms more precisely.

Second, the operating scale of family farms should be reasonably determined and family farms need to pay attention to moderate scale operations and not blindly expand their land scale. At the present stage, family farms in China should either stick to moderate scale operation, or transfer in a great amount of land under the support of the government to move beyond the bottom of the U-shape, to obtain a higher efficiency.

Third, family farms should be stimulated to optimize the internal operating environment, such as smooth their market channels, register brands and trademarks, and use fertilizer, so as to improve the productivity and market competitiveness of family farms.

Fourth, it is necessary for the government to create a favorable external environment for family farms, for example, build a standardized and multi-level rural financial market; increase support for financial credit; rationally plan government subsidies; and focus on the prevention and control of natural disasters.

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land

Article

The Non-Agriculturalization of Cultivated Land in Karst Mountainous Areas in China

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Abstract: When used for agricultural production, karst mountainous areas are susceptible to soil degradation due to the effects of soluble rocks and the climate. To mitigate the risk, the Grain for Green Project, a sizable initiative, was commenced to transition cultivated land away from agricultural use. This conversion of cultivated land to non-agricultural land has been significant. The study area considered in this research included four small towns in southwest China in karst mountainous areas with various morphologies. The investigation of the non-agriculturalization of cultivated land in the four sample areas revealed that the non-agriculturalization rate of cultivated land as a result of the Grain for Green Project has reached between 21.36% and 51.43% each decade. Thus, the Grain for Green Project has been advantageous for lowering the landscape ecological risk. Furthermore, because an increasing number of agricultural production materials have been introduced to the cultivated land, the conversion from cultivated land to non-agricultural land has not caused a staple food crisis on the national scale. However, it is impossible to observe all the potential drawbacks of the non-agriculturalization of cultivated land from satellite photos alone, and further social data collection is required. The findings of this study can offer precise information for policymaking in relation to the protection of rural cultivated land and rural spatial optimization in karst mountainous areas.

Keywords: non-agriculturalization rate; ecological risk; cultivated land change; landform; land management

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1. Introduction

Cultivated land resources are the foundation of rural development and provide residents with important basic living materials such as grain, vegetables, and oilseeds [1,2]. However, with the occurrence of rapid urbanization and industrialization worldwide, an increasing amount of rural agricultural land is occupied by non-agricultural land (such as residential land, roads, industrial land, etc.) [3,4]. The serious non-agriculturalization of cultivated land has caused problems such as food crises and the intensification of social contradictions. This has been demonstrated in studies conducted in China, Iran, and Indonesia [5–7]. As a result, the issue of the non-agriculturalization of cultivated land has been the focus of study in the fields of land science and rural sustainable development [8,9].

Many scholars have conducted research on the quantitative evaluation of the non-agriculturalization of cultivated land, the influence of the non-agriculturalization of cultivated land on the social economy, and the driving mechanism and management measures of cultivated land conversion [10–12]. Questionnaire surveys, spatial autocorrelation, and gravity models are widely used in the quantitative evaluation of the non-agriculturalization of cultivated land [13,14]. Studies have shown that the non-agriculturalization of cultivated land provides a spatial condition for urbanization and industrialization, but also leads to a decline in the amount of cultivated land and food shortages, ultimately resulting in an increasingly intensifying contradiction between food security and economic development [15,16]. Urbanization, industrialization, economic benefits, and national management policy are the driving factors of the non-agriculturalization of cultivated land at the macro scale [17–19]. The livelihood changes and income levels of farmers due to cultivated land conversion play an important role in non-agriculturalization at the micro scale [20,21]. In addition, numerous studies have found that the reform of land administration systems and the promotion of "compact" urban development can effectively alleviate the conversion of cultivated land to non-agricultural land [9,22]. Current research focuses on suburbs or rural areas characterized by rapid economic development, whereas there is little concern for underdeveloped rural mountainous areas. Moreover, the conversion of cultivated land to non-agricultural land strongly changes the land-use structure, which changes the rural ecological environment. However, the impact of the non-agriculturalization of cultivated land on the ecological environment has not yet been reported. Due to the interference of various complex human activities, developing countries with rapid economic development face the serious non-agriculturalization of cultivated land, which has a profound impact on food security.

As the most populous country in the world, China's cultivated land resources are relatively scarce, and the protection of cultivated land is an important task for land resource management [23]. Under the influence of China's rapid economic development, the problem of the non-agriculturalization of cultivated land caused by its occupation by built-up land is very prominent [11]. Simultaneously, blind deforestation and cultivation on steep slopes have caused serious soil erosion and frequent natural disasters in China over the past few decades. The Grain for Green Project, which was initiated in 2000 and aims to improve the quality of the ecological environment, has been implemented against the backdrop of the continuous rise in the national yield for staple grains. It encourages the conversion of a significant portion of sloping cultivated land to ecological land (forestland, shrubland, and grassland), which exacerbates the non-agriculturalization of cultivated land [15,24]. The Grain for Green Project has been primarily implemented in the karst mountainous regions of southwestern China, which are typical ecologically sensitive areas [25]. Furthermore, the rural economy in karst mountainous areas has significantly improved as a result of the influence of western development policies [26]. However, the lack of land resources in karst mountainous areas has caused a significant proportion of rural labor to migrate to cities, thereby disrupting the stability of the cultivated land landscape (such as cultivated land abandonment) and altering the ability of karst mountainous areas to maintain their natural landscapes. Furthermore, cultivated land has been converted into other high-yield non-agricultural land as a result of the conversion of farmers' livelihoods and the decrease in economic income from cultivated land [27,28]. While the quantification of land-use changes would aid in the understanding of the general characteristics of the conversion between different land-use types, it would not explain the mechanism by which cultivated land is converted to non-agricultural land, especially on a small scale.

According to the dominant landform types, four townships in southwestern China's Guizhou Province with different landform types were selected as typical representatives. The objectives of this study include the following: (1) to quantify the rate of conversion of cultivated land to non-cultivated land in karst mountainous areas; (2) to explore the slope gradient and spatial heterogeneity of the non-agriculturalization of cultivated land in karst mountainous areas; and (3) to analyze the correlation between the non-agriculturalization of cultivated land and landscape ecological risk. This study provides a reference for the protection of cultivated land and may help to clarify tradeoffs between the societal targets of land and the impacts of land-use changes in karst mountainous areas.

2. Materials and Methods

2.1. Overview of the Study Area

Karst landforms are a variety of surface and underground forms created by the long-term dissolution of soluble rocks by water. Due to the rugged terrain, thin soil, and shortage of surface water resources in karst landform areas, ecological fragility is prominent, the response to the interference of outside factors is weak, ecological restoration is difficult, and the population carrying capacity is low. The types of small-scale landforms in the karst mountainous areas of China are diverse, and there are heterogeneities in human activities and the natural conditions of different landforms; this results in differences in the land-use structures and their spatial patterns in different landform types [29]. According to the main landform types of karst mountainous areas in southwestern China, four typical townships in Guizhou Province with different landform types (Longchang with a karst mid-mountain landform, Liuguan with a karst basin landform, Xianchang with a karst trough valley landform, and Minxiao with a karst low hilly landform) were selected as the research areas (Figure 1). The altitude of Longchang with a karst mid-mountain landform is between 1283 and 2581 m, and the terrain relief is large. The altitude of Liuguan with a karst basin landform is between 1226 and 1382 m, the terrain in the central and eastern parts of this town is relatively flat, and there are low mountains in the southern and northern parts of the town. The altitude of Xianchang with a karst trough valley landform is between 758 and 1283 m, the central part of the town is a flat valley, and the eastern and western parts are high-altitude mountains. The altitude of Minxiao with a karst low hilly landform is between 758 and 1283 m. The town is located near the Fanjingshan Nature Reserve. In addition, as typical ecologically fragile areas in western China, the four selected towns belong to China's important ecological restoration areas, and the Grain for Green Project has been continuously implemented in this area for more than 20 years. Moreover, under the influence of poverty alleviation and resource development, the economy of karst mountainous areas has developed rapidly, and the per capita income reached 1715 USD/year by the end of 2020. However, compared with eastern China, the karst mountainous areas are still economically underdeveloped and suffer serious population loss [30].

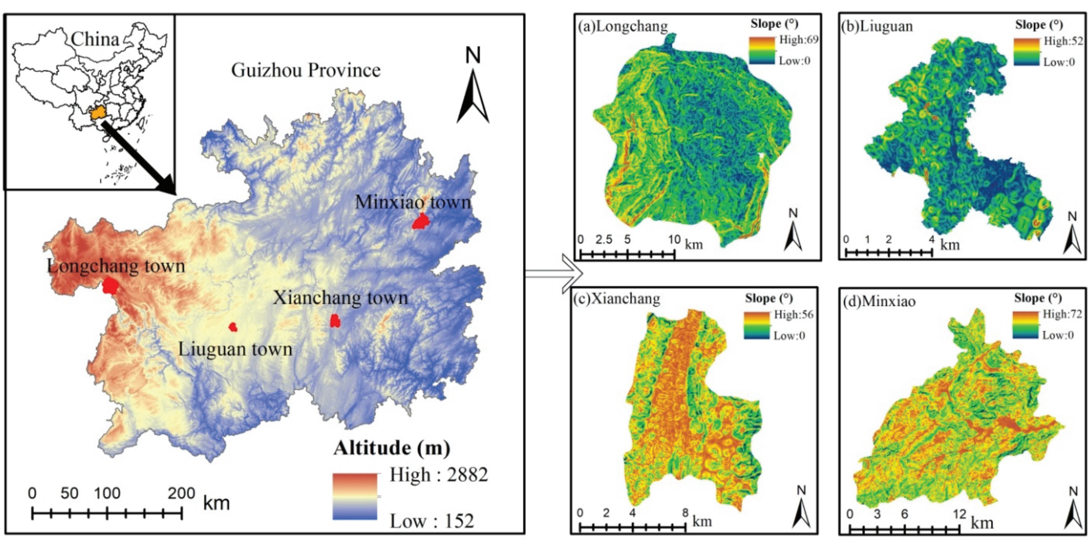

Figure 1. The locations of the four selected towns in karst mountainous areas. (**a**) Longchang, (**b**) Liuguan, (**c**) Xianchang, (**d**) Minxiao.

2.2. Data Sources and Processing

Two types of high-resolution remote sensing data from 2010 and 2020 were collected in this study, including SPOT remote sensing images (from March to November 2010) with a 5 m spatial resolution and Pleiades remote sensing images (from April to October 2020) with a 1 m spatial resolution. Image preprocessing was performed via geometric correction, image registration, image mosaic, and cutting. Due to the fuzzy boundaries between land-use types in the remote sensing images, it would be difficult for computer classification methods (such as supervised or unsupervised classification methods) to obtain good classification results. Therefore, the artificial visual interpretation of remote sensing images was adopted in this study. The detailed steps were as follows. First, the interpretation indicators of various land-use types were established via preliminary image interpretation and field investigation. Then, the images in 2010 and 2020 were visually interpreted, and the land use was divided into seven types: cultivated land, forestland, shrub-grassland, built-up land, roads, water bodies, and unused land (Figure 2). Finally, 400 field points were selected to evaluate the accuracy of the classification results. After the accuracy test, the mapping accuracy was found to exceed 89.16%, which indicates that the classification results were good and met the accuracy requirements of land data. Elevation data with a resolution of 30 m were downed from the platform of the Geospatial Data Cloud, Computer Network Information Center, Chinese Academy of Sciences (http://www.gscloud.cn, accessed on 18 August 2022). The slope analysis tool in ArcGIS software was used to generate slope data based on the elevation data, and the slope data were divided into five gradients via the quantile method (Table 1).

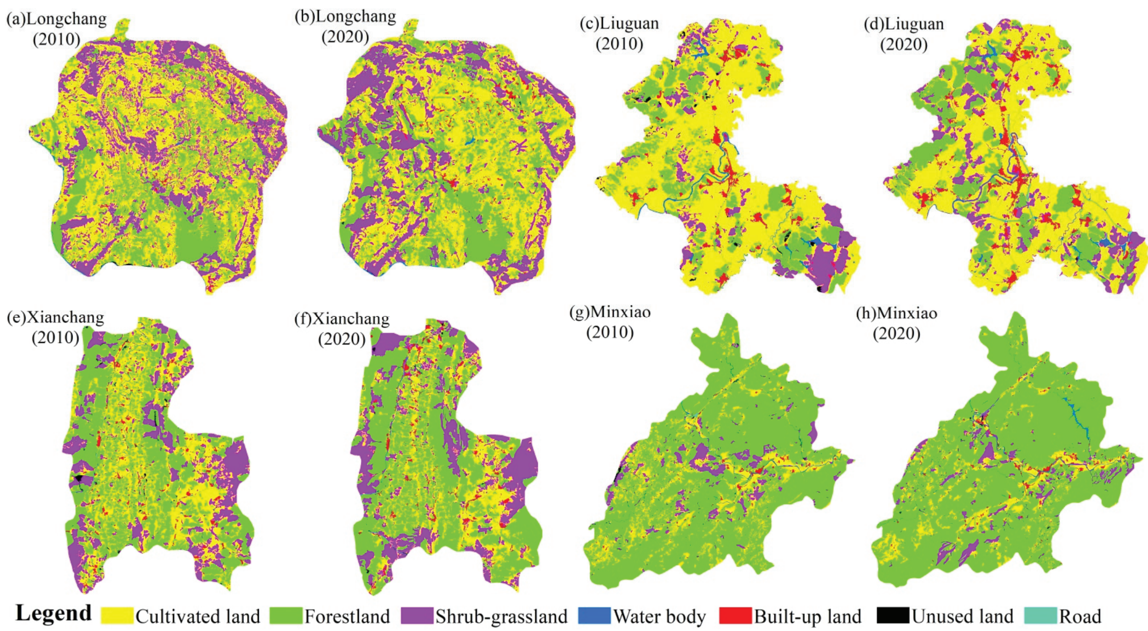

Figure 2. The distribution of land-use types. (**a**) Longchang in 2010,(**b**) Longchang in 2020, (**c**) Liuguan in 2010, (**d**) Liuguan in 2020, (**e**) Xianchang in 2010, (**f**) Xianchang in 2020, (**g**) Minxiao in 2010, (**h**) Minxiao in 2020.

Table 1. The slope classification of the karst mountainous areas.

Towns	Gradient I	Gradient II	Gradient III	Gradient IV	Gradient V
Longchang (karst mid-mountain)	0°–9.01°	9.02°–13.42°	13.43°–18.38°	18.39°–25.65°	25.66°–69.67°
Liuguan (karst basin)	0°–2.71°	2.72°–4.69°	4.70°–6.85°	6.86°–9.97°	9.98°–51.68°
Xianchang (karst trough valley)	0°–5.54°	5.55°–9.25°	9.26°–13.61°	13.62°–19.78°	19.79°–55.94°
Minxiao (karst low hilly)	0°–10.05°	10.06°–15.87°	15.88°–21.31°	21.32°–27.95°	27.96°–72.30°

2.3. Methods

2.3.1. Land-Use Change Matrix

In this study, the land-use change matrix is introduced to reflect the dynamic process of the reciprocal transformation between the areas of various land-use types at the beginning and end of a certain period. Its formula is as follows:

$$S_{ij} = \begin{bmatrix} S_{11} & S_{12} & \dots & S_{1n} \\ S_{21} & S_{22} & \dots & S_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ S_{n1} & S_{n2} & \dots & S_{nn} \end{bmatrix} \tag{1}$$

where S_{ij} represents the area converted from land-use type i to land use type j, n is the number of land-use types, and i and j represent the land-use types before and after the conversion, respectively.

2.3.2. Calculation Method of the Non-Agriculturalization of Cultivated Land

In this study, land-use types other than cultivated land are defined as non-cultivated land-use types (namely, forestland, shrub-grassland, built-up land, roads, water bodies, and unused land). Because forestland, shrub-grassland, water bodies, and unused land are crucial to the ecological environment, these land-use types are collectively referred to as ecological land in this article. Similarly, built-up land and roads are land-use types formed by human activities and have become the main space of human life. Therefore, they are collectively referred to as living land. Based on the preceding analysis, in this study, the non-agriculturalization of cultivated land is defined as the conversion of cultivated land into non-cultivated land-use types. It is composed of two parts: (1) the conversion of cultivated land into ecological land (forestland, shrub-grassland, water bodies, and unused land), and (2) the conversion of cultivated land into living land (built-up land and roads). Based on the data, the rate of conversion of cultivated land to non-cultivated land is calculated as follows:

$$N_e = W_i / G_j \times 100\% \tag{2}$$

$$N_l = L_i / G_j \times 100\% \tag{3}$$

$$N = N_e + N_l \tag{4}$$

where N represents the rate of conversion from cultivated land to non-cultivated land, N_e is the rate of conversion from cultivated land to ecological land (forestland, shrub-grassland, water bodies, and unused land), N_l is the rate of conversion from cultivated land to living land (built-up land and roads), W_i is the area of cultivated land converted to ecological land from 2010 to 2020, L_i is the area of cultivated land converted to living land from 2010 to 2020, and G_j is the area of cultivated land in 2010.

The area of cultivated land converted to non-cultivated land is calculated by the spatial analysis tool in ArcGIS. In addition, to achieve the clear spatial expression of the non-agriculturalization of cultivated land, the spatial pattern of the non-agriculturalization of cultivated land from 2010 to 2020 was presented by using the grid tool in ArcGIS.

2.3.3. Calculation Method of Landscape Ecological Risk

The calculation model of landscape ecological risk is established by considering the landscape disturbance index and landscape loss index. The landscape disturbance index represents the degree of external disturbance to different landscapes, which is calculated by the landscape separation index, dominance index, and fragmentation index. The landscape loss index represents the loss degree of landscape types under the interference of various factors.

$$U_i = bC_i + cF_i + aD_i \tag{5}$$

$$C_i = n_i / A_i \tag{6}$$

$$F_i = 0.5\sqrt{\frac{n_i}{A}} / \frac{A_i}{A} \tag{7}$$

$$D_i = 0.25 \times (n_i / N + m_i / M) + 0.5 \times A_i / A \tag{8}$$

where C_i represents the landscape fragmentation degree, F_i is the landscape separation degree, D_i is the landscape dominance degree, and the values of a, b, and c are, respectively, assigned as 0.5, 0.3, and 0.2 according to the expert scoring method. Moreover, N_i and N are, respectively, the numbers of patches in landscape i, and all landscape types, A_i and A are, respectively, the patch areas in landscape i and all landscape types, and M_i and M are, respectively, the number of grids in landscape i and the total number of grids.

$$R_i = U_i \times Q_i \tag{9}$$

where U_i represents the landscape disturbance index, and Q_i is the landscape vulnerability index. According to experts' experience, water bodies and unused land are the most vulnerable to external disturbances and have a vulnerability index of 5. Built-up land and roads are stable and have a vulnerability index of 1. Finally, cultivated land, shrub-grassland, and forestland have vulnerability indexes of 4, 3, and 2, respectively.

Based on the area ratio of various landscape types in each grid, the calculation model of the landscape ecological risk index is established as follows:

$$ERI_i = \sum_{i=1}^{n} \frac{A_i}{A} \times R_i \tag{10}$$

where ERI_i represents the landscape ecological risk index, A_i is the area of landscape i, A is the area of all landscape types, and R_i is the landscape loss index of landscape i.

The grid tool in ArcGIS software was used to divide Longchang, Liuguan, Xianchang, and Minxiao into 167, 157, 148, and 160 grids, respectively. Then, the landscape ecological risk index of each grid was calculated to obtain the risk value of the sample center, and the spatial pattern map of landscape ecological risk was generated by using the spatial interpolation tool in ArcGIS software. The landscape indices (N_i, N, A_i, and A in Equation (10)) required for landscape ecological risk calculation were obtained by Fragstats 4.2 software.

2.3.4. Correlation between the Non-Agriculturalization of Cultivated Land and Landscape Ecological Risk

The global and local Moran's indices were introduced to analyze the spatial correlation between the non-agriculturalization of cultivated land and landscape ecological risk. The global Moran's index was used to determine the correlation between the non-agriculturalization of cultivated land and landscape ecological risk in the whole research area. The local Moran's index was used to identify the distribution of the types of spatial agglomeration between the non-agriculturalization of cultivated land and landscape ecological risk in local areas (i.e., within the demarcated grid).

$$I = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}(x_i - \overline{x})(x_j - \overline{x})}{\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij} \sum_{i=1}^{n} (x_i - \overline{x})^2} \tag{11}$$

$$I_i = \frac{(x_i - \overline{x})}{S^2} \sum_{j=1}^{n} W_{ij}(x_j - \overline{x}) \tag{12}$$

where I and I_i are, respectively, the global and local Moran's indices, and X_i and X_j are, respectively, the values of the non-agriculturalization of cultivated land and landscape ecological risk in spatial units i and j. Moreover, $\overline{x}$ is the average value of the non-agriculturalization of cultivated land and landscape ecological risk of all spatial units, W_{ij} is the spatial weight, and S^2 is the variance of the non-agriculturalization of cultivated land and the landscape ecological risk value of each spatial unit.

A value of I greater than 0 indicates that there is a positive spatial correlation between the two variables. The larger the value, the more obvious the spatial agglomeration. A value of I less than 0 indicates a negative spatial correlation. If the value of I is equal to 0, there is no correlation between the two variables. According to the calculation results of I_i, the agglomeration types of the study area were divided into high-high, low-low, high-low, low-high, and not significant areas.

3. Results

3.1. Land-Use Change Matrix

From 2010 to 2020, the increased area of cultivated land in the four towns mainly resulted from shrub-grassland and forestland, while the decreased area of cultivated land was mainly converted to shrub-grassland, forestland, and built-up land. The transition area between cultivated land, forestland, and shrub-grassland in the four towns was large, whereas the transition area in water bodies and unused land was small. The increased area of built-up land and roads mainly resulted from cultivated land (Table 2).

3.2. Changes in the Non-Agriculturalization of Cultivated Land

Based on Equations (3)–(5), the rate of conversion from cultivated land to non-cultivated land was obtained, as reported in Table 3. The total rate of conversion from cultivated land to non-cultivated land in Xianchang with a karst trough valley landform was found to be higher than that in Minxiao with a karst low hilly landform. The total rates of conversion from cultivated land to non-cultivated land in Longchang with a karst mid-mountain landform and Liuguan with a karst basin landform were found to be lower than those in the other two towns. The rate of conversion from cultivated land to ecological land, in descending order, was found to be that of Xianchang, Minxiao, Longchang, and Liuguan. The rates of conversion of cultivated land to living land in Minxiao, Xianchang, and Liuguan were found to be higher than that in Longchang (Table 3).

Table 2. The land-use change matrix from 2010 to 2020 (hm^2).

Town	Land Use Types	Cultivated Land	Forestland	Shrub-Grassland	Water Bodies	Built-Up Land	Unused Land	Roads	Total Area in 2010
Longchang (karst mid-mountain)	Cultivated land	8674.70	951.97	2224.76	5.06	238.76	5.41	95.22	12,195.88
	Forestland	832.35	4422.79	746.47	3.29	142.01	1.87	35.61	6184.39
	Shrub-grassland	1718.58	1705.13	3130.53	14.76	121.64	10.35	51.82	6752.81
	Water bodies	7.47	6.57	9.82	60.02	0.08	0.80	0.53	85.29
	Built-up land	76.19	26.38	29.76	0.01	287.60	1.14	8.44	429.52
	Unused land	6.80	0.62	2.81	10.80	0.52	2.44	0.82	24.82
	Roads	97.01	39.61	33.77	0.88	17.73	0.71	132.96	322.67
	Total area in 2020	11,413.10	7153.07	6177.92	94.82	808.34	22.72	325.40	25,995.38
Liuguan (karst basin)	Cultivated land	1818.86	251.98	255.48	14.26	78.34	0.59	34.25	2453.75
	Forestland	119.61	542.28	105.39	2.18	10.86	0.79	3.23	784.34
	Shrub-grassland	204.60	95.36	143.36	1.91	4.72	0.00	3.89	453.83
	Water bodies	15.17	2.83	11.05	33.56	0.49	0.00	1.08	64.18
	Built-up land	20.47	10.22	11.39	0.71	104.61	0.04	1.15	148.58
	Unused land	6.77	6.52	13.93	0.30	0.17	0.03	0.16	27.88
	Roads	0.65	0.05	0.12	0.03	0.45	0.00	27.67	28.96
	Total area in 2020	2186.12	909.24	540.71	52.95	199.62	1.45	71.43	3961.52
Xianchang (karst trough valley)	Cultivated land	1520.95	1221.56	530.27	22.65	140.81	6.60	21.49	3464.34
	Forestland	655.70	2954.71	765.72	5.46	43.28	8.49	19.17	4452.53
	Shrub-grassland	234.41	808.00	992.40	0.77	16.96	3.62	4.51	2060.67
	Water bodies	25.27	8.56	2.82	2.87	3.55	0.21	0.19	43.46
	Built-up land	79.20	64.10	23.92	2.23	69.10	0.98	4.04	243.57
	Unused land	6.91	16.31	22.15	0.01	0.78	0.65	1.33	48.13
	Roads	5.40	9.13	6.33	0.25	5.65	0.16	48.35	75.27
	Total area in 2020	2527.83	5082.36	2343.61	34.24	280.12	20.71	99.08	10,387.96
Minxiao (karst low hilly)	Cultivated land	2532.27	1087.71	329.43	47.16	150.23	9.98	93.33	4250.11
	Forestland	443.17	17774.27	667.29	43.65	64.10	12.08	85.10	19,089.67
	Shrub-grassland	119.29	1129.55	343.23	8.08	5.31	0.23	7.62	1613.31
	Water bodies	21.11	13.65	12.93	95.73	3.31	0.85	4.51	152.09
	Built-up land	29.60	21.26	8.68	1.70	210.11	0.81	9.72	281.89
	Unused land	6.87	19.86	18.26	3.95	1.29	1.54	3.11	54.88
	Roads	19.97	27.37	12.81	4.23	5.92	0.33	62.42	133.06
	Total area in 2020	3172.28	20,073.68	1392.63	204.50	440.26	25.82	265.83	25,575.00

Table 3. The overall characteristics of the rate of conversion from cultivated land to non-cultivated land from 2010 to 2020 (%).

Town	Rate of Conversion from Cultivated Land to Ecological Land	Rate of Conversion from Cultivated Land to Living Land	Total Rate of Conversion from Cultivated Land to Non-Cultivated Land
Longchang (karst mid-mountain)	26.02	2.71	28.73
Liuguan (karst basin)	21.36	4.55	25.91
Xianchang (karst trough valley)	51.43	4.72	56.15
Minxiao (karst low hilly)	34.69	5.59	40.28

Note: Ecological land includes forestland, shrub-grassland, water bodies, and unused land. Living land includes built-up land and roads. Non-cultivated land includes ecological land and living land.

With the increase of the slope gradient (from gradient I to V), the rate of conversion of cultivated land to non-cultivated land was found to increase in Longchang with a karst mid-mountain landform and Liuguan with a karst basin landform but decreased in Xianchang with a karst trough valley landform and Minxiao with a karst low hilly landform. The rate of conversion of cultivated land to living land in the four towns with different landforms was found to decrease from slope gradient I to V. The change characteristics of the rate of conversion from cultivated land to ecological land in Longchang and Liuguan were found to be contrary to those in Xianchang and Minxiao from gradient I to V (Table 4).

Table 4. The slope gradient characteristics of the non-agriculturalization of cultivated land from 2010 to 2020 (%).

Town	Conversion Types	Gradient I	Gradient II	Gradient III	Gradient IV	Gradient V
Longchang (karst mid-mountain)	Rate of conversion from cultivated land to ecological land	3.25	3.77	4.67	6.33	8.00
	Rate of conversion from cultivated land to living land	0.79	0.69	0.54	0.44	0.25
	Total rate of conversion from cultivated land to non-cultivated land	4.04	4.45	5.20	6.77	8.25
Liuguan (karst basin)	Rate of conversion from cultivated land to ecological land	2.78	3.61	4.20	5.15	5.63
	Rate of conversion from cultivated land to living land	1.27	1.05	1.02	0.61	0.59
	Total rate of conversion from cultivated land to non-cultivated land	4.04	4.66	5.22	5.76	6.22
Xianchang (karst trough valley)	Rate of conversion from cultivated land to ecological land	12.44	12.43	10.81	8.77	6.98
	Rate of conversion from cultivated land to living land	2.16	1.38	0.75	0.28	0.14
	Total rate of conversion from cultivated land to non-cultivated land	14.60	13.81	11.56	9.05	7.12

Table 4. *Cont.*

Town	Conversion Types	Gradient I	Gradient II	Gradient III	Gradient IV	Gradient V
Minxiao (karst low hilly)	Rate of conversion from cultivated land to ecological land	10.81	9.49	7.24	5.10	2.04
	Rate of conversion from cultivated land to living land	3.38	1.15	0.63	0.33	0.10
	Total rate of conversion from cultivated land to non-cultivated land	14.19	10.64	7.87	5.43	2.14

Note: Ecological land includes forestland, shrub-grassland, water bodies, and unused land. Living land includes built-up land and roads. Non-cultivated land includes ecological land and living land. The slope is divided into five gradients (from gradient I to V) according to the slope value from lowest to highest.

The rate of conversion from cultivated land to forestland in Xianchang with a karst trough valley landform and Minxiao with a karst low hilly landform was found to be higher than those in Liuguan with a karst basin landform and Longchang with a karst mid-mountain landform. The rates of conversion from cultivated land to shrub-grassland in Minxiao and Liuguan were found to be lower than those in Longchang and Xianchang. The rates of conversion from cultivated land to water bodies and unused land in the four towns were found to be low. Moreover, the rates of conversion from cultivated land to built-up land and roads in Minxiao, Xianchang, and Liuguan were found to be higher than those in Longchang (Table 5).

Table 5. The rate of conversion from cultivated land to each non-cultivated land type from 2010 to 2020 (%).

Conversion Type	Longchang (Karst Mid-Mountain)	Liuguan (Karst Basin)	Xianchang (Karst Trough Valley)	Minxiao (Karst Low Hilly)
Conversion to forestland	7.81	10.27	35.26	25.59
Conversion to shrub-grassland	18.24	10.41	15.31	7.75
Conversion to water bodies	0.04	0.58	0.65	0.91
Conversion to unused land	0.04	0.02	0.19	0.23
Conversion to built-up land	1.96	3.19	4.06	3.53
Conversion to roads	0.78	1.40	1.62	2.20

The high-value area of the non-agriculturalization rate (>20%) in Longchang is concentrated in the western part, while the low-value area (<10%) is concentrated in the eastern and southern parts (Figure 3a). The high-value area of the non-agriculturalization rate (>20%) in Liuguan is widely distributed and mainly located in the western, northern, and central parts, while the areas with a non-agriculturalization rate of less than 20% are scattered (Figure 3b). The high-value area of the non-agriculturalization rate (>20%) in Xianchang is mainly distributed in the central part, and the non-agriculturalization rate in most of the eastern and western regions is less than 20% (Figure 3c). In most areas of Minxiao, the non-agriculturalization rate is less than 20%, and these regions are mainly located in the western, central, and southern areas (Figure 3d).

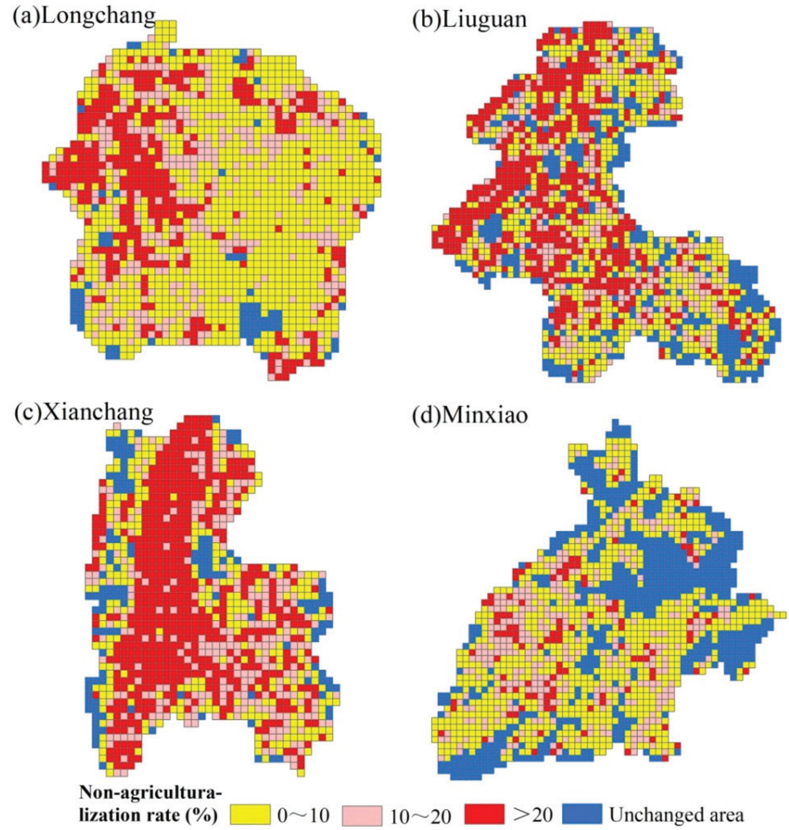

Figure 3. The spatial patterns of the non-agriculturalization of cultivated land from 2010 to 2020. (**a**) Longchang, (**b**) Liuguan, (**c**) Xianchang, (**d**) Minxiao.

3.3. Changes of Landscape Ecological Risk

Overall, the amounts of change of the landscape ecological risk in Longchang with a karst mid-mountain landform and Minxiao with a karst low hilly landform decreased from 2010 to 2020, while those in Liuguan with a karst basin landform and Xianchang with a karst trough valley landform increased. With the increase of the slope gradient, the amount of change of the landscape ecological risk index in the four towns was found to gradually decrease (Table 6).

Table 6. The changes of landscape ecological risk from 2010 to 2020.

Towns	Gradient I	Gradient II	Gradient III	Gradient IV	Gradient V	Total Area
Longchang (karst mid-mountain)	−1.4018	−1.2992	−1.1084	−0.8274	−0.4499	−1.0180
Liuguan (karst basin)	1.2768	1.0701	0.9876	0.9398	0.8968	1.0344
Xianchang (karst trough valley)	0.1763	0.133	0.0555	−0.0402	−0.0327	0.0606
Minxiao (karst low hilly)	−0.0626	−0.0549	−0.0447	−0.0322	−0.0247	−0.0373

Note: The slope is divided into five gradients (from gradient I to V) according to the slope value from lowest to highest.

Except for the southern part, most parts of Longchang experienced a decrease in landscape ecological risk, and the central part exhibited a significant decrease (Figure 4a). The landscape ecological risk increased in most parts of Liuguan, and the amount of increase of the landscape ecological risk in the southeastern part was higher than that in other parts (Figure 4b). The landscape ecological risk increased in the central part of Xianchang but decreased in the eastern and western parts (Figure 4c). The landscape ecological risk in Minxiao decreased in the western and eastern parts but increased in the southeastern and northern parts (Figure 4d).

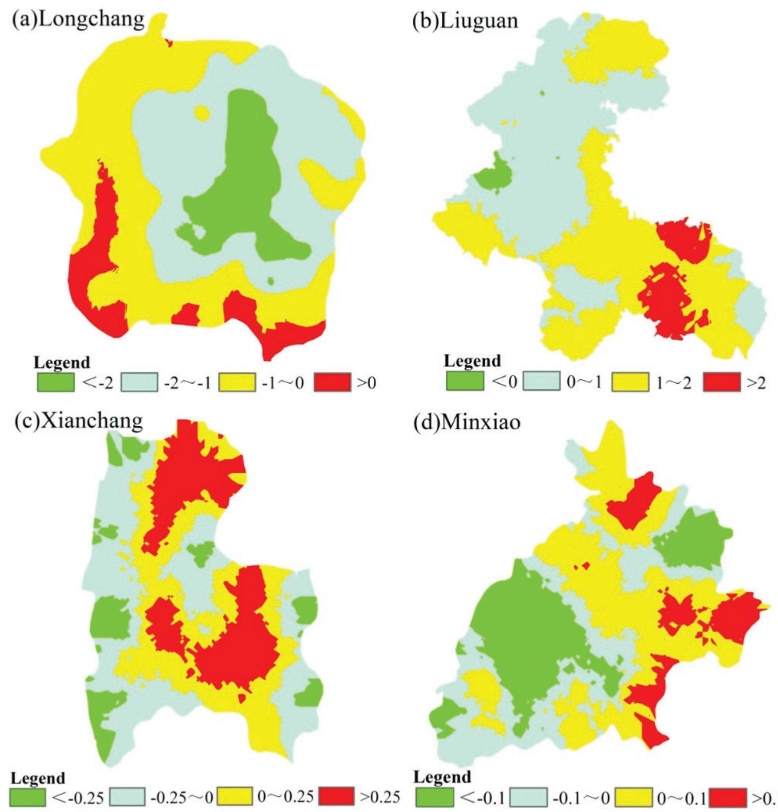

Figure 4. The spatial patterns of changes in landscape ecological risk from 2010 to 2020. (**a**) Longchang, (**b**) Liuguan, (**c**) Xianchang, (**d**) Minxiao.

3.4. Correlation between the Non-Agriculturalization of Cultivated Land and Landscape Ecological Risk

A negative correlation was found between the non-agriculturalization of cultivated land and landscape ecological risk in the four towns. The degrees of correlation between the non-agriculturalization of cultivated land and landscape ecological risk in Liuguan with a karst basin landform and Xianchang with a karst trough valley landform were higher than those in Longchang with a karst mid-mountain landform and Minxiao with a karst low hilly landform. Except for Liuguan, the degrees of correlation between the non-agriculturalization of cultivated land and landscape ecological risk in the other three towns were found to gradually decrease from slope gradient I to V (Table 7).

Table 7. The correlation coefficient (global Moran's index) between the non-agriculturalization of cultivated land and landscape ecological risk.

Town	Gradient I	Gradient II	Gradient III	Gradient IV	Gradient V	Total Area
Longchang (karst mid-mountain)	−0.197 **	−0.193 **	−0.186 **	−0.165 **	−0.086 **	−0.171 **
Liuguan (karst basin)	−0.280 **	−0.281 **	−0.290 **	−0.303 **	−0.322 **	−0.297 **
Xianchang (karst trough valley)	−0.325 **	−0.323 **	−0.315 **	−0.295 **	−0.291 **	−0.334 **
Minxiao (karst low hilly)	−0.151 **	−0.149 **	−0.143 **	−0.132 **	−0.127 **	−0.146 **

Note: ** indicates a significant correlation at the 0.01 level, * represents a significant correlation at the 0.05 level. The slope is divided into five gradients (from gradient I to V) according to the slope value from lowest to highest.

The high-high and low-high areas of Longchang are concentrated in the western and southern parts, while the low-low and high-low areas are concentrated in the central part (Figure 5a). The high-high and low-high areas in Liuguan are mainly distributed in the southern part, while the low-low and high-low areas are mainly distributed in the northwestern part (Figure 5b). The northern and southern parts of Xianchang are dominated by high-high and low-high areas, while the western and eastern parts are dominated by low-low and high-low areas (Figure 5c). The eastern and central parts of Minxiao are dominated by low-low and high-low areas, while the southeastern and northern parts are dominated by high-high and low-high areas (Figure 5d).

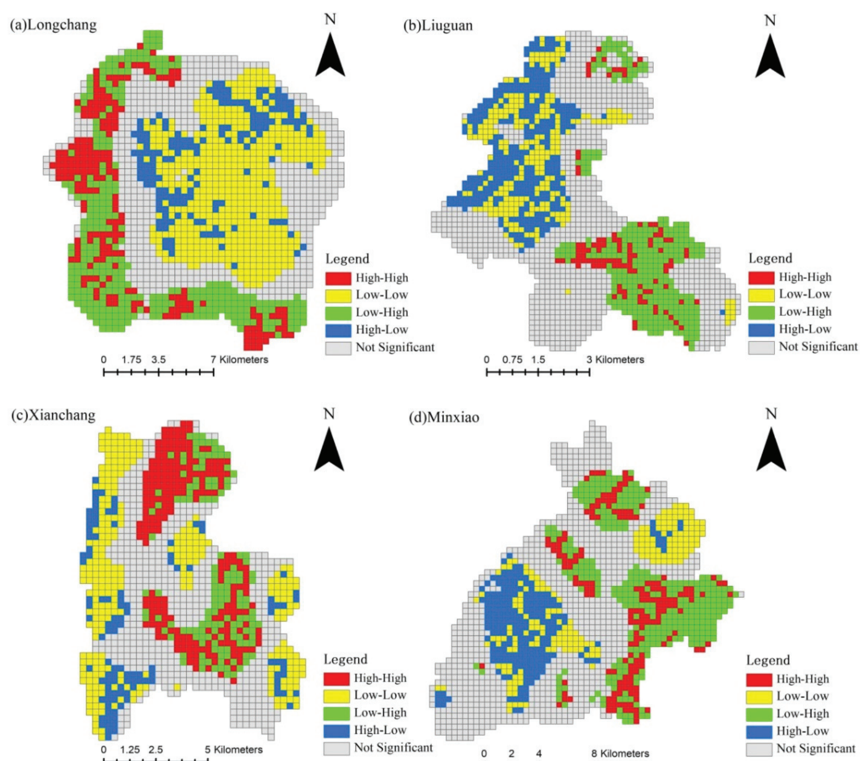

Figure 5. The spatial patterns of the types of agglomeration between the non-agriculturalization of cultivated land and landscape ecological risk. (**a**) Longchang, (**b**) Liuguan, (**c**) Xianchang, (**d**) Minxiao.

4. Discussion

4.1. Comparison with Previous Research Results

This study found that the karst mountainous areas in western China face the serious non-agriculturalization of cultivated land, which is consistent with the research results of scholars in Africa, Europe, and eastern China [4,9,10]. However, regarding the formation factors of the non-agriculturalization of cultivated land, the results of this study differ from those conducted in other regions around the world. Ecological management policy (namely, the Grain for Green Project) is the key factor causing the non-agriculturalization of cultivated land in the karst mountainous areas of western China, while non-agriculturalization in other regions of the world is mainly caused by urbanization and industrialization [31,32]. In addition, this study found a negative correlation between the non-agriculturalization of cultivated land and landscape ecological risk, i.e., the non-agriculturalization of cultivated land has a positive impact on the ecological environment, which is contrary to the research results of Yang [33] and Yang [34]. The reason for this is that the cultivated land in the karst mountainous areas considered in this study has been mainly converted to ecological land. In contrast, Yang [33] and Yang [34] found that cultivated land was mainly converted to built-up land.

4.2. Formation Mechanism of the Non-Agriculturalization of Cultivated Land in Karst Mountainous Areas

From the 1950s to the end of the century, a large amount of sloping land in karst mountainous areas in China was reclaimed to cope with the increased demand for food caused by the surging population. To deal with the serious ecological problems (such as rock desertification and soil erosion) caused by excessive land reclamation, the Grain for Green Project was implemented in the 21st century, which resulted in the conversion of a large amount of sloping cultivated land to ecological land [35]. Therefore, although the project is helpful for the restoration of the ecological environment, it causes the serious conversion of cultivated land to non-agriculturalization land-use types in karst mountainous areas. In addition, although economic development due to China's western development policy has led to the conversion of a portion of cultivated land in karst mountainous areas to built-up land and roads in the past ten years [36,37], the resulting rate of conversion of the non-agriculturalization of cultivated land has been far lower than the impact of the Grain for Green Project; this is related to the low demand for artificial land resulting from population losses and a low economic level. It should be noted that the cultivated land in karst mountainous areas is mainly converted into ecological land, and the increase of the natural landscape reduces the degree of landscape fragmentation and vulnerability. Therefore, there is a negative correlation between the non-agriculturalization of cultivated land and landscape ecological risk in karst mountainous areas.

Different landform regions have different natural conditions and human activities, which lead to differences in the distribution and utilization of cultivated land [38]. Under the interference of complex human activities, the changes of cultivated land in different karst landforms are bound to be different, which causes variations in the non-agriculturalization characteristics of cultivated land in different landforms. For example, Minxiao with a karst low hilly landform is located in the surrounding area of the Fanjing Mountain Nature Reserve. To protect and restore the ecological environment, a large amount of sloping cultivated land has been converted to forestland and shrub-grassland, which has caused a high non-agriculturalization rate in this town. However, the terrain of Liuguan is relatively flat, and there is little sloping farmland. The Grain for Green Project has had a relatively small influence on the conversion of cultivated land to non-agricultural land in this town, resulting in a lower non-agriculturalization rate in this town as compared to that in other towns with different landforms.

4.3. Land Management Policy

In view of the serious situation of the non-agriculturalization of cultivated land in karst mountainous areas, the following measures are suggested. (1) It is suggested that a balanced relationship between economic development, ecological restoration, and cultivated land protection be coordinated. First, the traditional mode of economic development in karst mountainous areas must be changed to reduce the amount of cultivated land occupied by built-up land. Second, it is necessary to reasonably arrange the implementation planning of the Grain for Green Project and prevent a large amount of cultivated land from being converted into ecological land. Finally, the red line of cultivated land protection should be delimited, and priority protection should be given to high-quality and concentrated contiguous cultivated land. The non-agriculturalization of high-quality cultivated land should be avoided. (2) It is necessary to improve the level of the intensive utilization of built-up land, and the government should establish an economic penalty mechanism to prevent the excessive conversion from cultivated land to built-up land. (3) It is necessary to improve the irrigation conditions of cultivated land, increase the usage degree of agricultural machinery, and improve the agricultural production efficiency. In addition, it is necessary to increase planting subsidies for cultivated land to prevent the abandonment of cultivated land, especially sloping cultivated land.

4.4. Limitations

The spatial resolution of the remote sensing images is one of the factors affecting the reliability of the research results. In view of the small spatial scale of the four selected towns, high-precision remote sensing images were selected for use in this study. However, due to the difficulty in obtaining long-term historical remote sensing images with high precision, only the past decade (between 2010 and 2020) was selected as the research period. Thus, the short research period was a limitation of this study.

5. Conclusions

The issue of the conversion of cultivated land into non-cultivated land in karst mountainous areas in China has been very serious. The conversion is mainly manifested as the conversion of cultivated land to forestland and shrub-grassland. The rate of conversion from cultivated land to ecological land is significantly higher than that from cultivated land to living land. There are differences in the non-agriculturalization of cultivated land in different slope gradients of different karst landforms. The Grain for Green Project has led to the conversion of a large amount of cultivated land into ecological land in karst mountainous areas in China and has played a key role in the non-agriculturalization of cultivated land in this area. The increase of ecological land and the decrease of cultivated land resulting from the non-agriculturalization of cultivated land have reduced the degree of landscape disturbance, which has led to a negative correlation between the non-agriculturalization of cultivated land and landscape ecological risk. It is worth noting that the conversion of cultivated land into non-cultivated land has not caused food risk, as revealed by the grain yield data on the national scale. This study is of great value to the formulation of protection strategies for cultivated land. Future research should predict the future conversion of cultivated land to non-agricultural land under different development scenarios based on a mathematical spatial model. In addition, in future research, questionnaires will be used to analyze the impacts of various economic factors on the non-agriculturalization of cultivated land at the scale of farmers.

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Article

Spatial–Temporal Change in Paddy Field and Dryland in Different Topographic Gradients: A Case Study of China during 1990–2020

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Abstract: As a country with a vast area and complex terrain, the differentiation between paddy field and dryland under different topographic gradients in China is difficult. Based on a land-use grid data set with an accuracy of 1 km, this study applied the Topographic Potential Index and used land-use transition matrices and landscape analysis to compare the change in dryland and paddy field in China from 1990 to 2020 at different elevations, slopes, and slope aspects. The results indicate that paddy field and dryland were mostly distributed in areas with better photothermal conditions. However, in recent years, the paddy field and dryland on the "sunny" slope decreased. Specifically, the area of paddy field and dryland on the southeast, south, and southwest slopes decreased, while they increased on the northwest, north, and northeast slopes. From 1990 to 2020, land conversion among paddy field, dryland, and other land use was mostly concentrated in the third ladder (<500 m elevation) of China. However, the changes in paddy field and dryland have now become active on the second ladder of China. Moreover, the change from other land to dryland on the second ladder accounted for nearly 50% of the country's change from other land to dryland. Paddy fields and drylands in areas with low elevation and low slopes were reduced, whereas those with higher elevation and higher slopes increased, indicating that the arable land in mountainous areas increased. This indicates that the topographic conditions of arable land that become worse may aggravate soil erosion in the planting process. The landscape fragmentation of paddy field and dryland increased. Compared with paddy field, the dryland was more aggregated, the shape was more complex, and the land plots were more fragmented. As a result, paddy field and dryland show significant differences in their spatial–temporal pattern, landscape characteristics, and land-use changes, and these results can provide an important reference for the sustainable utilization of arable land resources.

Keywords: paddy field; dryland; topographic gradient; landscape characteristics; land-use change

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1. Introduction

China is a huge nation with significant regional variations in land and water resources. Divided by the Qinling Mountains–Huaihe River line, a unique pattern of arable land use of "paddy fields in the south and drylands in the north" has formed. In the south, paddy fields account for the majority of the total area of paddy fields in China. The soil types in the south are mainly yellow–brown soil and red soil (on the Middle-Lower Yangtze Plain), lateritic red soil and latosol soil (on the Pearl River Delta Plain), purple soil and paddy soil (in the Sichuan Basin), and yellow soil (in the hilly southeastern region). The climate in the south is dominated by a tropical and subtropical monsoon climate, with an accumulated temperature of 4500–8000 °C, abundant precipitation, and sufficient heat, which forms a pattern of aquatic-based paddy farming. In the north, drylands account for the majority of the total drylands in China. The soil types are mainly Huangmian soil and Heilu soil (in the Loess Plateau), gray–brown desert soil (in Xinjiang), brown soil and cinnamon soil (in the North China Plain), and black soil and dark-brown soil (in the Northeast Plain). The warm-temperate continental monsoon climate in the north, with an accumulated precipitation of approximately between 400 and 800 mm, forms scarce water resources, which contribute to a pattern of wheat- and maize-based dryland farming.

However, the change in paddy field and dryland is continuously dynamic and implicit, and its long-term accumulation may lead to implicit differences in arable land use. Taking the quantity and structure of paddy field and dryland in each province of China as an example, the increase in drylands and the decrease in paddy fields occurred simultaneously over the past 30 years. The province with the largest increase in paddy fields is Heilongjiang, with a cold-temperate climate in the northeast (+27,030 km^2). The province with the largest increase in drylands is Xinjiang, with a dry climate in the northwest (+23,306 km^2). The province with the largest decrease in both paddy fields and drylands is Guangxi Province, with fertile soil in south China (paddy fields and drylands decreased by 23,306 and 14,719 km^2, respectively). In addition, relevant studies also pointed out that arable land has decreased in south China and increased in North China [1,2]. Specifically, the paddy fields increased rapidly in the northeast, whereas the drylands increased rapidly in the northwest. The spatial barycenter of paddy field and dryland in China moved northward, which indicates that the arable land moved from better agricultural areas to worse ones [3,4]. Thus, paddy fields and drylands are mostly reduced in areas with a better natural environment, while the newly added drylands and paddy fields are mostly located in areas with worse natural endowments. For example, benefited by the warm and humid climate, the Middle-Lower Yangtze Plain contributed one of highest yields of rice, wheat, and cotton in China. On the other hand, in inland Northwest China, surface water only accounts for approximately 8% of the total runoff in China because of the dry climate. The decrease in arable land in the Yangtze Plain and the increase in arable land in Northwest China shows a spatial mismatch of natural endowment and land resources. As a result, a serious spatial mismatch exists between the distribution of paddy field and dryland and the distribution of high-quality natural resources in China [5–9].

Research on the distribution patterns of paddy field and dryland has increased rapidly over the past 30 years. Previous studies mostly focused on local areas with unique geomorphological characteristics [10,11] and were devoted to analyzing the spatiotemporal change, landscape characteristics, or ecological service efficiencies of paddy field and dryland from the perspective of a single topographic element [10,12,13]. In Heilongjiang Province, Li [14] and Chen [15] found that the spatial expansion of arable land showed a strong directional trend, and the topography and geomorphology conditions were the key factors influencing the changes in paddy field and dryland. Gao [16] found that new arable and lost arable land were mainly concentrated in the plains, followed by the tablelands and hills. It was found that the drylands and paddy fields in the Loess Plateau and Chongqing city were mainly distributed at lower elevations [17,18]. By comparing land-use images from 1933, 1955, 1990, and 2005, Liu [19] found that new paddy fields in the Jinjing River of Hunan Province mainly came from woodland, which was mainly affected by topography conditions (especially elevation). By using the logit model, Zhong [20] analyzed the low mountain hilly area in southeastern China from 1999 to 2006 and found that the loss of agricultural land was the highest at low altitudes, followed by medium and high altitudes. The above studies indicate the importance of topographic factors when analyzing arable land change. Topographic differences impact the configuration of surface water, fertilizer, air, and heat, which forms the spatiotemporal differences between paddy field and dryland. Therefore, the change in paddy field and dryland on different topographic gradients should become a new tool for studying the mechanism of arable land utilization. However, in a vast area with great geographical differences, such as in China, the differentiation of long-term spatial–temporal changes in paddy field and dryland based on topographic gradients is missing.

It is crucial to study the spatial–temporal evolution and internal changes in paddy field and dryland under different topographic gradients in China. As the two major subtypes of arable land, paddy field and dryland may show different changes, further reflecting the implicit transformation of arable land use. This study refines the research perspective of arable land use by separately observing paddy field and dryland and discusses the following questions:

I. When observing topographic conditions in terms of elevation, slope, and slope aspect, are there any differences in the spatial distribution between paddy field and dryland?

II. What is the difference in the land type changes among paddy field, dryland, and other land under different topographic conditions?

III. What do the landscape characteristics of paddy field and dryland look like from the perspective of different topographic conditions?

To address these problems, this paper took the topographic gradient as the research perspective and analyzed the spatial–temporal differentiation of two types of arable land use, paddy field and dryland, at different elevations, slopes, and slope aspects. The scientific basis for optimizing and reconstructing sustainable arable land use was provided based on the research results.

2. Research Methods and Data Source

2.1. Data Sources

This paper used land-use raster data on China with a resolution of 1 km in 1990, 1995, 2000, 2005, 2010, 2015, and 2020. These data came from the Chinese Academy of Sciences, Resource, and Environmental Science Data Center (https://www.resdc.cn/, accessed on 10 February 2021). The land-use raster data were established based on remote sensing satellite imagery data (Landsat 8 OLI and GF-2). Using a high-resolution remote sensing drone ground survey observation system, the spatial distribution of the land-use cover was interpreted artificially by manual visual interpretation. The testing involved a large number of samples and achieved > 94.3% accuracy [1], and such testing has played an important role in national land research. The land-use classification included six land-use types: arable land, woodland, grassland, water area, construction land, and unutilized land. These data extracted the arable land in the data set and included the two major subtypes of arable land used in the analysis: dryland and paddy field. Specifically, dryland included rain-fed land and land with irrigation facilities that grows dryland crops; paddy field contained land with irrigation facilities that grows aquatic crops.

2.2. The Identification of the Topographic Conditions of Paddy field and Dryland

This study used 250 m DEM raster data to calculate the elevations and slopes of paddy field and dryland using the ArcGIS Toolbox. We extracted by mask the 1 km land-use data by the reclassified DEM information to obtain the different topographic conditions of the paddy field and dryland distribution. Based on the suitability of growing staple crops, the elevations were divided into 7 gradients including 0–200, 200–500, 500–1000, 1000–1500, 1500–2500, 2500–3500, and >3500 m. Similarly, the slopes were divided into 5 grades: 0–2°, 2–6°, 6–15°, 15–25°, and >25°. The slope directions were divided into north, northeast, east, southeast, south, southwest, west, and northwest categories.

2.3. The Transformation between Paddy Field and Dryland

This paper calculated the land-use transformation matrix among paddy field, dryland, and other land-use types based on the toolbox in ArcGIS 10.2. The calculations were as follows:

Firstly, paddy field, dryland, and other land-use types in the A_{th} year were reclassified as 1, 2, and 3. Paddy field, dryland, and other land-use types in the B_{th} year were reclassified as 10, 20, and 30.

Secondly, the land-use layers of the A_{th} year and the B_{th} year were summed in the raster calculator, and the attribute data of the newly exported layer indicated the number of rasters that changed from one land-use type in the A_{th} year to another one in the B_{th} year. For instance, 12 indicates the land-use change from a paddy field in the A_{th} year to dryland in the B_{th} year. Detailed attributed data and the implication of the land-use change are listed in Table 1.

Thirdly, the total area of land changed from one land-use type to another was calculated by multiplying the number of the changed rasters by the area of the rasters (i.e., 1 km^2 in this study).

Table 1. The attribute data and the implication of the land-use change.

Grid Value	Implication	Grid Value	Implication
11	Unchanged paddy field	22	Unchanged dryland
12	Paddy field→Dryland	21	Dryland→Paddy field
13	Paddy field→Other land	23	Dryland→Other land
31	Other land→Paddy field	32	Other land→Dryland

2.4. The Landscape Characteristics of Paddy Field and Dryland

In land use, different land units combine into different spatial patterns such as land patch densities, shape characteristics, and aggregation degrees. These features constitute the landscape differences between paddy field and dryland. This paper evaluated the landscape characteristic of paddy field and dryland in terms of three aspects: intensity, shape, and vergence. Eight indexes were further analyzed: patch number, landscape aggregation degree, etc. (Table 2). By importing the raster data of paddy field and dryland into Fragstats software, this study calculated the values of the landscape indexes of paddy field and dryland from 1990 to 2020 [21,22].

Table 2. Introduction of the landscape indexes.

Categories	Indexes	Title	Introduction
Intensity	NP	Number of patches	NP is the total number of all patches in the landscape, which can reflect the landscape spatial pattern.
	PD	Patch density	PD is the number of patches per unit area.
	LPI	Largest patch index (%)	LPI is the proportion of the largest patch of a land-use type in the whole landscape, which is used to measure the characteristics of the dominant landscape patches.
Shape	LSI	Landscape shape index	LSI is the shape complexity of arable land patches, which was measured by the deviation of the shape of the land patch from a circle or a square of the same area.
	AWMSI	Area-weighted mean shape index	AWMSI is the sum of the average shape factor of each land patch multiplied by the weight (the land patch area in the total landscape area). Bigger landscape patches have a higher weight than smaller patches.
Vergence	AI	Aggregation index (%)	AI refers to the aggregation degree of the landscape based on the common boundary length of patches of the same type of landscape.
	DIVISION	Landscape isolation	DIVISION refers to the individual isolated distribution of different patches in the landscape types.
	SPLIT	Splitting Index	SPLIT refers to the ratio of landscape fragmentation to the total landscape area index, which is used to describe the dispersion of the landscape pattern.

2.5. Topographic Potential Index

Because the distribution of land-use types is highly related to elevation and slope, this paper adopts the Topographic Position Index composed of slope and elevation to reflect the comprehensive topographic features of the paddy field and dryland.

$$TPI = lg\left[\left(\frac{E}{E_0}+1\right)*\left(\frac{S}{S_0}+1\right)\right] \quad (1)$$

where TPI refers to the Topographic Potential Index; E and E_0 are the elevation and the average elevation of an area, respectively; S and S_0 are the slope and the average slope of an area, respectively. The T value increases along with the increase in slope and elevation.

When the slope increases while the elevation decreases, or when the elevation increases while the slope decreases, the value of *TPI* is in the middle of the two. Referring to the relevant literature [23], this paper classified the topographic position index (abbreviated as TPI) into three levels: high (>0.8), medium (0.4–0.8), and low (<0.4).

3. Result Analysis

3.1. Changes in the Topographic Characteristics of Paddy Field and Dryland

The results showed some similarities in the distribution of the TPI of paddy field and dryland (Figure 1). Firstly, paddy fields and drylands with a low TPI were mainly distributed in the low-elevation areas of eastern China. Specifically, the paddy fields with low a TPI were mainly distributed in the Yangtze Plain areas (including Jiangsu, Shanghai, Anhui, Zhejiang, Hunan, Hubei, and Sichuan), the southern areas of China (Guangdong and Taiwan), the northeastern area (Liaoning and Heilongjiang), and the northeast area (Ningxia Province), while the drylands with a low TPI were mainly distributed in the northern area (Shandong, Henan, Hebei, and Shaanxi provinces), the northeastern area (Liaoning, Jilin, Heilongjiang, and Inner Mongolia provinces), the northwestern area (Xinjiang), and the southern area (Guangdong Province). Secondly, the paddy fields and drylands with a medium TPI were mainly scattered in the second ladder (1000–2000 m elevation) area and small parts of the first ladder (>4000 m elevation) and third ladder (<500 m elevation) in China. Specifically, the paddy fields with a medium TPI were distributed in the south of Shaanxi Province, and the drylands were distributed in Shaanxi, Shanxi, Gansu, Ningxia, Chongqing, Sichuan, Guizhou, Guangxi, Yunnan, and other provinces. Thirdly, the paddy fields and drylands with a high TPI were scattered in the southwest of China, and the drylands area far surpassed that of paddy fields.

An obvious change occurred in the topographic condition of arable land. The paddy fields with a low TPI decreased (Table S1 in the Supplementary Materials), while the paddy fields and drylands with a medium and high TPI increased. Specifically, the proportion of paddy fields with a low TPI decreased from 86.9% to 84.9%, and the proportion of drylands with a low TPI decreased from 76.5% to 75.4%. Because the low TPI areas are mainly distributed in the third ladder of China, which is flat and low in elevation, the hydrothermal conditions and the development degree of its paddy fields and drylands are better, the loss of paddy fields and drylands with a low TPI due to the fact of urban expansion is regrettable, which may lead to a further decline in the suitability of agricultural production [24].

From the perspective of elevation (Figure 2), 40% of the drylands and 64% of paddy fields were distributed at 0–200 m elevation, which decreased over time. The dryland area was greater than that of paddy field at the same elevation. From 1990 to 2020, the most obvious change in dryland and paddy field was concentrated at an elevation of 0–200 m. When looking at the change in dryland, this study found that the dryland increased in all elevations except for 0–200 m, with the highest annual growth rate (1.01%) in the >3500 m elevation area and the lowest annual growth rate (0.03%) in the 1500–2500 m elevation area. When looking at the change in paddy field, the results showed that the paddy field area increased at 200–500 m, 2500–3500 m, and >3500 m elevations but decreased at the other elevations, with the highest average annual growth rate (2.25%) at >3500 m elevations and the lowest average annual growth rate (0.01%) at 200–500 m elevations.

In terms of the slope condition (Figure 3), most of the paddy fields and drylands were concentrated at the 0–2° slope and decreased along with the increase in the slopes. From 1990 to 2020, paddy fields and drylands gradually moved from lower to higher slopes; the area of paddy fields and drylands in flatter areas (0–6° slope) decreased, whereas the area of paddy fields and drylands in areas with a slope > 6° increased. When looking at the change trends, dryland showed a fluctuating change (first increased and then decreased at 0–2° and 2–6° slopes), while paddy field showed a steadily decreasing trend at 0–2° and 2–6° slopes. When looking at the obvious change, dryland changed the most at a 6–15° slope (increased by 15,026 km^2), whereas the paddy field area changed the most at a 0–2°

slope (decreased by 18,846 km^2). When looking at the fastest change, the dryland area and paddy field area increased the fastest (0.6% and 1.09% a year) at a slope of >25°. In summary, the increase in sloping arable land changed significantly, and the emergence of steeply sloping paddy fields and dryland is especially alarming. Because sloping paddy field and dryland have limits regarding soil and water conservation [17], to guarantee the crop yield sustainably, more slope treatment practices, such as drainage ditches, protection forest, silt arresters, and contour ploughing (terrace field), are needed in this area.

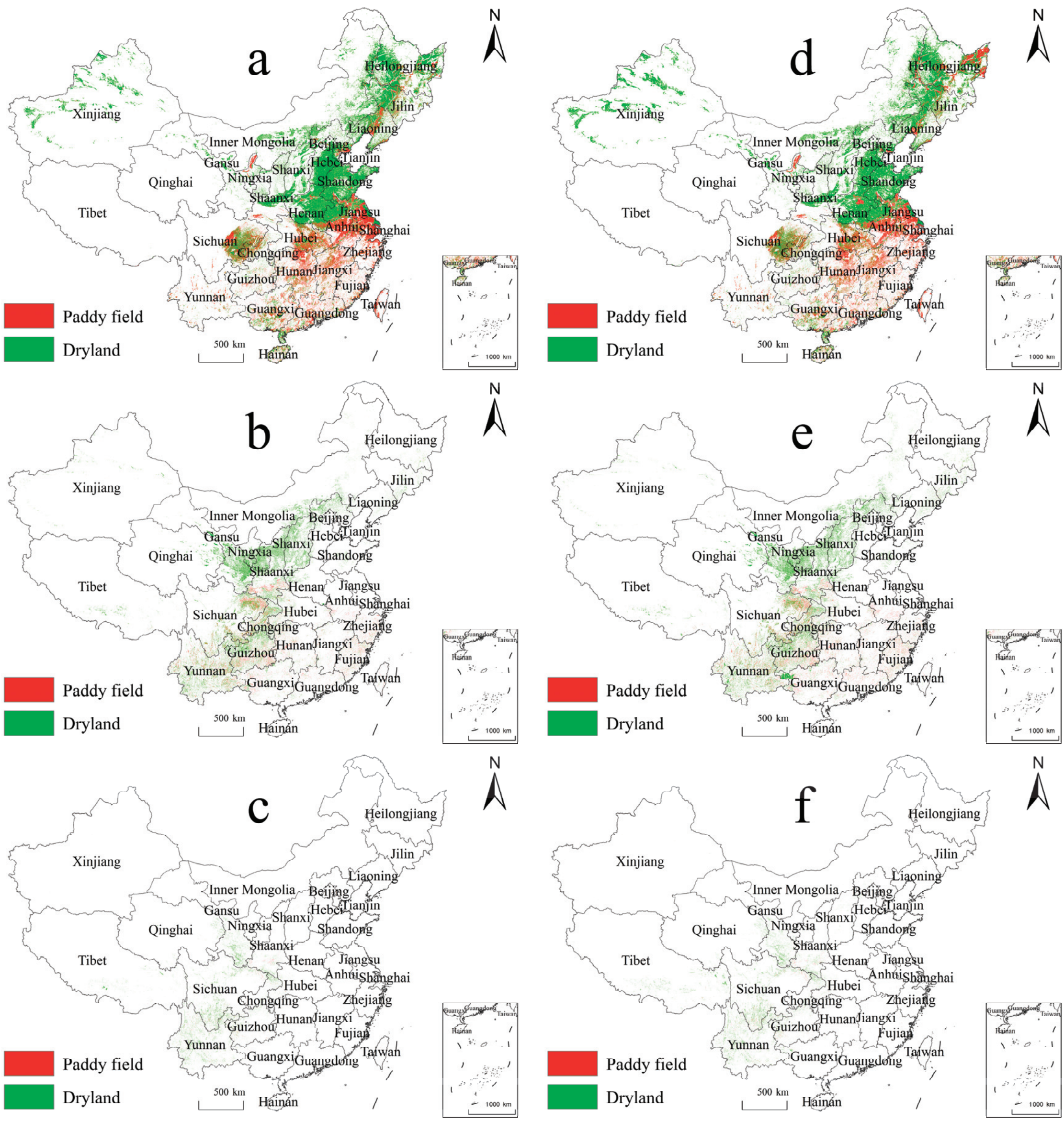

Figure 1. Distribution of paddy field and dryland under different TPIs in China in 1990 and 2020. ((**a**), low (<0.4) TPI in 1990; (**b**), medium (0.4–0.8) TPI in 1990; (**c**), high (>0.8) TPI in 1990; (**d**), low (<0.4) TPI in 2020; (**e**), medium (0.4–0.8) TPI in 2020; (**f**), high (>0.8) TPI in 2020).

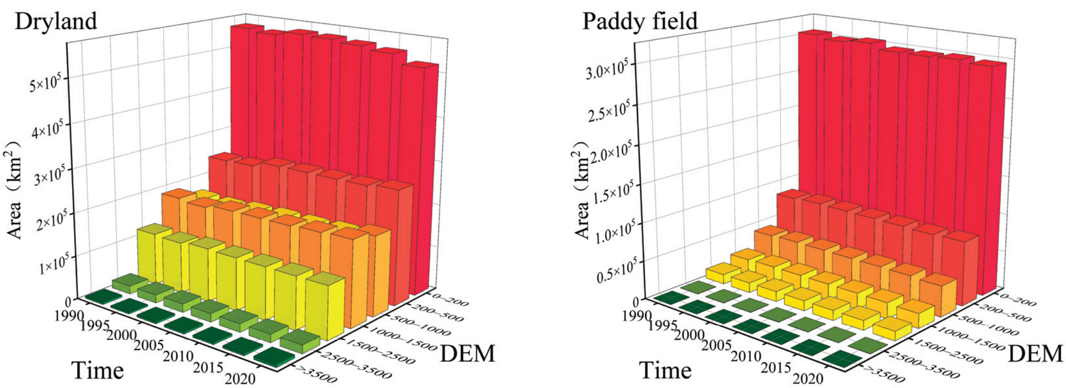

Figure 2. Changes in the elevations of paddy field and dryland. (For detailed data, refer to Table S2 in the Supplementary Materials).

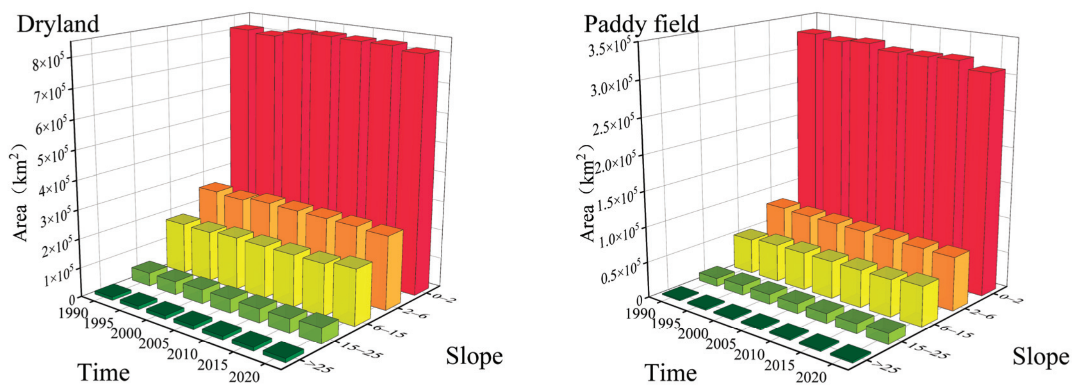

Figure 3. Change in the slopes of paddy field and dryland. (For detailed data, refer to Table S3 in the Supplementary Materials).

When looking at the slope aspects (Figure 4), the results showed that the paddy fields and drylands were mainly distributed on the southern, southwestern, southeastern, eastern, and western slopes of hills or mountains. Moreover, important to note is that the area of paddy fields and drylands on southeastern, southern, and southwestern slopes generally decreased, while the area of paddy fields and drylands on northwestern, northern, and northeastern slopes generally increased. Moreover, the area of paddy fields and drylands increased the most in the north, whereas the area of paddy fields decreased most in the south, and drylands decreased most in the southeast. The results indicate that the area of paddy fields and drylands with better light conditions decreased. Under the influence of man-made disturbance in the urbanization process, the advantages of ideal light and heat resources on arable land were ignored, and the area of paddy fields and drylands with superior natural conditions were reduced.

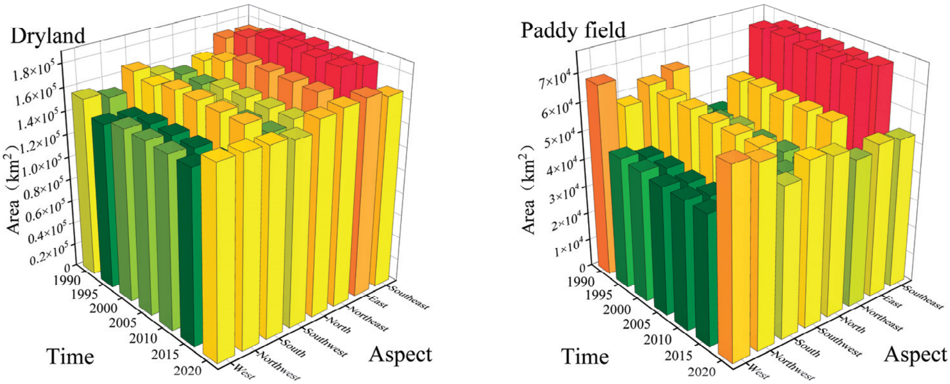

Figure 4. Change in the slope aspects of paddy field and dryland. (For detailed data, refer to Table S4 in the Supplementary Materials).

3.2. The Land Conversion of Paddy Field, Dryland, and Other Land

The spatial distribution of the land-use changes among paddy field, dryland, and other land from 1990 to 2020 is shown in Figure 5.

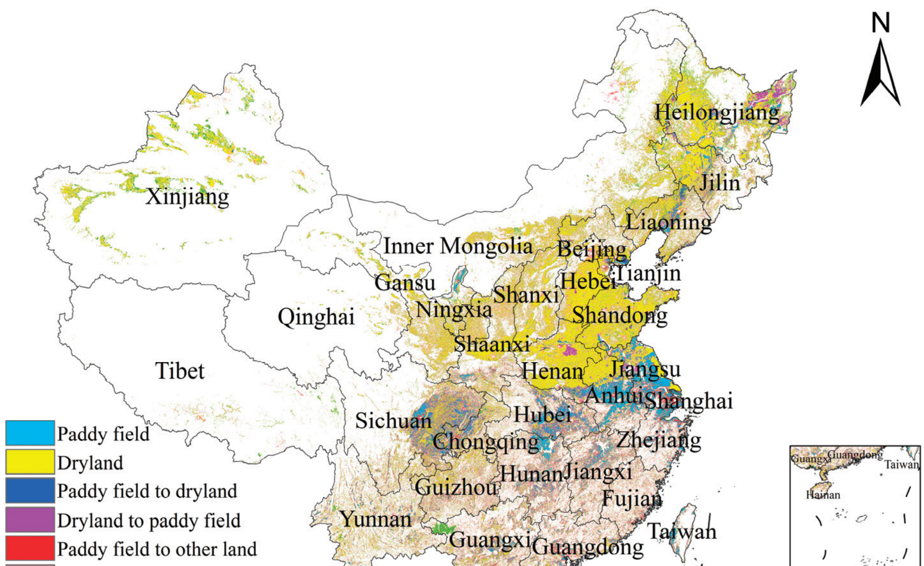

Figure 5. Land conversion between paddy field, dryland, and other land from 1990 to 2020.

In terms of the loss of paddy fields, the transition from paddy field to dryland was concentrated in Sichuan, Hebei, and Liaoning provinces. The seasonal water shortage and the decline in groundwater levels may be the major reasons for this change. On the North China Plain, long-term planting and industrial production induces sever groundwater shortages, which form a huge groundwater "funnel" in China. To reduce massive water usage, the government is actively encouraging farmers to change paddy field to dryland by providing subsidies [25]. In Sichuan, seasonal drought occurs frequently due to the spatial–temporal variability of rainfall. Eighty percent of the rainfall in Sichuan is concentrated in May to September. In spring and canicular days, the possibility of droughts is higher than 60% [26]. The transition from paddy field to other land was mostly concentrated in areas with higher urbanization levels, such as the Yangtze River Delta, the Pearl River Delta, and Chengdu–Chongqing. Taking the Yangtze River Delta as an example, fertile land and a temperate climate are beneficial for agricultural production. As one of the richest regions, the Yangtze River Delta contributes more than 20% GDP yearly to the whole country. However, most construction land is transformed from paddy field in this area [27]. Thus, a spatial overlap can be seen between the high-quality paddy fields and economically developed areas [5,9]. As a result, massive losses of paddy fields with better hydrothermal conditions should be protected against with stronger practices, especially in rapidly urbanized areas.

In terms of newly added paddy fields, most of the new paddy fields in the north came from the old drylands, especially in central Henan Province, central Jiangsu Province, and eastern Heilongjiang Province (Table S5 in the Supplementary Materials). In Henan Province, as the hub of the ecological protection and high-quality development strategy of the Yellow River Basin and the Mid-Line of the South–North Water Diversion Project [28], the local paddy field had a good geographical advantage, which helped supply water resources and plain farming and provided the basis for the transition from dryland to paddy fields. In Jiangsu Province, local land consolidation planning policies encouraged the change from dryland plantations to a rice–wheat rotation to increase the economic value of arable land output. This kind of policy support provided a strong incentive for transitioning from local dryland to paddy field. In eastern Heilongjiang Province, the long-term conservation of massive amounts of fertile black soil on the plain area and the flood control projects for rice fields provided sufficient advantages for the transition from dryland to paddy field. Moreover, the consolidation projects of low-yield fields helped to improve the centralization of paddy field patches. In general, paddy field has higher economic benefits (for instance, rice has a higher price compared to wheat and corn), which stimulates farmers to change their dryland to paddy field to obtain a higher income. Because paddy field is a non-negligible source of carbon emissions [29], the transition from dryland to paddy field may lead to an increase in greenhouse gas emissions, which needs further monitoring in future research.

In terms of drylands loss, the transition from dryland to paddy field was concentrated in the central part of Henan Province, the central part of Jiangsu Province, and the eastern part of Heilongjiang Province. The transition from dryland to other land was mainly concentrated in the periphery of urban agglomerations such as the Beijing–Tianjin–Hebei Region. It can be seen that the larger-scale reduced dryland was concentrated in zones with a better natural resource endowment and a stronger economic location.

In terms of the newly added drylands, the transition from paddy field to dryland was concentrated in Sichuan, Hebei, and Liaoning, and a larger scale of converting other land to dryland was more concentrated in Xinjiang and Guangxi. Among them, converting other land to dryland in Guangxi was mainly concentrated in the west of Guangxi, and the primary source of new, local dryland was the reclamation of abandoned industrial and mining land. The new dryland came from areas with poor suitability for development and utilization.

3.3. Land-Type Change in Paddy Field and Dryland under Different Topographic Conditions

3.3.1. Land-Type Change in Paddy Field and Dryland at Different Elevations

Land conversion between paddy field, dryland, and other land from 1990 to 2020 was mainly concentrated at an elevation of 0–200 m (Figure 6). Among them, the greatest area of land conversion occurred between dryland and other land, followed by the conversion between paddy field and other land. The area of the conversion between paddy field and dryland was the lowest.

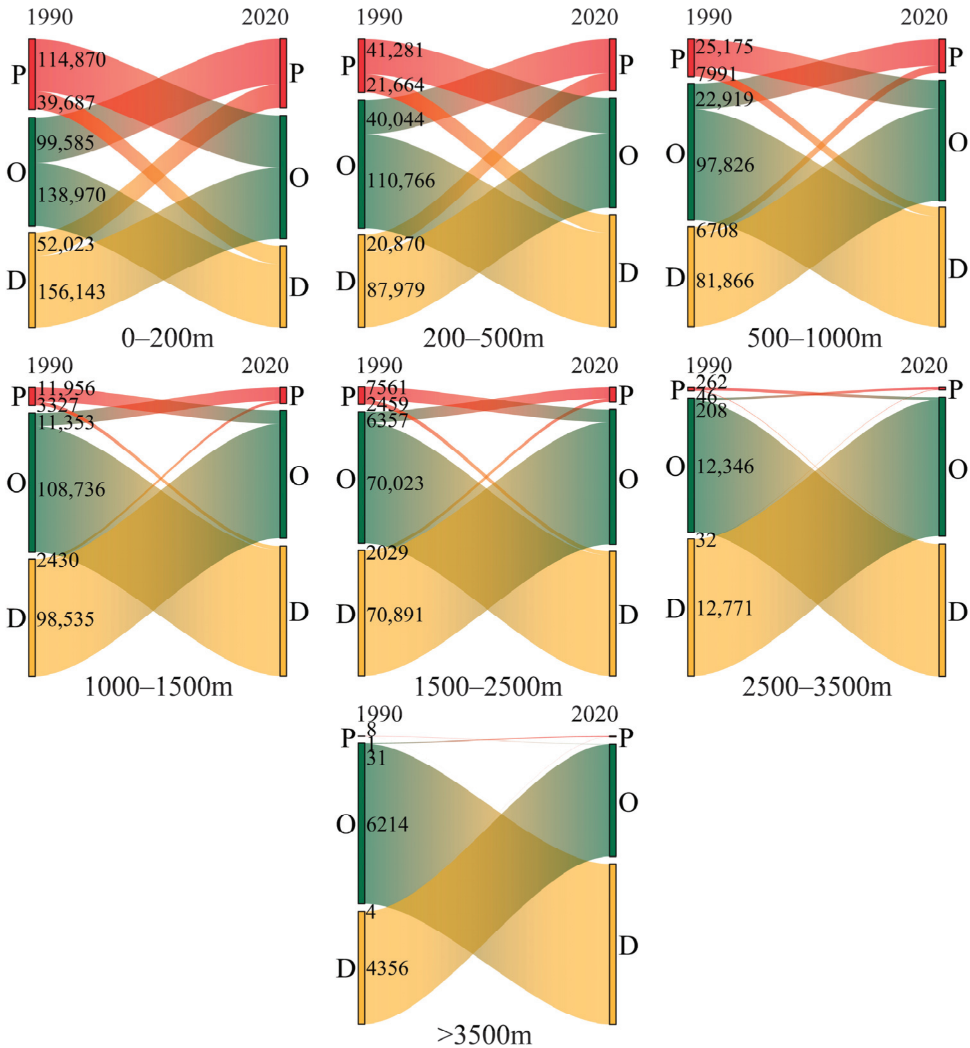

Figure 6. Land conversion between paddy field, dry land, and other land at different elevations from 1990 to 2020. P, paddy field; D, dryland; O, other land. The numbers in the figures refer to the area among the land changes (km^2).

It is worth noting that when looking at the interconversion between paddy field and dryland, the results show that at a 0–200 m elevation, the area changed from dryland to paddy field was much greater than that of paddy field to dryland. On the contrary, at a >200 elevation, the change from paddy field to dryland was more than that of dryland to paddy field.

In terms of the conversion between paddy field and other land, the area of paddy field to other land at each elevation was more than that of other land to paddy field. Unlike paddy field, the conversion between dryland and other land was not only active at the 0–200 m elevation but also significant at the 1000–1500 m elevation (the "second ladder" of China). This discovery confirms the importance of further analyzing the change in dryland and other lands at higher elevations in western China.

3.3.2. Land-Type Change in Paddy Field and Dryland at Different Slopes

From 1990 to 2020, land conversion among paddy field, dryland, and other land was mainly located on 0–2° slopes, and the area of land-use change decreased along with the increase in slope (Figure 7). Among them, the land conversion area between dryland and other land was the largest, followed by the conversion between paddy field and other land, whereas the conversion between paddy field and dryland was the lowest. In terms of the interconversion between paddy field and dryland, the area changed from dryland to paddy field at a 0–2° slope was more than that of paddy field to dryland, but on other slopes, the area changed from paddy field to dryland was larger. In terms of the conversion between dryland and other land, the dryland area changed to other land on a >25° slope was more than that of other land to dryland, but on other slopes, the area changed from other land to dryland was higher. In terms of the conversion between paddy field and other land, the area changed from paddy field to other land was more than that of other land to paddy field on slopes, which indicates that the decrease in the paddy field area was significant whether the terrain conditions were steep or flat.

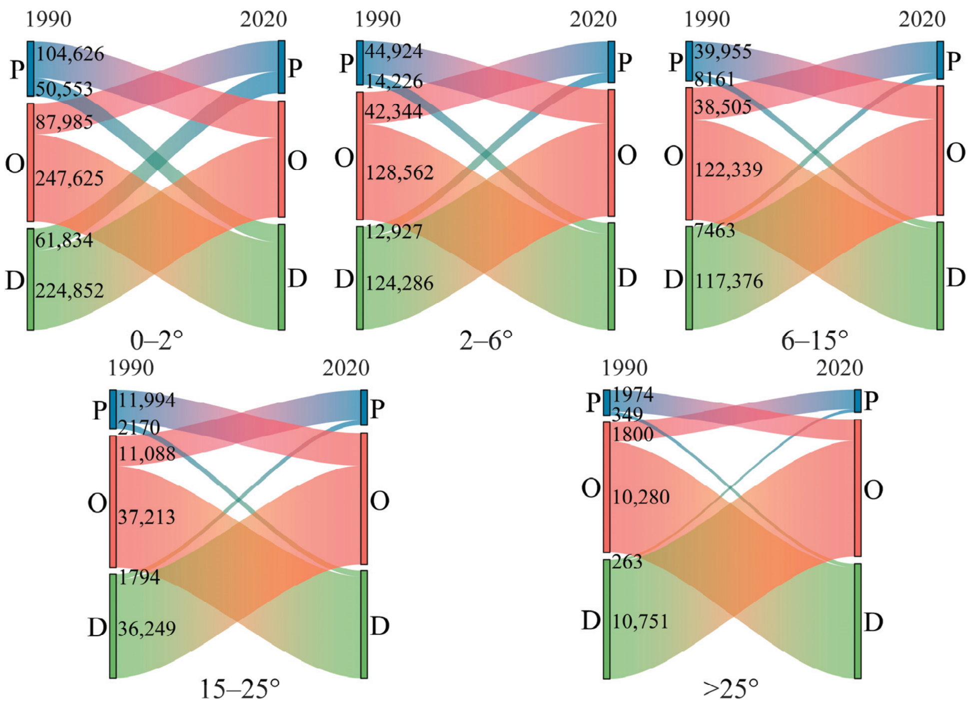

Figure 7. Land conversion between paddy field, dryland, and other land at different slopes from 1990 to 2020.

3.3.3. Land-Type Change in Paddy Field and Dryland on Different Slope Aspects

On the eastern slope, the conversion from paddy field to dryland, the conversion from dryland to other land, and the conversion from paddy field to other land were the largest. On the western slope, the change from dryland to paddy field, the change from other land to dryland, and the change from other land to paddy field were the greatest.

The conversion between dryland and other land was the most prominent, the conversion between paddy field and other land was the second-most prominent, and the conversion between paddy field and dryland was the least prominent.

It is worth noting that, when comparing the southern slope (with better photothermal conditions) and the northern slope (with worse light conditions), the results show that the loss of paddy field and dryland was greater on the southern slope than on the northern slope, while the increase in paddy field and dryland was greater on the northern slope than on the southern slope. In other words, the paddy fields and drylands with better light conditions in mountainous and hilly areas decreased (Figure 8).

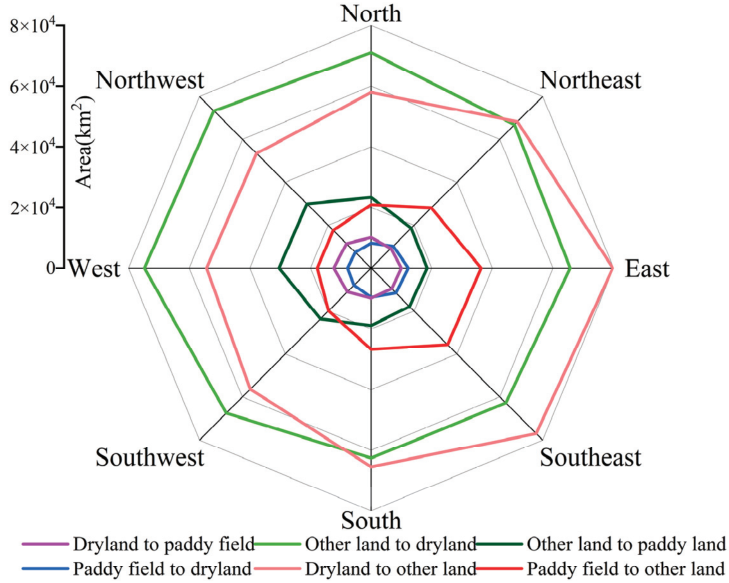

Figure 8. Land conversion between paddy field, dryland, and other land at different slope aspects from 1990 to 2020.

3.4. The Landscape Characteristics of Paddy Field and Dryland under Different Topographic Conditions

The landscape indexes of paddy field from 1990 to 2020 are shown in Table 3. In terms of the intensity indices, the NP and PD increased, which indicates that the landscape of the paddy field became more fragmented. The LPI increased, which indicates that the dominance of the main paddy field patches increased. Specifically (Tables S6–S8 in the Supplementary Materials), the largest NPs appeared at 200–500 m, on a 2–6° slope, and on the western slope aspect; the largest increase in the NP appeared at 200–500 m, on a 15–25° slope, and on the northern slope aspect; the largest decrease in the NP appeared at 0–200 m, on a 2–6° slope, and on the southern slope aspect. The largest PDs were distributed at 2500–3500 m, on a 15–25° slope, and on the northeastern slope aspect. The largest increase in the PD appeared at >3500 m and on the southern slope aspect, and the largest decrease in the PD appeared on a 6–15° slope and the northwestern slope aspect. The largest LPIs were distributed at >3500 m DEM, on a 0–2° slope, and on the southeastern slope aspect; the largest increase in the LPI was distributed at 0–200 m and on the southern slope aspect; the largest decrease in the LPI was distributed at >3500 m, on a 6–15° slope, and on the southeastern slope aspect.

In terms of the shape indices, the AWMSI and LSI experienced fluctuated growth, which indicates that the shape of the paddy patches tended to be complex and irregular. Specifically (Tables S6–S8 in the Supplementary Materials), the largest LSIs were distributed at 0–200 m, on a 2–6° slope, and on the western slope aspect; the largest increase in the LSI appeared at 200–500 m, on a 15–25° slope, and on the northern slope aspect; the largest decrease in the LSI appeared at 0–200 m, on a 2–6° slope, and on the southern slope aspect. The largest AWMSIs were distributed at 0–200 m, on a 0–2° slope, and on the southeastern slope aspect; the largest increase in the AWMSI was distributed at 0–200 m;

the largest decrease in the AWMSI was distributed at 200–500 m, on a 0–2° slope, and on the southeastern slope aspect.

In terms of the vergence indices, the AI decreased while the DIVISION and SPLIT increased, which meant that the landscape of paddy field tended to be more dispersed. Specifically (Tables S6–S8 in the Supplementary Materials), DIVISION decreased at 0–200 m and 1000–1500 m but increased at other elevations, slopes, and slope aspects. The largest SPLITs were distributed at 200–500 m, on a 2–6° slope, and on the western slope aspect, whereas the largest increase in the number of SPLIT was distributed at 200–500 m, on a 6–15° slope, and on the northern slope aspect, and the largest decrease in the number of SPLIT was distributed at 1000–1500 m, on a 2–6° slope, and on the southern slope aspect. The largest AIs were distributed at 0–200 m, on a 0–2° slope, and on the western slope aspect, the largest increase in the AI was distributed on a >25° slope and on the northwestern slope aspect, and the largest decrease in the number of SPLIT was distributed at >3500 m, on a 0–2° slope, and on the southern slope aspect. After 2015, the AI increased while the DIVISION and SPLIT decreased slightly, which indicates that along with the land consolidation projects, the landscape of paddy field appeared to be more concentrated.

Table 3. Results of the landscape pattern analysis of paddy field.

Category	Index	1990	1995	2000	2005	2010	2015	2020
Intensity	NP	63,269	62,748	63,935	64,902	65,098	65,753	64,574
	PD	0.1339	0.1331	0.1349	0.1393	0.14	0.1414	0.1405
	LPI	12.55	12.23	13.65	13.80	13.70	13.46	14.23
Shape	LSI	334.23	334.05	337.28	340.51	342.46	345.18	337.89
	AWMSI	14.85	15.00	16.03	15.93	15.93	15.65	16.05
Vergence	AI	51.44	51.39	51.06	50.15	49.85	49.44	50.23
	DIVISION	0.9775	0.9789	0.9762	0.9763	0.977	0.978	0.9776
	SPLIT	44.35	47.34	42.08	42.25	43.41	45.38	44.52

The intensity indices of dryland are shown in Table 4. The NP and PD increased while the LPI decreased, which indicates that the landscape fragmentation of dryland became more significant. Specifically (Tables S9–S11 in the Supplementary Materials), the largest NPs were distributed at 500–1000 m, on a 2–6° slope, and on the eastern slope aspect; the largest increase in the NP appeared at 500–1000 m, on a 6–15° slope, and on the northern slope aspect; the largest decrease in the NP appeared at 0–200 m, on a 0–2° slope, and on the southeastern slope aspect. The largest PDs were distributed at >3500 m, on a >25° slope, and on the western slope aspect; the largest increase in the PD was distributed at 1500–2500 m and on the eastern slope aspect; the largest increase in the PD was distributed at >3500 m, on a 15–25° slope, and on the northern slope aspect. The largest LPIs were distributed at 0–200 m, on a 0–2° slope, and on the northern slope aspect; the largest increase in the number of LPIs was distributed at 0–200 m, on a 6–15° slope, and on the northern slope aspect; the largest decrease in the number of LPIs was distributed at >3500 m, on a 0–2° slope, and on the southern slope aspect.

In terms of the shape indices, the AWMSI and LSI increased, which indicates that the shape of the dryland tended to be more complex and irregular. Specifically (Tables S9–S11 in the Supplementary Materials), the largest LSIs were distributed at 1000–1500 m, on a 2–6° slope, and on the eastern slope aspect; the largest increase in the LSI was distributed at 500–1000 m, on a 15–25° slope, and on the northern slope aspect; the largest decrease in the LSI was distributed at 1000–1500 m, on a 2–6° slope, and on the southeastern slope aspect. The largest AWMSIs were distributed at 0–200 m, on a 0–2° slope, and on the northern slope aspect; the largest increase in AWMSI was distributed at 0–200 m, on a 0–2° slope, and on the northern slope aspect; the largest decrease in the AWMSI was distributed at 1000–1500 m, on a 2–6° slope, and on the southern slope aspect.

In terms of the vergence indices, the AI decreased while the DIVISION and SPLIT increased, which proves the fragmentation and diversification characteristics of dryland landscape. Specifically (Tables S9–S11 in the Supplementary Materials), DIVISION was larger at other elevations, slopes, and slope aspects; the largest increase in the DIVISION was distributed at >3500 m, on a 0–2° slope. The largest SPLITs were distributed at 2500–3500 m, on a 15–25° slope, and on the western slope aspect; the most significant increase in SPLIT was distributed at >3500 m, on a >25° slope, and on the western slope aspect; the largest decrease in the SPLIT was distributed at 200–500 m, on a 6–15° slope, and on the northern slope aspect. The largest AIs was distributed at 0–200 m, on a 0–2° slope, and on the northern slope aspect.

Table 4. Results of the landscape pattern analysis of dryland.

Category	Index	1990	1995	2000	2005	2010	2015	2020
Intensity	NP	107,926	105,567	108,719	109,163	109,796	111,141	110,920
	PD	0.0831	0.0822	0.082	0.0822	0.083	0.0841	0.0839
	LPI	30.69	25.04	28.64	27.98	27.90	27.02	25.19
Shape	LSI	455.79	448.42	459.63	460.44	462.10	466.72	464.46
	AWMSI	56.50	51.63	59.65	57.21	57.12	56.80	57.27
Vergence	AI	60.06	60.46	60.13	60.07	59.86	59.44	59.65
	DIVISION	0.8988	0.9256	0.9073	0.9126	0.9132	0.9166	0.9163
	SPLIT	9.89	13.44	10.78	11.45	11.52	11.99	11.94

In general, the landscape fragmentation of paddy field and dryland increased, but dryland showed a higher aggregate degree and more obvious change towards complex shapes and fragmentation of land plots. Furthermore, most of the fragmentation and complexity in the shape of paddy field and dryland were concentrated in low-elevation areas with flat terrain, which emphasizes the loss of high-quality arable land with superior topographic conditions. In addition, the dryland in high-elevation areas tended to be more dispersed and more complicated, which needs further observation for long-term agricultural production.

4. Discussion

4.1. Changes in Microterrain Factors Led to a Decrease in Paddy Field and Dryland with Good Photothermal Conditions

As the primary resources of arable land use, water, heat, light, and other natural factors impact the growth of crops. Scholars have found that as a microterrain factor, the slope aspect has a significant effect on the growth and spatial distribution of plants [30]. The slope aspect determines the photothermal conditions of vegetation through the reception of solar radiation and hydrological processes which, in turn, affects crop growth. In countries in the Northern Hemisphere, the northern slope aspect has lower temperatures, lower light intensity, higher relative humidity, and more abundant soil nutrients [31–33], while the southern slope aspect has sufficient light, less moisture, and large diurnal temperature differences. Therefore, most studies indicate that plants on the southern slope aspect have a higher photosynthetic level and are more productive [34–36]. Similarly, this paper showed that 40.56% of paddy fields and 38.48% of drylands in China were distributed on the southern, southwestern, and southeastern slope aspects, which further proves the higher suitability of paddy field and dryland use on southern slopes.

However, the results of this paper found that the area of paddy field and dryland with better light conditions in China was decreasing. The area of paddy fields and drylands on the southeastern, southern, and southwestern slopes generally decreased from 1990 to 2020 but increased on the northwestern, northern, and northeastern slopes. Furthermore, conversion from paddy field and dryland to other land was more active on the southern, southeastern, eastern, and northeastern slopes. These results indicate the worsened solar-thermal conditions of paddy field and dryland, which may cause an explicit potential decline in the productivity of arable land. Though some studies have paid attention to the change in arable land area and spatial distribution, the change in productivity caused by the microterrain changes in arable land is rarely discussed, which needs further attention in future research.

4.2. In Addition to the "Third Ladder", the Changes in Paddy Field and Dryland Have Become Active on the "Second Ladder" of China

The terrain of China is high in the west and low in the east. According to the elevation from west to east, the whole country can be roughly divided by three ladders including the first ladder (>4000 m) in the west, the second ladder (1000–2000 m) in the middle, and the third ladder (<500 m) in the east. This study found that the land conversion of paddy field and dryland in China mainly occurred in the eastern plain on the third ladder. Similarly, relative studies have supported this conclusion such as the large-scale conversion from paddy field to dryland and construction land in the Beijing–Tianjin–Hebei Region [37], the conversion from other land to dryland and paddy field in the Northeast China Plain [4,15], and the conversion from paddy field and dryland to construction land in Yangtze Plain areas [27].

It is worth emphasizing that this article has a new finding. In addition to the third ladder, the transition between paddy field, dryland, and other land on the second ladder was also active (such as at an elevation of 1000–1500 m). Coincidentally, Chi [38] and Dong [39] also found that a large area of the land conversion of paddy field, dryland, and other land occurred on the second ladder, such as Inner Mongolia, in recent years. Therefore, the land-use change in paddy field and dryland became active on the second ladder. Although climatic conditions, population density, and economic development on the second ladder are poorer than that on the third ladder, the use of arable land at higher elevations is proven to have increased.

The reasons for this can be found by tracing the regional development of the second ladder. Since the implementation of the China Western Development Strategy in 2000, the Chinese government has increased its support for land consolidation and basic arable land construction in the west and has carried out a series of ecological restoration projects to prevent desertification and improve the ecological environment of arable land. Such policy supports resulted in a significant increase in new agricultural modernization, agricultural capital investment, and per capita arable land area [40]. After the agricultural tax was abolished by the No. 1 Central Document in 2006, "The Guidance on Promoting Sustainable Development of Agriculture and Animal Husbandry in Northwest Arid Regions" was issued, which increased agricultural subsidies in poor areas in West China. These have further motivated the enthusiasm for farm production on the second ladder.

It is worth mentioning that in 2017, the government began to permit trans-provincial "land-ticket transactions" to keep an arable land requisition–compensation balance (i.e., arable land occupied by urban construction in provinces with a land shortage can be replenished by provinces with abundant arable land reserve resources). Benefited by abundant land resources, the provinces on the second ladder developed and replenished a large amount of new arable land in "land-ticket transactions", which has also contributed to the dramatic land conversion between paddy field, dryland, and other land at the second ladder.

However, because of the special arid climate environment of the second ladder, the increase in arable land in this area may further intensify the contradiction of water use [41], which will cause the degradation of the ecosystem and the quality of arable land and lead to an increase in desertification over the long term [42–44]. Therefore, faced with the active conversion of paddy field and dryland on the second ladder, the local government needs to focus on pushing forward the delineation of the "three lines" (i.e., urban development boundary, permanent basic arable land, and ecological protection red line) and the "three areas" (i.e., urban space, agricultural space, and ecological space) in territorial space planning. Unsuitable arable land with high costs and ecological risks should be retired and the reclamation of arable land in ecologically fragile areas should be limited to rationalize the land-use structure at a higher elevation. Moreover, large-scale land use in Europe has shown some adverse effects such as the persistence of pesticides and other agricultural inputs. Taking a cue from this, the government in China has new opportunities and challenges [45]. The government should further strengthen the arable land-use intensity and high-standard cropland construction and actively promote the protection of arable land such as by letting land lie fallow and through reasonable crop rotation [46]. To improve the acceptance of environmentally friendly techniques, the government should provide more subsidies for eco-friendly agriculture to farmers.

4.3. Increased Paddy Field and Dryland on Slopes Exacerbated the Erosion Risk

From the perspective of land suitability, arable land in low-elevation plains is rich in water and heat resources, which is more suitable for agricultural production. This study found that paddy fields at low elevations (0–200 m) accounted for 64.6% of the total paddy field area, and paddy fields on low slope (0–2°) areas accounted for 67.62% of the total paddy field area. Drylands at low elevations (0–200 m) and low slopes (0–2°) accounted for 39.78% and 61.46% of the total dryland area, respectively. Compared with dryland, paddy field is more sensitive to topography and have higher requirements for water retention. However, this study found that the paddy field and dryland went "up the hill", i.e., an increasing number of paddy fields and drylands appeared at higher elevations (>200 m) and steeper slopes (>6°). Because of the large quick water flow on slopes, the phenomenon of soil and water erosion caused by the increase in paddy field and dryland on slopes needs more attention [47]. Rice cultivation in China and Southeast Asia is an important source of farmers' income. The increasingly unideal topographic conditions of paddy fields may bring about more socioeconomic uncertainties, which need further study on the consequences by researchers.

In addition, in terraced fields on slopes, paddy fields tend to exhibit a higher water and fertilizer retention capacity and lower soil erosion intensity than drylands [48]. For example, Gao [49] and Xiao [50] found that paddy fields were less affected by soil erosion than drylands in karst areas, and Chen [51] pointed out that the paddy fields in Taiwan's mountains were less affected by rainfall erosion than drylands. However, this paper found that the transition from paddy field to dryland within a >2° slope and >200 m elevation was greater than the transition from dryland to paddy field. Taking the mountainous southwest China (including Chongqing, Sichuan, Guizhou, and Yunnan) as an example, the area of paddy field to dryland within a >2° slope and >200 m elevation was 24,080 and 25,981 km^2, respectively, which is much higher than the area from dryland to paddy field (15,022 and 16,561 km^2). As a result, considering the massive change from paddy field to dryland, stronger water–soil conservation is highly needed to improve the productivity of mountainous arable land.

4.4. The Landscape Fragmentation of Paddy Field and Dryland Emphasize the Importance of Land Consolidation

This study states that paddy field and dryland both tended to be dispersed, fragmented, and complex in shape, but compared with paddy field, dryland was more aggregated and showed a stronger change towards complex and fragmented shapes.

Similarly, previous studies showed that Heilongjiang had increased fragmentation in terms of the paddy field landscape [14,52]; landscape fragmentation and the heterogeneity of dryland and paddy field were intensified in Guangdong Province [21]. Moreover, the paddy field in the Jinjing River of Hunan [19] and the paddy field and dryland in the Dongting Lake area [22] showed increased fragmentation and dispersed distribution. These findings are consistent with the conclusions of this paper. Inversely, the decrease in landscape fragmentation of dryland in the Horqin region [53], the fluctuating fragmentation of paddy field and dryland in the Loess Plateau [54], and the decline in the fragmentation of dryland and paddy field decreased in the Karst area of Chishui City [55] and Zhoushan Island [56]. These conclusions are partly different in this study. As a result, the landscape characteristics of paddy field and dryland have zonal differences, but both show fragmentation, irregular shape, and complex distribution. Therefore, increasing the concentration level and contiguity of land plots and strengthening the infrastructure of water, roads, and forests via targeted land consolidation projects should be the major measures used to alleviate the inefficiency of arable land production caused by the unpredictable landscape characteristics of paddy field and dryland.

5. Conclusions

Based on 1 km land-use grid data from 1990 to 2020, this study applied a landscape analysis, the land-use change matrix for different topographic grades of China, to determine the divergent patterns and the spatial–temporal changes in paddy field and dryland resources under different terrain gradients. The results show that:

First, although paddy field and dryland were mostly distributed in areas with better photothermal conditions, the area of paddy fields and drylands on sunny slopes significantly decreased in recent years. The area of paddy fields and drylands on the southeastern, southern, and southwestern slopes decreased, while the area of paddy fields and drylands on the northwestern, northern, and northeast slopes increased.

Second, from 1990 to 2020, land conversion between paddy field, dryland, and other land was mainly concentrated in the third ladder (0–200 m DEM), but the changes in the second ladder (500–2500 m DEM) became prominent.

Third, paddy field and dryland went "up the hill". Paddy field and dryland at low-elevation, low-sloping areas were reduced, and those at higher-elevation, higher-sloping areas increased, which may trigger potential soil erosion. Meanwhile, at high slopes and high elevations, the transition from paddy field to dryland was more prominent.

Finally, there were differences in the landscape characteristics of paddy field and dryland. Although the fragmentation of patches, dispersion of distribution, and complexity of shapes of paddy field landscapes increased, the new paddy field showed the characteristics of aggregation in some areas (such as the northeast and Sichuan). In contrast, although the fragmentation of patches, dispersion of distribution, and complexity of shapes of dryland landscapes increased, the landscape agglomeration characteristics were higher compared to paddy field, decreasing with time.

Based on the research findings, this paper puts forward some suggestions on the utilization of paddy field and dryland. Firstly, the government should strengthen the protection of arable land on sunny slopes and control the conversion from arable land to construction land on sunny slopes in traditional agricultural production areas. Secondly, the protection of water resources in the utilization of arable land in the second ladder regions (such as Xinjiang and Gansu) should be strengthened, and unsuitable arable land should be retired from agricultural production. Thirdly, the government should protect the arable land on the plain area and limit the extensive use of paddy field and dryland on sloping areas to reduce the aggravation of soil erosion. Lastly, land consolidation should emphasize reducing the landscape fragmentation and dispersed distribution of arable land patches.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/land11101851/s1. Table S1: The area of paddy field and dryland under different TPI in China in 1990 and 2020; Table S2: Change in the elevations of paddy field and dryland; Table S3: Change in the slopes of paddy field and dryland; Table S4: Change in slope aspects of paddy field and dryland; Table S5: Land use transformation matrices for paddy field, dryland, and other land among the 32 provinces; Table S6: Landscape indices of paddy field in different elevations; Table S7: Landscape indices of paddy field in different slopes; Table S8: Landscape indices of paddy field in different slope aspects; Table S9: Landscape indices of dryland in different elevations; Table S10: Landscape indices of dryland in different slopes; Table S11: Landscape indices of dryland in different slope aspects.

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land

Article

The Use of Cultivated Land for Multiple Functions in Major Grain-Producing Areas in Northeast China: Spatial-Temporal Pattern and Driving Forces

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Abstract: The increasing scarcity of cultivated land resources necessitates the continuous change in cultivated land functions. Cultivated land has gradually changed from being used for a single function to multiple functions. The use of cultivated land for multiple functions has become an important way to achieve the sustainable use, management, and protection of cultivated land. In this, the development of different functions of cultivated land must be coordinated. Thus, clarifying the evolution trend of the use of cultivated land for various functions, calculating the coupling and coordination degrees of these multiple functions, and identifying the driving factors in these uses play important roles in realizing the orderly development of cultivated land multifunctionality. This paper defined multifunctioning cultivated land as containing a production function, a social function, and an ecological function. Based on the socioeconomic panel data and geospatial data of Heilongjiang, Jilin, and Liaoning, which are the major grain-producing areas of northeast China, in the years 2005, 2010, 2015, and 2020 we calculated the multiple function coupling coordination degree of cultivated land using the Coupling Coordination Degree Model and identified the driving forces in the evolution of the spatial-temporal pattern of cultivated land multifunctionality using Geodetector. The results show that from 2005 to 2020, there were significant regional differences in terms of the production, social, and ecological functions of cultivated land in the research areas. The multifunctional coupling coordination degree of cultivated land in the study areas was gradually improved. The spatial-temporal evolution of the multifunctional coupling coordination degree of cultivated land was found to mainly be influenced by the level of agricultural development, such as the level of per capita disposable income and the rate of effective irrigation of cultivated land. The government should attempt to guarantee the comparative benefits of agricultural production to increase the income level of farmers; increase investment in agricultural infrastructure construction to improve the level of agriculture development; and implement a strict farmland protection policy to achieve the continuous improvement of the productivity of cultivated land, realize the ordered development of coupling, and improve the coordination of the use of cultivated land for multiple functions. The results of this study are applicable not only to northeast China but also to other major grain-producing areas that are under pressure to protect their cultivated land and achieve the suitable use of cultivated land.

Keywords: cultivated land multifunctionality; coupling coordination degree; spatial-temporal pattern; driving force; major grain-producing areas; northeast China

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1. Introduction

Healthy cultivated land use systems have functional continuity [1]. The function of cultivated land refers to the ability of cultivated land to provide products and services, and it evolves in a complex process from a single function into multiple coordinated functions [2,3]. The multifunctionality of cultivated land has become an essential attribute of its use [3].

Cultivated land has traditional production and service functions necessary for human society [4]. With the development of the economy and technology, cultivated land is now not limited to traditional functions and has transitioned from having a single function to multiple functions [3,5]. As a basic resource and material guarantee for human survival, the multiple functions of cultivated land include its use to provide products and services necessary for human survival and development [6]. These functions of cultivated land include production functions, such as providing food, vegetables, and oil; ecological functions, such as regulating the atmosphere and maintaining water and soil; social functions, such as ensuring farmers' livelihood and maintaining national food security; cultural functions, such as providing farming landscapes and spatial landscapes; and non-commercial functions, such as for building space reserves and other space-bearing reserve functions [7]. Thus, the utilization of cultivated land has led to its gradual expansion from production functions to social security functions and ecological functions [3,5,7]. Cultivated land is an irreplaceable basic resource needed for human survival and development and a core element contributing to food security and regional sustainability [8–10]. Therefore, the multifunctional use of cultivated land is an important concept that must be considered when assessing reginal cultivated land use changes and their effects on the sustainable use of cultivated land. Thus, the coupling coordination level of cultivated land used for multiple functions should be determined, as it can provide a feasible reference for optimizing the efficiency of the regional utilization of cultivated land [11].

The multiple functions of cultivated land start from its use for agricultural functions [12–15]. The Global Land Project (GLP) takes the multifunctionality of land as the basic framework with which to analyze the coupling of natural, ecological, social, and economic systems [16]. The multiple functions of cultivated land have been widely considered by scholars. The existing research on this concept mainly focus on the assessment of multiple functions of cultivated land [1,3,17–19]. The assessment of the multiple functions of cultivated land has been widely discussed since the implementation of the Land Use and Land Cover Change (LULL) program [3,20]. The current studies focusing on the assessment of the multiple functions of cultivated land concentrate on two major aspects: the assessment of each land use function individually and the comprehensive assessment of the multiple functions of cultivated land. Studies focused on the assessment of individual land use functions mainly aim to quantify each function of cultivated land, such as its production, ecological, social, or economic functions [21–25]. In the research on comprehensive cultivated land multifunction assessment, a growing number of studies have obtained the total intensity level of different function of cultivated land by summing the value of each cultivated land function [19,26] and some studies have analyzed the driving forces behind the use of cultivated land for multiple functions [3,27,28].

However, the emphasis of most studies was often on a single function or the impact issues of separate functions. While the comprehensive function of cultivated land is the result of coupling the coordinated development of the multiple functions, the multifunctional coupling coordination degree of cultivated land has rarely been reported on, much less the spatial-temporal pattern and driving forces of the coupling coordination degree of cultivated land used for multiple functions. Thus, our understanding of the multiple functions of cultivated land is poor. Furthermore, long-term studies can be used to examine the evolution mechanism of cultivated land used for multiple functions and offer a policy reference to increase the use of cultivated land for multiple functions, an area which lacks attention. As it stands, in the research of cultivated land multifunctionality, less focus has been provided to major grain-producing areas. In order to improve the shortcomings of the existing research, a better understanding of the spatial-temporal pattern of cultivated land used for multiple functions in major grain-producing areas is needed, and the spatial-temporal pattern, driving forces, and influencing mechanisms of the multifunctional coupling coordination degree of cultivated land need to be identified as well. Through this, effective policies can be promoted to improve the use of cultivated land to achieve the goal of sustainable cultivated land use, especially in the major grain-producing areas.

As an important grain base, northeast China is a major grain-producing area, shouldering the responsibility of ensuring national food security. However, in face of the challenges of cultivated land degradation [29] and reduced agricultural production efficiency [30], the sustainable use of cultivated land in northeast China is now seriously threatened. Thus, based on the main functional positioning of northeast China as a major grain-producing area, identifying the spatial-temporal evolution of the multifunctional coupling coordination degree of cultivated land is of great importance in order to take full advantage of cultivated land resources, maximize cultivated land utilization efficiency and yield, ensure ecological security, and maintain social stability in northeast China. Additionally, it is of strategic significance for ensuring the national food security of China.

Considering the research gaps highlighted above and the strategic positioning of the major grain-producing areas in northeast China as a national breadbasket, this study used Heilongjiang province, Jilin province, and Liaoning province as its research area to analyze the spatial-temporal pattern of cultivated land used for multiple functions, including its production, social, and ecological functions; assess the multifunctional coupling coordination degree of cultivated land; identify the spatial-temporal pattern trend and driving forces of the multifunctional coupling coordination degree of cultivated land; and finally put forward measures for the optimization of the usage of cultivated land for multiple functions. The reminder of this paper is structured as follows. Section 2 describes the materials and methods. The Comprehensive Index Model is used to calculate the evaluation value of cultivated land functions. The Coupling Coordination Degree Model is used to assess the multifunction coupling coordination degree of cultivated land. Geodetector is used to explore the driving forces behind the evolution of the multifunctional coupling coordination degree of cultivated land. Section 3 discusses the empirical results of the models. Sections 4 and 5 present the discussion and conclusions of this study, respectively.

2. Materials and Methods

2.1. Study Area

Heilongjiang province, Jilin province, and Liaoning province are located in the northeast of China, in the hinterland of northeast Asia, with the geographical coordinates of 38°43′–53°33′ north latitude and 118°53′–135°05′ east longitude (Figure 1). The three provinces are surrounded by mountains and water with plains in the middle. Topographically, this region has a high altitude in the southeast, north, and northwest and a low altitude in the northeast, southwest, and central areas. The terrain of this area is mainly composed of mountains, hills, plains, and water bodies. The northeast plain, which consists of Sanjiang Plain, Songnen Plain, and Liaohe Plain, is the largest plain in China, and has extensive agricultural development. There are many rivers in the region, such as Yalu River, Songhua River, Mudanjiang River, Heilongjiang River, and Wusuli River. Most of the region is characterized by a temperate continental monsoon climate, featuring concurrent rain and heat. The region is widely covered by Black soil and it is a highly fertile area, making it suitable for crop growth. In 2021, the total economic output of the three provinces was CNY 5569.9 billion, and their total grain output was 144,456,400 tons, accounting for 21.2% of the total national grain output. The area of sown grain was 23,815,900 hectares, accounting for 20.3% of the total national area sown with grain. The total land area of the three provinces is 8.1×10^7 hm^2, and the total cultivated land area is 3.0×10^7 hm^2, accounting for 37.4% of the total land area. Thus, it is an important grain-producing area in China and a national grain base. By taking the three provinces as our study areas in order to analyze the spatial-temporal evolution and the driving forces of the multifunctional coupling coordination degree of cultivated land, we aimed to not only optimize the multifunctional coupling coordination of cultivated land in the three provinces, but also provide a useful reference for the multifunctional utilization of cultivated land in other major grain-producing areas.

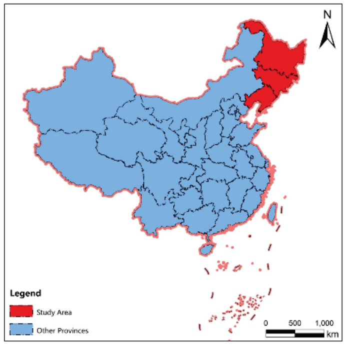

Figure 1. Location of study area.

2.2. Data Sources

The statistical data used in this study mainly came from the *Liaoning Statistical Yearbook, Jilin Statistical Yearbook, Heilongjiang Statistical Yearbook, China Statistical Yearbook (County-Level)* in 2006, 2011, 2016, and 2021, as well as the officially released statistics for national economic and social development for Liaoning, Jilin, and Heilongjiang. The geographic information data mainly came from http://www.gscloud.cn/ (accessed on 12 July 2022), while the vector data, land use data, and annual average precipitation data for Liaoning, Jilin, and Heilongjiang came from https://www.resdc.cn/ (accessed on 17 July 2022). In this study, 36 cities (districts) in Liaoning, Jilin, and Heilongjiang were selected as the study units.

2.3. Methods

In this subsection, the methods used in this study are presented. Section 2.3.1 presents the multifunctional evaluation index system used for cultivated land and introduces the reasons for the selection of the index used for each function. Section 2.3.2 presents the indicator standardization method used and the process used for the calculation of indicator weight and function weight. Section 2.3.3 describes the Comprehensive Index Model used to calculate the value of each cultivated land function and the Coupling Coordination Degree Model used to assess the multiple function coupling coordination degree of cultivated land. Section 2.3.4 displays the calculation process followed by Geodetector, which was used to explore the driving forces of the evolution of the multifunctional coupling coordination degree of cultivated land.

2.3.1. Establishment of Multifunctional Cultivated Land Evaluation Index System

As the cultivated land system is an open and complex system, this study focused on the production, social, and ecological functions of cultivated land and comprehensively considered other factors such as nature, society, economy, and ecology in order to select multifunctional indicators of cultivated land in major grain-producing areas in northeast China. On the basis of the comprehensive consideration of the systematicness, scientificity, objectivity, and data availability of multifunctional indicators of cultivated land, twelve indicators were selected based on three aspects, production, social, and ecological functions, to establish a multifunctional evaluation index system at the city scale in the study areas (shown in Table 1). The reasons for indicator selection were as follows:

- Production function

The production function represents the use of cultivated land to produce food crops and cash crops, which is the basic function of cultivated land [7,31]. Cultivated land's production function provides agricultural products for society and economic income for farmer households [32]. The cultivated land reclamation rate is the ratio of reclaimed land area to the total land area and can effectively reflect the development and utilization of cultivated land resources in a certain area. The higher the cultivated land reclamation rate is, the higher the intensity of land development and utilization is [25,26]. The per capita cultivated land area, grain crop yield, per hectare agricultural output, and per hectare mechanization level reflect the availability of cultivated land resources per capita. Moreover, the grain output per unit area, gross agricultural output per unit area, and mechanization level of cultivated land utilization reflect the production function of cultivated land. Keeping other factors constant, the more inputs of productive factors there are per unit area of cultivated land, the more output is generated [32,33]. In the same token, the higher the degree of agricultural mechanization is, the higher the production capacity of cultivated land resources is [34,35]. Therefore, the five indicators of cultivated land reclamation rate, per capita cultivated land area, grain crop yield, per hectare agricultural output, and per hectare mechanization level were selected to comprehensively express the production function of cultivated land under certain natural conditions and production factor inputs.

- Social function

Social function refers to the role played by cultivated land in farmers' livelihood and employment security [7]. With regard to the function of guaranteeing farmers' basic livelihood, it is necessary to comprehensively consider the grain supply capacity and economic income supply capacity of cultivated land, as well as its capacity to guarantee stable employment. The food self-sufficiency rate reflects the ability of the output of cultivated land to meet the regional population's food demand. The agricultural contribution to Gross Domestic Product (GDP) and the income ratio between urban and rural residents reflect the influence of agriculture on the national economy, its contribution to the national economy, and its ability to guarantee the livelihood of rural residents [25,34,36]. Meanwhile, the land-bearing capacity of the rural labor force reflects the ability of agriculture to guarantee employment for the rural population [37]. Therefore, in this study we selected four indicators, namely, food self-sufficiency rate, agriculture contribution to GDP, the ratio of income between urban and rural residents, and the land-bearing capacity of the rural labor force, to comprehensively express the social function of cultivated land under certain social and economic conditions.

- Ecological function

Ecological function relates to the role played by cultivated land in climate regulation, soil and water conservation, biodiversity maintenance, and relieving environmental pressure [7,38]. If a paddy field area is larger, its biodiversity level is higher and its ecological security maintenance function is stronger [39]. The ratio between the area of paddy field and cultivated land indicates the ecological advantage of the cultivated land category. The farmland ecosystem diversity index reflects the richness of crop varieties and the strength of ecological functions [40]. The farmland ecosystem diversity index is the ratio of the area sown with major food crops such as wheat, paddy rice, corn, soybean, and potato to the area sown with major cash crops such as oil and cotton out of the total area sown with staple farm crops in the study areas. The larger the index value is, the higher the crop variety is and the stronger the ecological functions are [41]. In this study, the fertilizer load of cultivated land was selected as a negative indicator of the environmental pressure on cultivated land. This is calculated as the ratio of the amount of fertilizer applied to the total cultivated land area. The larger the indicator value is, the greater the environmental pressure is. Therefore, in this study we selected three indicators, ecological advantage of cultivated land, farmland ecosystem diversity index, and fertilizer load of cultivated land, to comprehensively express ecological functions in a specific area.

Table 1. Multifunctional cultivated land evaluation index.

Function	Indicator	Calculation Method	Trend	Indicator Weight (%)	Function Weight (%)
Production function	Cultivated land reclamation rate	Cultivated land area/total land area (%)	+	20.1	46.2
	Per capita cultivated land area	Cultivated land area/total population (hm^2/person)	+	26.5	
	Grain crop yield	Grain output/total sown area of grain crops (kg/hm^2)	+	20.5	
	Per hectare agricultural output	Gross agricultural output/cultivated land area (CNY 10,000/hm^2)	+	17.6	
	Per hectare mechanization level	Total power of agricultural machinery/cultivated land area (kW/hm^2)	+	15.3	
Social function	Food self-sufficiency rate	Grain output × (permanent resident population × 400 kg/person)$^{-1}$ (%)	+	35.9	26.2
	Agriculture contribution to GDP	Gross agricultural output/regional GDP (%)	+	25.1	
	The income ratio between urban and rural residents	Rural per capita disposable income/urban per capita disposable income (%)	+	12.7	
	The land-bearing capacity for the rural labor force	Number of rural agricultural employees/cultivated land area (person/hm^2)	+	26.3	
Ecological function	The ecological advantage of cultivated land	Paddy field area/cultivated land area (%)	+	33.3	27.6
	Farmland eco-diversity index	$-\sum a_i \ln a_i$, where a_i is the ratio (%) between the sown area of various crops and the total area sown with farm crops	+	38.3	
	Fertilizer load of cultivated land	Fertilizer application amount/cultivated land area (t/hm^2)	-	28.4	

2.3.2. Indicator Standardization and Weight Calculation

- Standardization of Indicators

In order to eliminate the influence of indicator unit dimensions and ensure the comparability of each indicator, the range standardization method was used to standardize each indicator. The calculation formulas of positive and negative indicators are as follows:

$$\text{Positive indicator}: \ X_{ij} = \frac{x_{ij} - x_{jmin}}{x_{jmax} - x_{jmin}} \tag{1}$$

$$\text{Negative indicator}: \ X_{ij} = \frac{x_{jmax} - x_{ij}}{x_{jmax} - x_{jmin}} \tag{2}$$

where X_{ij} is the value after standardization, x_{ij} is the actual value of the j indicator in i city, x_{jmax} is the maximum value of j indicator, and x_{jmin} is the minimum value of j indicator. The trend of each indicator is listed in Table 1.

- Calculation of indicator and function weight

Subjective and objective determination methods were used to comprehensively determine the indicator weight. The Yaahp software was used to determine the subjective weight, the entropy method was used to determine the objective weight, and the comprehensive weight was obtained by the weighted average of the subjective weight and objective weight. The calculation formulas for objective weight and comprehensive weight are:

$$Y_{ij} = \frac{X_{ij}}{\sum_{i=1}^{m} X_{ij}} \tag{3}$$

$$e_j = -k \sum_{i=1}^{m} \left(Y_{ij} \cdot \ln Y_{ij} \right) \tag{4}$$

$$d_j = 1 - e_j \tag{5}$$

$$W_{kj} = \frac{d_j}{\sum_{j=1}^{n} d_j} \tag{6}$$

$$W_j = \frac{\left(W_{kj} + W_{zj} \right)}{2} \tag{7}$$

where Y_{ij} is the ratio of j index in i city, X_{ij} is the standardized value, e_j is the index information entropy, d_j is the redundancy of information entropy, W_{kj} is the objective weight of j index, W_{zj} is the subjective weight, and W_j is the comprehensive weight. In $k = 1/\ln m$, m is the number of cities evaluated and n is the number of indicators. The indicator weight and function weight are shown in Table 1.

2.3.3. Assessment of Multifunctional Cultivated Land

- Calculation of evaluation value of multifunctional cultivated land

The Comprehensive Index Model was applied to calculate the values of the production, social, and ecological functions of each city in the study areas. The formula is:

$$U = \sum_{j=1}^{\mu} \left(X_{ij} \cdot W_j \right) \tag{8}$$

where U is the evaluation indicator of each function of cultivated land, j is the evaluation indicator, and μ is the number of evaluation indicators for this function.

- Calculation of multifunctional coupling coordination degree of cultivated land

The production, social, and ecological functions of cultivated land are not independent of each other but rather are mutually restricted and influenced. Thus, the comprehensive assessment of the utilization of cultivated land can be achieved by calculating the multifunctional coupling coordination degree of cultivated land. The Coupling Coordination Degree Model can be used to calculate the multifunction coupling coordination degree of cultivated land. The formulas needed are:

$$C = \sqrt[3]{\frac{U_1 U_2 U_3}{\left(\frac{U_1 + U_2 + U_3}{3} \right)^3}} \tag{9}$$

$$T = W_1 U_1 + W_2 U_2 + W_3 U_3,\ W_1 + W_2 + W_3 = 1 \tag{10}$$

$$D = \sqrt{C \cdot T} \tag{11}$$

where C is the compatibility degree and U_1, U_2, and U_3 are the production, social, and ecological function evaluation values of cultivated land, respectively. T is the multifunctional comprehensive evaluation indicator of cultivated land. Additionally, W_1, W_2, and W_3 are the undetermined coefficients of each function, namely, the comprehensive weight values of each function, where W_1 = 46.2%, W_2 = 26.2% and W_3 = 27.6%. Finally, D is the multifunctional coupling coordination degree of cultivated land.

2.3.4. Identification of Driving Forces of the Multifunctional Coupling Coordination Degree of Cultivated Land

As an open system, cultivated land is influenced by human production and economic activities. The spatial-temporal evolution process of the coupling and coordinated development among the production, social, and ecological functions of cultivated land is jointly influenced by the endowment of cultivated land resources, the level of agricultural development, and social and economic factors [3,25]. In order to reveal the factors influencing the change in the multifunctional coupling coordination degree of cultivated land in the study areas, in this paper we selected ten influencing factors, as shown in Table 2. Geodetector was used to explore the driving forces from the perspective of single factors and dual factors [42] in order to analyze the driving forces behind the multifunctional coupled coordinated development of cultivated land in the study areas.

Table 2. Selection of factors influencing the multifunctional coupling coordination degree of cultivated land in the study areas.

Influencing Factors	Indicators	Unit	Symbol
Cultivated land resource endowment	Slope	°	X1
	Altitude	m	X2
	Annual precipitation	mm	X3
Agricultural development level	Contribution of primary industry to GDP	%	X4
	Average salary level of agriculture, stockbreeding, forestry, and fishery	CNY	X5
	Rural per capita disposable income level	CNY	X6
	Effective irrigation rate of cultivated land	%	X7
Socioeconomic factors	Fiscal expenditure related to agriculture	%	X8
	Contribution of industry to GDP	%	X9
	Urbanization level	%	X10

In this study, the natural discontinuity grading method was used to discretize the influencing factors, and then the differentiation, factor detection, and interaction detection module in Geodetector were used to analyze the driving forces. The formula for the expression of differentiation and factor detection is:

$$q = 1 - \frac{1}{N\sigma^2} \sum_{h=1}^{L} N_h \sigma_h^2 \tag{12}$$

where q represents the degree to which the influencing factor explains the dependent variable, with the range of [0,1]. The larger the value of q is, the stronger the ability of the influencing factor to explain the dependent variable is, and vice versa. N is the total number of cities in the study areas; σ^2 is the total variance of the multifunctional coupling coordination degree of cultivated land in each city in the study areas; L is the number of layers of influencing factors; and N_h and σ_h^2, represents the number of cities (districts) and the discrete variance of layers h divided by the influencing factors, respectively. The detection of influencing factor interaction refers to the detection of the difference between $q(x_1)$ and $q(x_2)$ when two influencing factors x_1 and x_2 act on the dependent variables separately and $q(x_1 \cap x_2)$ when the interaction of two influencing factors x_1 and x_2 act together on the dependent variables. This can be used to determine whether two influencing factors x_1 and x_2 acting together enhances or weakens the dependent variables or whether there is no combined impact on the dependent variables at all.

2.3.5. Summary

In the above subsections, the methodological process is illustrated. We further summarize the correspondence between methodological process and research results. Based on the multifunctional cultivated land evaluation index system, we chose twelve indicators to characterize the different functions of cultivated land. In order to eliminate the influence of indicator unit dimensions and ensure the comparability of each indicator, we standardized and weighted each indicator. As functions of cultivated land are not independent of each other but are mutually influenced, we applied the Comprehensive Index Model and the Coupling Coordination Degree Model to calculate the evaluation value of cultivated land functions (U) and the multifunction coupling coordination degree of cultivated land (D) of each city in the study areas in 2005, 2010, 2015, and 2020.

Based on the calculation results of the multifunctional cultivated land evaluation values, the functional level of cultivated land used for multiple functions was divided into five grades (Table 3); the degree of multifunctional coupling coordination of cultivated land was also divided into five grades (Table 4). Additionally, the number of cities (districts) in each province in the different grades by year is shown in Table 4.

Table 3. Grade and level of evaluation values of the functions of cultivated land.

Evaluation Values of Cultivated Land Functions (U)	Functional Grade	Functional Level
(0.0~0.2)	1	Low level
(0.2~0.4)	2	Relatively low level
(0.4~0.6)	3	Middle level
(0.6~0.8)	4	Relatively high level
(0.8~1.0)	5	High level

Table 4. Grading and level of multifunctional coupling coordination degree of cultivated land and related quantitative distribution by year, province, and city (district).

Coupling Coordination Degree D	Coordinated Grade	Coupling Coordination Level	2005			2010			2015			2020		
			HLJ	JL	LN	HLJ	JL	LN	HLJ	JL	LN	HLJ	JL	LN
(0.0~0.2)	1	Serious disorder	4	2	4	2	1	1	1	2	3	2	1	3
(0.2~0.4)	2	Moderate disorder	9	2	4	6	3	3	5	2	1	0	2	1
(0.4~0.6)	3	Barely coordinated	0	5	6	5	5	10	7	5	7	4	6	7
(0.6~0.8)	4	Basically coordinated	0	0	0	0	0	0	0	0	3	7	0	3
(0.8~1.0)	5	Well-coordinated	0	0	0	0	0	0	0	0	0	0	0	0

Note: HLJ: Heilongjiang; JL: Jilin; and LN: Liaoning.

The calculation results of both U and D are visualized by using the hierarchical graphs in Sections 3.1 and 3.2, respectively, and the spatial-temporal evolution characteristics of every single function and the multifunctional coupling coordination of cultivated land are also explained in these two subsections, respectively. In order to explore the driving forces of the spatial-temporal evolution characteristics, Geodetector was applied in the research. The results analyzed by Geodetector are shown in Section 3.3. Based on the single factor detection and dual-factor detection results of Geodetector, driving forces of the evolution of the multifunctional coupling coordination degree of cultivated land is identified in Section 3.2, further, the influence mechanism of the driving forces is analyzed in Section 3.3.3. Following are the research results.

3. Results

3.1. Spatial-Temporal Evolution Characteristics of Multifunctional Cultivated Land

3.1.1. Production Function of Cultivated Land

The spatial-temporal evolution of the production function of cultivated land in the study areas is shown in Figure 2. It can be seen that the production function of cultivated land in the study areas increases year by year: the production function of cultivated land in Heilongjiang shows a trend of generally increasing, the production function improvement of cultivated land in Jilin is relatively weak, and the production function of cultivated land in some cities in Liaoning is improving. The cities (districts) with a high value for the evaluation of the production function of cultivated land are mainly distributed in Heilongjiang and the central and eastern areas of Liaoning, which boast a high land reclamation rate, high grain yield, relatively complete agricultural infrastructure, and relatively good agricultural mechanization level. As a result, the cultivated land output is high. The evaluation value of the production function of cultivated land in the Daxing'anling area of northern Heilongjiang was at a low level for a long time, mainly due to the cold climate, low cultivated land reclamation rate, and low grain yield, which led to the low land output in this area. However, on the whole, it can be seen that the production function of cultivated land in Heilongjiang is quite high. As an important national grain base, Heilongjiang has a good agricultural production foundation and natural resource endowment advantages. Its cultivated land production capacity is increasing year by year; thus, this area effectively ensures national food security.

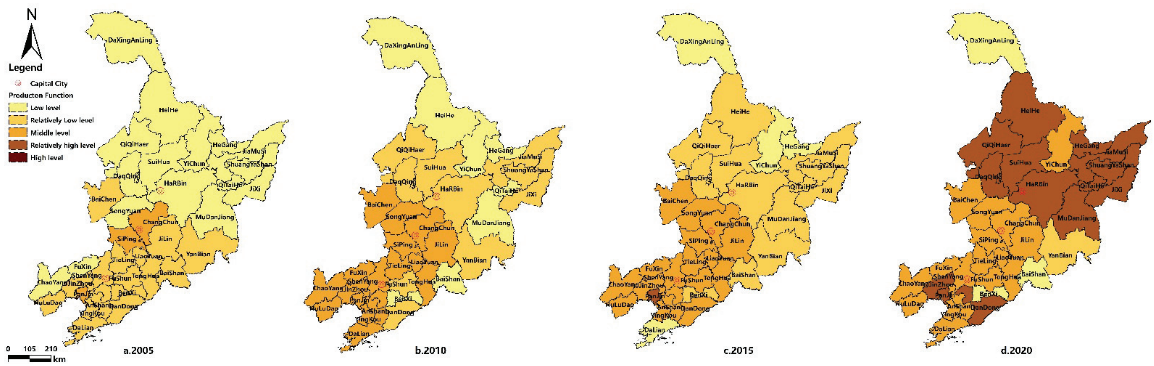

Figure 2. Spatial-temporal distribution of the production function of cultivated land in 2005, 2010, 2015, and 2020.

3.1.2. Social Function of Cultivated Land

The spatial-temporal evolution of the social function of cultivated land in the study areas is shown in Figure 3, where it can be seen that the social function of cultivated land in the study areas is increasing year by year. In 2005, nearly half of the cities (districts) in the study areas were at the middle level in terms of the land's social function. By 2020, only nine cities (districts) in the study areas were at a low level or relatively low level, and nearly one-third of the cities (districts) achieved a high level in terms of the land social function; these were mainly distributed in Heilongjiang and Liaoning. In cities with a high social function level, the production function of cultivated land was also quite high. On the basis of fully developing and utilizing cultivated land resources, farmers constantly improve their grain production capacity and grain self-sufficiency. As a result, the agricultural output value and household income of farmers in these areas are also high, with a large rural agricultural labor force because cultivated land features a large agricultural labor force, demonstrating its prominent social security function. With the national cultivated land protection policy favoring the major grain-producing areas in northeast China and further rural revitalization strategies being implemented, agriculture has become the dominant industry in the major grain-producing areas in northeast China. This has effectively solved the employment problem faced by the local agricultural labor force, and the per capita disposable income of farmers has increased year by year, providing strong social security for farmers in the study areas. Over time, the social function of cultivated land in the study areas has gradually strengthened, with these areas gaining increasing prominence in terms of social security.

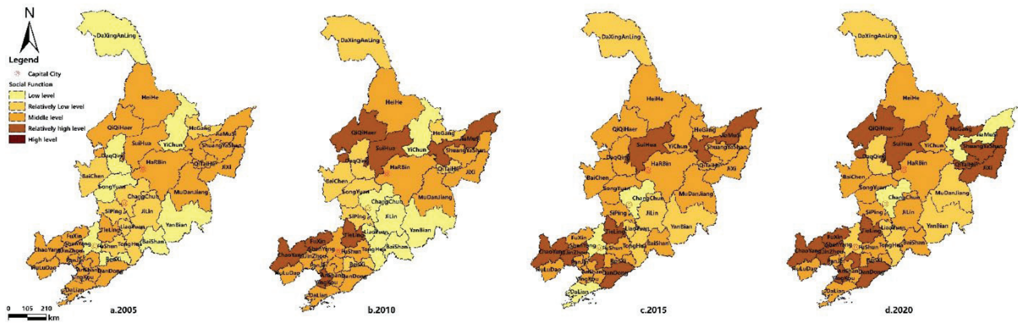

Figure 3. Spatial-temporal distribution of the social function of cultivated land in 2005, 2010, 2015, and 2020.

3.1.3. Ecological Function of Cultivated Land

The spatial-temporal evolution of the ecological function of cultivated land in the study areas is shown in Figure 4, where it can be seen that the ecological function of cultivated land in the study areas has been at a high level since 2005. From the temporal perspective, it can be seen that the ecological function of cultivated land in the study areas has not undergone any significant change in pattern. Generally speaking, Heilongjiang is the area with the highest ecological function of cultivated land, while Liaoning has the lowest ecological function among the three provinces. However, from 2005 to 2020, Liaoning saw an improvement in terms of its ecological function of cultivated land after previously undergoing a decline. Northeast China is the main grain-producing area in China, with a good climate, beneficial hydrothermal conditions, and a large proportion of paddy fields, which are mainly distributed along the Shenyang–Changchun–Harbin line of the three northeast plains and the coastal areas of major rivers. The Heilongjiang paddy fields are mainly distributed across Sanjiang Plain, Songnen Plain, Harbin, and Suihua, while the Liaoning and Jilin paddy fields are mainly distributed in the central areas of various provinces [43,44]. In recent years, the provinces and cities in the study areas have vigorously promoted the development of farmland water conservation facilities and increased the effective irrigation area of the cultivated land, thus significantly improving the biodiversity of paddy fields. In addition to rice, corn, wheat, millet, sorghum, beans, potatoes, and other crops cover large planting areas in the study areas, effectively improving the diversity of the farmland ecosystem. Due to the national cultivated land protection policy, the reduction in fertilizer application has significantly reduced the fertilizer load of cultivated land in the study areas, thus improving the ecological function of cultivated land in these areas. Through the implementation of important measures such as the triple protection policy for cultivated land and the ecological restoration of land space, the ecological value of cultivated land in these areas has been effectively improved, while the ecological function of cultivated land has also been significantly enhanced.

3.2. Spatial-Temporal Evolution of Multifunctional Coupling Coordination Degree of Cultivated Land

The production, social, and ecological functions of cultivated land are interrelated and influence one another. In the process of cultivated land utilization, the change and development of any function causes a change in the degree of multifunctional coupling coordination of cultivated land. The spatial-temporal evolution of the multifunctional coupling coordination degree of cultivated land in the study areas is shown in Figure 5.

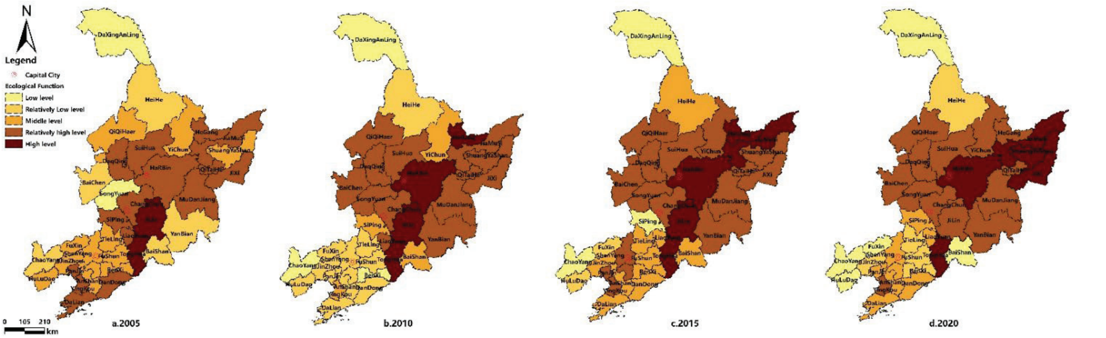

Figure 4. Spatial-temporal distribution of ecological function of cultivated land in 2005, 2010, 2015, and 2020.

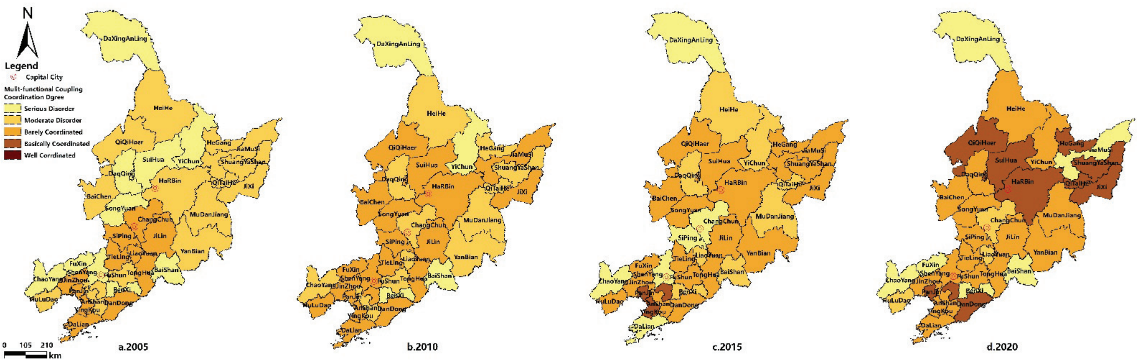

Figure 5. Spatial-temporal evolution of multifunctional coupling coordination degree of cultivated land in 2005, 2010, 2015, and 2020.

From Figure 5 and Table 4, it can be seen that the coupling coordination degree of the production, social, and ecological functions of cultivated land in different years differs significantly in different regions. From 2005 to 2020, the multifunctional coupling coordination degree of cultivated land in all provinces and cities in the study areas showed a trend of improvement, but the number of cities (districts) with serious imbalance remained basically unchanged. From 2005 to 2010, the multifunctional coupling coordination degree of cultivated land in the study areas was largely barely coordinated, and there were no cities (districts) with a coupling coordination degree greater than 0.6. In 2015, there were three cities in Liaoning whose multifunctional cultivated land coupling coordination degrees were between 0.6 and 0.8; these were largely coordinated and were distributed in the central part of Liaoning. At this time, there were no mostly coordinated cities (districts) in Heilongjiang and Jilin. By 2020, there were seven cities (districts) in Heilongjiang and three cities (districts) in Liaoning whose multifunctional cultivated land coupling coordination degrees were largely coordinated; these were mainly distributed in the south of Heilongjiang and the middle of Liaoning. The degree of multifunctional coupling coordination of cultivated land in Jilin was largely barely coordinated, showing that there was no significant change during the study period.

The cultivated land resources in the study areas are abundant and the quality of the cultivated land there is good. With the modernization and intensification of agriculture, the intensive and large-scale utilization of cultivated land, and the improvement of the social and economic levels in these areas, the multifunctionality of cultivated land in most cities (districts) in the study areas is gradually developing in an orderly manner. However, the mode of land operation dominated by traditional agricultural production, to a certain extent, leads to farmers having a high dependence on the production functions of cultivated land while neglecting the orderly development of the social and ecological functions of cultivated land, thus limiting the coordinated development of the multifunctional coupling of cultivated land. Therefore, from the temporal perspective, the degree of the multifunctional coupling and coordinated of cultivated land in the study areas has been improved, but this improvement is not significant, and the degree of multifunctional coupling and coordinated of cultivated land in some cities (districts) shows a serious imbalance.

3.3. Driving Forces behind the Multifunctional Coupling Coordination Degree of Cultivated Land

3.3.1. Single Factor Detection

To reveal the driving forces behind the spatial-temporal evolution of the multifunctional coupling coordination degree of cultivated land in different years in the study areas, the differentiation and factor detection module of Geodetector was used for analysis. The differences in the driving forces and the results of factor detection for each year are shown in Table 5.

Table 5. Results of single factor detection of the spatial-temporal evolution of the multifunctional coupling coordination degree of cultivated land in the study areas in 2005, 2010, 2015, and 2020.

	2005			2010			2015			2020	
Ranking	*q* Statistic	*p* Value	Ranking	*q* Statistic	*p* Value	Ranking	*q* Statistic	*p* Value	Ranking	*q* Statistic	*p* Value
X1	0.2986 **	0.0166	X1	0.3279 **	0.0114	X6	0.2114 **	0.0216	X7	0.2706 **	0.0165
X10	0.2265 **	0.0467	X6	0.2215 **	0.0362	X10	0.1809 **	0.0257	X6	0.1859 **	0.0411
X4	0.1920 *	0.0921	X4	0.1782	0.4243	X7	0.1267 **	0.0480	X4	0.1317 **	0.0362
X8	0.1587	0.2102	X10	0.1373	0.4056	X1	0.1204	0.4848	X1	0.0887	0.2969
X3	0.1363	0.2099	X7	0.1654	0.5118	X4	0.1175	0.6644	X2	0.0806	0.6780
X2	0.1058	0.5346	X8	0.1615	0.1965	X3	0.0908	0.6252	X8	0.0448	0.9114
X9	0.0856	0.4660	X2	0.1212	0.6708	X2	0.0649	0.8626	X3	0.0371	0.5930
X6	0.0853	0.8518	X9	0.0794	0.8596	X9	0.0608	0.9053	X10	0.0258	0.9198
X5	0.0790	0.8319	X5	0.0722	0.8470	X8	0.0407	0.8204	X5	0.0251	0.9486
X7	0.0614	0.7363	X3	0.0329	0.9882	X5	0.0053	0.7302	X9	0.0128	0.9430

Note: * and ** represent statistically significance at 10% and 5%, respectively.

Generally speaking, the factors that have a significant impact on the spatial-temporal evolution of the multifunctional coupling coordination degree of cultivated land in the study areas include the slope of cultivated land (X1), the contribution of primary industry to GDP (X4), the rural per capita disposable income level (X6), the effective irrigation rate of cultivated land (X7), and the urbanization level (X10).

From 2005 to 2020, the *q*-value ranking of the rural per capita disposable income and the effective irrigation rate of cultivated land increased, indicating that the construction of modern irrigation and water conservancy facilities and the improvement of the agricultural income level are conducive to promoting the orderly development of the multifunctional coupling coordination degree of cultivated land. The *q*-value ranking of the primary industry's contribution to GDP remained basically unchanged and only passed the significance test in 2005 and 2010, indicating that the pulling effect of the primary industry on economic development had a limited effect on the multifunctional coupling coordination degree of cultivated land. The *q*-value ranking of the slope and urbanization level declined, illustrating that with the development of science and technology, the influence of the natural local conditions of cultivated land and the number of agricultural populations on cultivated land utilization declined. In 2020, both of these failed to pass the significance test and their *q*-value was small, indicating that these factors have basically no influence on the ordered development of cultivated land used for multiple functions.

3.3.2. Dual-Factor Detection

The factor interaction detection module of Geographical Detector was used in our analysis to explore the effect of the factor interaction on the spatial-temporal evolution of the coupling coordination degree of cultivated land in the study areas. The results obtained for the dual-factor interaction of the spatial-temporal evolution of the multifunctional coupling coordination degree of cultivated land in the study areas are shown in Figure 6.

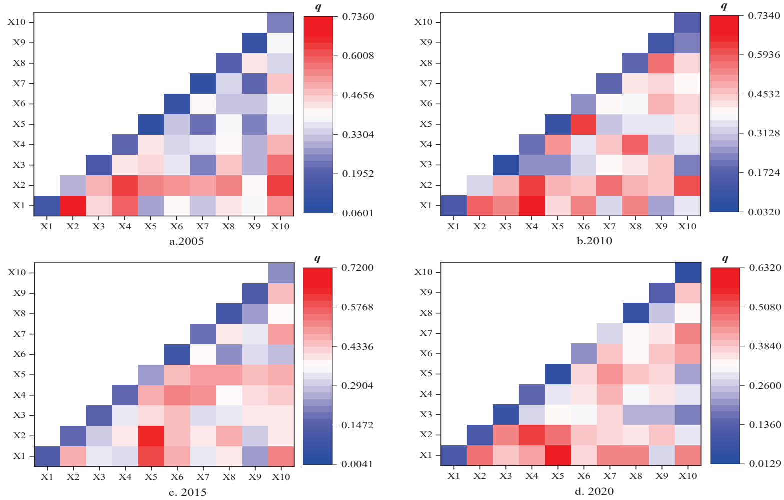

Figure 6. The detection results for the dual-factor interaction of the spatial-temporal evolution of the multifunctional coupling coordination degree of cultivated land in the study areas in 2005, 2010, 2015, and 2020.

According to the results obtained for the factor interaction, the interaction among factors has shown dual-factor enhancement and nonlinear reinforcement, indicating that the multifunctional coupling coordination degree of cultivated land in the study areas is influenced by multiple factors. Figure 6 shows that the interaction between slope factor (X1) and other factors is strong, with the strong interaction between the four factors representing the level of agricultural development. It is worth noting that there is an interaction between the altitude factor (X2) and the other factors, but it can be seen that this interaction tends to weaken over time. The interaction between the rural per capita disposable income level (X6), the effective irrigation rate of cultivated land (X7), and other factors relating to the agricultural development level is strong, and it can be seen that this interaction tends to increase over time. The interaction between the average salary level (X5) of those working in agriculture, stockbreeding, forestry, and fishery and other factors is also strong, but the influence of a single factor is not significant. The results obtained for the interaction among factors further verify that the agricultural development and cultivated land resource endowment are the key driving factors that influence the spatial-temporal evolution of the multifunctional coupling coordination degree of cultivated land in the study areas, demonstrating the complexity of the spatial-temporal evolution of the multifunctional coupling coordination degree of cultivated land.

3.3.3. Influence Mechanism

Among the natural resource endowments, the slope is the only key factor that influences the evolution of the spatial-temporal pattern of the multifunctional coupling coordination degree of cultivated land in the study areas. The slope of cultivated land reflects the topographic conditions of the surface units to which the cultivated land belongs and is an important indicator for grading the quality of cultivated land. Under the appropriate slope conditions, cultivated land resources can be fully and effectively utilized, ensuring the grain yield and agricultural income, enriching the crop variety, and attracting agricultural labor to engage in agricultural production, thus improving the production, social, and ecological functions of cultivated land and promoting the multifunctional coupling coordination degree of cultivated land. However, the q-value ranking of the influence of altitude, average annual precipitation, and other indicators on the multifunctional coupling coordination degree of cultivated land each year is in the middle level and has not passed the significance test, indicating those two indicators have limited effects on the coordinated development of cultivated land utilization and multifunctional coupling. If one wants to improve the multifunctional coupling coordination degree of cultivated land, one should start by upgrading the natural conditions of cultivated land, improving its quality, and ensuring the suitability of cultivated land.

The agricultural development level strongly explains the spatial-temporal pattern of the multifunctional coupling coordination degree of cultivated land in the study areas. Over time, the effect of the rural per capita disposable income level and effective irrigation rate of cultivated land on the spatial-temporal pattern of the multifunctional coupling coordination degree of cultivated land gradually strengthens. The increase in farmers' disposable income can effectively improve agricultural production factors and can lead to the allocation of more funds for agricultural production, land transfer, the employment of labor force, the use of modern agricultural machinery, etc. The improvement of agricultural development is conducive to realizing the large-scale and intensive utilization of cultivated land, thus enhancing the production function of cultivated land. The construction of farmland water conservancy facilities can further improve the mechanization level of agricultural production, increasing farmland biodiversity and thus promoting the orderly development of the production, social, and ecological functions of farmland, moving towards coupling and a coordinated direction.

The influence of social factors on the spatial-temporal evolution of the multifunctional coupling coordination degree of cultivated land in the study areas is generally weak. Among the three factors, only urbanization had a significant influence on the multifunctional coupling coordination degree of cultivated land in 2005 and 2015, indicating that with the improvement of the urbanization level, the rural population gradually declined, resulting in a reduction in agricultural labor force input to a certain extent, which was not conducive to the development of the production function and social function of cultivated land or to its coupling and coordinated development. Therefore, in 2020, this factor only had a very weak effect on the multifunctional coupling coordination development of cultivated land.

4. Discussion

4.1. Policy Implications for Utilization and Management of Multifunctional Cultivated Land

Achieving the coordinated development of cultivated land for multiple functions is a long-term goal. In this study, we calculated and evaluated the values of each function of cultivated land and the multifunctional coupling coordination degree of cultivated land. Visualizing their spatial-temporal pattern can help us in understanding the evolution of the use of cultivated land for multiple functions. In addition, revealing the key driving factors behind the spatial-temporal evolution of the multifunctional coupling coordination degree of cultivated land can help us to clearly define the main factors influencing the coordinated development of various functions of cultivated land and allow us to put forward suitable and feasible development paths and plans for the orderly utilization of cultivated land for multiple functions. The policy implications are as follows:

Guaranteeing the comparative benefits of agricultural production and steadily increasing the level of disposable income of rural residents: The research results show that the disposable income level of rural residents is an important factor affecting the evolution of the multifunctional coupling coordination degree of cultivated land. Therefore, through policy regulation, the government should stabilize the price of agricultural production materials, increase the market price of grain crops, and raise the subsidy standard of grain cultivation to ensure the comparative benefits of agricultural production. By continuously improving the comparative income level of agriculture, steadily increasing the level of disposable income of rural residents, and continuously improving the economic and production functions of arable land, the multifunctional utilization and management of cultivated land can be improved.

Enhancing the construction of agricultural production infrastructure to improve the level of agricultural development: According to the research results, the effective irrigation rate of cultivated land is an important factor affecting the development of the multifunctional coupling coordination of cultivated land. This shows that the construction of agricultural production infrastructure should be further improved in order to provide good production conditions for agriculture. Especially in the main grain-producing areas, agricultural production is the basis of all social and economic activities. It is therefore necessary to continuously improve the construction of agricultural infrastructure, create a good production environment for agricultural production, and effectively promote the coordinated development of multifunctional cultivated land based on the improvement of its production function.

Strictly implementing the farmland protection policy and continuously improving farmland productivity: Among the natural resource endowment conditions, the slope of cultivated land is a key factor affecting the evolution of the multifunctional coupling coordination degree of cultivated land. Slope represents the basic condition of cultivated land resources, and a suitable arable land slope is the foundation of agricultural production, ensuring a good grain yield, enriching the diversity of agricultural crops, and improving farmers' enthusiasm for farming. Therefore, the farmland protection policy must be strictly implemented and the use of farmland with suitable slopes for non-food and non-agricultural production must be strictly prohibited. Through the implementation of policies and measures such as "storing grain in the land" and "storing grain in technology" to protect the cultivated land effectively, we can improve the quality of cultivated land and the production capacity of cultivated land. The coordinated development of multifunctional cultivated land is promoted through the synergistic improvement of the production, social, and ecological functions of cultivated land.

4.2. Contribution to Research, Limitations, and Future Perspectives

During the rapid process of rural development, ensuring the success of multifunctional cultivated land in China has become a critical objective in achieving the sustainable use of cultivated land. The existing studies in this area have provided us a cultivated land multifunction utilization level through the improved TOPSIS model [3], but the results of empirical analysis can only tell us the distance from the current utilization level to the optimal utilization level of multifunctional cultivated land. This does not allow us to clearly evaluate the actual use of multifunctional cultivated land. Thus, in this study we combined the Comprehensive Index Model and the Coupling Coordination Degree Model to calculate the exact coupling coordination degree of multifunctional cultivated land, which provided much clearer results relating to the multiple functions of cultivated land. Furthermore, the existing studies in this area mostly focus on the factors influencing cultivated land use [26,38,45]. However, cultivated land is a complex system and the interaction of different factors can have an impact on multifunctional cultivated land. Detailed analyses of cultivated land used for multiple functions and the impact of its interaction are rare. Thus, we used Geodetector to explore the effect of the interaction of multiple factors on the multifunctional coupling coordination degree of cultivated land, providing a deeper understanding of the spatial-temporal patterns and driving forces behind the use of cultivated land for multiple functions.

However, in this study we only considered the production, social, and ecological functions of cultivated land, ignoring other factors such as landscape functions, cultural functions, reserve functions, etc. In a future follow-up study, our analysis of the use of cultivated land for multiple functions will be further extended to allow for the establishment of an index system for the evaluation of multifunctional cultivated land. This will be supplemented with microdata to allow us to further analyze the spatial distribution of the multifunctional coupling coordination degree of cultivated land, to explore the trend of the spatial-temporal evolution of the multifunctional coupling coordination degree of cultivated land more scientifically, and to provide scientific reference for the management and utilization of multifunctional cultivated land.

5. Conclusions

In this paper, we analyzed the production, social, and ecological functions as well as the spatial-temporal evolution of the multifunctional coupling coordination degree of cultivated land in major grain-producing areas of northeast China in 2005, 2010, 2015, and 2020, revealing the driving forces. The research showed that:

From 2005 to 2020, the production, social, and ecological functions of cultivated land in the study areas showed significant regional differences, and the multifunctional coupling coordination degree of cultivated land in the study areas showed a trend of gradual improvement, but did not reach a level of good coordination. As time passed, the number of cities (districts) in the study areas where the degree of multifunctional coupling coordination of cultivated land was seriously out of balance remained unchanged.

As for the driving forces, the spatial-temporal evolution of the multifunctional coupling coordination degree of cultivated land in the study areas was mainly influenced by the level of agricultural development. According to the results obtained from the analysis of the factor detection module of Geographical Detector, the level of per capita disposable income in rural areas and the effective irrigation rate of cultivated land representing the level of agricultural development were ranked highest in almost every year, showing a strong explanatory power for the spatial-temporal pattern of the multifunctional coupling coordination degree of cultivated land. In addition, the slope factor in the natural resource endowment category and the urbanization factor in the socioeconomic category also exerted an important influence on the spatial-temporal pattern of the multifunctional coupling coordination degree of cultivated land in the study areas.

Author Contributions: J.G. is responsible for conceptualization, formal analysis, writing—original draft preparation, and writing—review and editing. Y.Z. is responsible for methodology. R.Z. is responsible for writing—review and editing. H.S. is responsible for visualization. All authors have read and agreed to the published version of the manuscript.

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Article

A New Framework of Green Transition of Cultivated Land-Use for the Coordination among the Water-Land-Food-Carbon Nexus in China

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Abstract: As a fundamental solution to the ecological problems of resources and environment, the Green Transition of Cultivated Land-use (GTCL) has become an inherent requirement for promoting ecological progress and implementing the food security strategy in the new era. This paper proposed a theoretical framework of GTCL and constructed a GTCL development index system based on four aspects: water, land, food and carbon; then, by applying a comprehensive evaluation model, a coupling coordination model and exploratory spatial data analysis, the development level of GTCL in China's 31 provinces, municipalities and autonomous regions in 2000, 2005, 2010, 2015 and 2020 was evaluated and the spatial and temporal rates of change of "water, land, food and carbon" (WLFC) and their coupling coordination were finally analyzed to reveal the "water, land, food and carbon" effect of GTCL. Results showed that the systemic changes of WLFC and its coupling coordination degree of GTCL presented a spatial and temporal coincidence with a high degree of consistency; from 2000 to 2020, the overall GTCL rate in all Chinese provinces, municipalities and autonomous regions showed a "W"-shaped fluctuation uptrend. In the past five years, the development level of GTCL was higher in Northeast China, followed by Central China and North China, while South China was at a low level. In addition, WLFC showed a more obvious "W"-shaped fluctuation, with higher coupling coordination in Northeast China in good coordination and lower coordination in East China and Southwest China. Therefore, according to the results of the study, areas were divided into: benefit leading area, quality improvement area, connotation tapping potential area, ductile development area and ecological reserve area for the regulation of GTCL in all Chinese provinces, municipalities and autonomous regions.

Keywords: cultivated land protection; Green Transition of Cultivated Land-use (GTCL); Water-Land-Food-Carbon (WLFC); coupling coordination

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1. Introduction

Cultivated land serves as an important prerequisite and guarantee for grain yield, and the material basis for human production, life and survival. Since the 21st century, the term "Anthropocene" has been widely mentioned and a series of risk events such as "gray rhinoceros" and "black swan" have evolved into global food crisis, environmental crisis, ecological crisis and major public events, making the whole society more and more concerned about cultivated land conservation. With the further increase of global population, increasingly higher requirements of quality of life, limited growth in cultivated land area, and a series of hazards of environmental pollution to the ecosystem, food security has become an important topic of global sustainable development [1–3]. According to the report "The State of the World's Land and Water Resources for Food and Agriculture in 2021: System at breaking point" released by the Food and Agriculture Organization of the United Nations (FAO), the state of the planet's soil, land and water resources has deteriorated dramatically over the past decade, increasing pressure to meet the food needs of nearly 10 billion people worldwide by 2050. If agricultural water withdrawals are likely to increase by about 35% in order to achieve a 50% increase in grain yield, the world will face a major challenge in providing water, energy and food. Admittedly, the enormous pressure to increase grain yield also comes with the cost of global ecological degradation. Deforestation for agriculture is estimated to be a significant source of greenhouse gas emissions, accounting for 17% of global carbon emissions, as well as harms such as soil erosion and biodiversity reduction [4]. Moreover, the heavy use of chemical fertilizers, pesticides, and plastic films can lead to significant nitrous oxide emissions and affect global warming [5]; excessive use of nitrogen and phosphorus fertilizers can cause (leaching, erosion) pollution of water resources, and its production can result in CO_2 emissions [6]; plastic residual films can damage the soil structure of the tillage layer, causing difficult infiltration of groundwater and secondary soil salinization [7]; pesticides present a risk if they are not used in a proper professional way, and even damage the ecological environment through the atmosphere, water bodies, soil, and food [8]. Therefore, there is an urgent need to find sustainable ways to increase food supply and protect the environment in agroecosystems.

As a traditional agricultural power, China feeds 22% of the world's population with 7% of the world's cultivated land [9]. Its grain yield has remained stable at over 1.3 trillion jin (a metric unit equal to exactly 500 g) for seven consecutive years [10], but there is also a "double high" phenomenon of high stocks and high imports. The rapid development of urbanization has led to the loss of cultivated land [11], and the number in hectares per capita of cultivated land areas is less than 1/2 of the world average; the pursuit of unit grain yield and excessive intensive production have brought serious negative environmental effects, and exposed cultivated land resources to the serious situation of declining soil organic matter, soil erosion, soil acidification, rapid decline of groundwater, and farmland pollution [12,13]. China's cultivated land system is on the verge of breaching its environmental boundary threshold. Relying on a large number of chemical inputs, China consumes nearly a third of the world's chemical fertilizers and uses 2.5 times more pesticides per unit area than the world average [14]. N and P losses in 2018 were 821.5 kilotons and 2137.8 kilotons, respectively, which fall in the high-risk zone [15]. China accounts for 13% of global irrigation water use, has a blue water footprint of 224.5 billion cubic meters and suffers from acute water scarcity [16]. China contributes 33% and 36% of global excess agricultural nitrogen and phosphorus and is responsible for 28% of all global N_2O emissions from croplands [3]. In addition, 19.4% of China's cultivated land is subject to soil contamination, which adversely affects grain yield [17,18]. In the short term, China's food supply is relatively adequate and maintains a tight balance with the ecological environment. However, in the long term, the spatial distribution of China's water, land and food resources is uneven [12] and ensuring food security remains China's top priority. The "North-to-South Grain Transfer" has put the north, where water resources are insufficient, in a dilemma of water resource "overload" and ecological environment degradation, which is not conducive to sustainable socio-economic development. As China's 14th Five-Year Plan suggests, emphasis should be, once again, put on promoting green development, pushing comprehensive green transition of economic and social development, and modernizing harmonious coexistence between man and nature. As stated in Subsection 8, "The action for consolidating and enhancing carbon sink" of the Action Plan for Carbon Dioxide Peaking Before 2030, efforts shall be stepped up to promote carbon emission reduction and carbon sequestration in agriculture and rural areas, develop green, low-carbon and circular agriculture, and take action to improve the quality of cultivated land [19]. Therefore, the coordinated and sustainable development of water resources, land resources, energy (carbon) and food systems is a major issue that the country needs to address urgently.

Food, energy and water are the three basic human needs, and their coupling has become a major global concern [20–22]. The society also faces major challenges in providing water, energy and food [23]. Bonn 2011 Conference: The Water, Energy and Food Security Nexus first proposed using "nexus" to see the complex relationship between the three. In the 17 Sustainable Development Goals (SDGs) set by the United Nations, SDG 2: Zero Hunger (sustainable food production), SDG 12: Ensure sustainable consumption and production patterns (transition to sustainable development), and SDG 15: Ensure the conservation, restoration and sustainable use of terrestrial ecosystems (protect terrestrial ecosystems and promote the sustainable use of ecosystems) relate to the sustainable use of each element of the WEF respectively. The WEF nexus has become the basis for achieving the SDGs [24]. In China, WEF-nexus-related studies are limited at the inter-regional level, mainly focusing on the safety evaluation and influence factors of WEF [25–27] or on one aspect or "water-land", "land-carbon", "water-carbon" and "food-water" relationships [28,29], which is not sufficient to coordinate the sustainable development of regional agriculture. Theoretically, Zhao [30] proposed a system coupling model of "water-land-energy-carbon" to reflect the matching relationship of various regional resources, the efficiency of exploitation and utilization, and the degree of human and social impacts on the environment, so as to achieve the goals of efficient utilization of regional water-land-energy resources, carbon emission reduction, and social production optimization. Subsequently, it was extended to water-land-food-energy nexus [31], land-water-food-environment nexus [32] or food-water-land-ecosystem nexus [33]. However, food security deserves further attention in practical studies of cultivated land-use.

The above studies show that the WEF nexus, based on broad and multiple perspectives, can make a significant contribution to the field of sustainability. However, there is still a scarcity about WLFC nexus; synergistic water-land-food-carbon development is rarely discussed and the complexity of policy formulation and management regarding GTCL is still in shortage. Therefore, the motivation and novelty of this study is to fill this gap in the WLFC-nexus field and to quantitatively assess the development of GTCL from the perspective of WLFC. The details of the objectives are as follows: 1. to construct a theoretical framework for WLFC-based GTCL; 2. to dissect the spatial and temporal differentiation of GTCL; 3. to explore the coupling coordination of WLFC in cultivated land systems; 4. to propose a ductile regulation strategy based on WLFC nexus.

2. Theoretical Framework and Research Methods

2.1. Case Study and Data Sources

Given the availability of data, choosing the panel data of 31 provinces, municipalities and autonomous regions of China from 2001 to 2021 as research units, this study treated 31 Chinese provinces, municipalities and autonomous regions. Figure 1 depicts the study area, but for the time being, due to data loss, Hong Kong, Macao and Taiwan are not included. The data in this paper are obtained from the 2001, 2006, 2011, 2016 and 2021 China Statistical Yearbook and China Rural Statistical Yearbook.

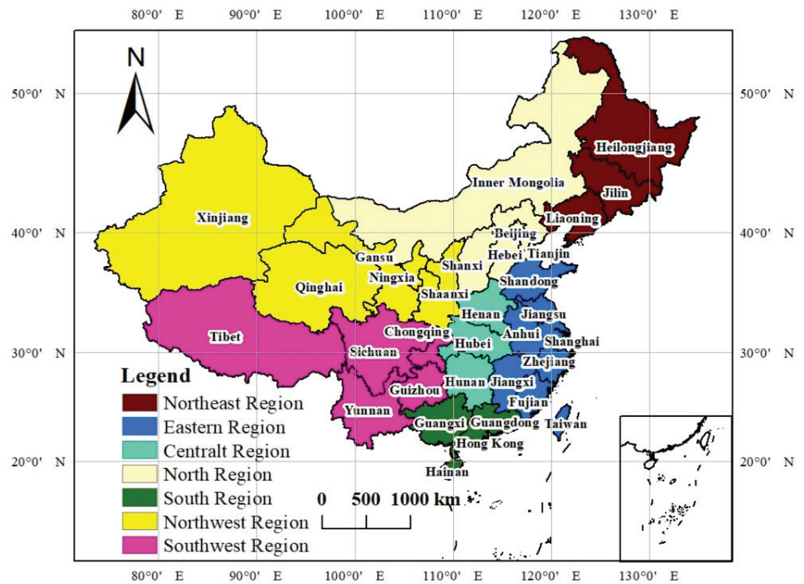


Figure 1. Study area.

2.2. Green Transition of Cultivated Land-Use (GTCL)

Cultivated land is the land used for crop planting, growing and harvesting as well as agricultural products production. A cultivated land system refers to the natural-ecological system of cultivated land resources and the economic-social system of human activities around the conservation and sustainable use of cultivated land resources in a specific regional space and in a certain time sequence and the complex system formed by the interaction of "element-structure-function-value" transition process through trade-offs/synergies, antagonism/adaptation, gain/loss, etc. [34]. Through the exchange of biotic and abiotic elements with other systems, material circulation, energy flow and information transfer, etc. are constantly taking place within the system. A cultivated land system has a whole development life cycle featuring element inputs, planting management, crop production, grain outputs, etc. Water, land, food and carbon are not only key elements of cultivated systems, but also important resource bases for natural and socio-economic life [35]. "Water" is the material and medium necessary for life activities and the raw material for most industrial production processes; the water system in a cultivated land system includes surface water, groundwater and unconventional water supply [36]. "Land" is the basis and place of human production activities and the source of nutrients for crop growth. Land is an important and non-renewable scarce resource in the cultivated land system, and socio-economic development must depend on land resources, which not only store energy and water resources, but also carry human living space and food needed for life. "Food" is the power source of economic and social systems, and the "food" system in the cultivated land system includes the supply and demand of food [37]; "carbon" is the material basis of living organisms and major energy sources, as well as the emission and metabolites of various human socio-economic activities [38]; carbon emissions from cultivated land systems come from various direct or indirect carbon emissions during the life cycle of cultivated land-use, mainly from pesticides, chemical fertilizers, agricultural films, tillage, agricultural machinery and irrigation. The development and utilization of water, land, food and carbon resources are interrelated and interact with each other. Since the regional cultivated land-use system is complex and has a large spatial heterogeneity, water-land-food combinations and carbon emission intensity vary with natural and social zones and industries in the region.

As shown in Figure 2, based on the life cycle development process of the cultivated land-use system, elements of different types in the "nature-culture" involving water, land, food, and carbon form a new subsystem in the "horizontal-vertical" structure through the material cycle, energy flow and information transfer. However, there is no linear evolutionary substitution between the four subsystems of "water-land-food-carbon" and the interaction between them is enhanced along with the human demand for the diversification, hierarchy and regionalization of cultivated land, as well as better understanding of the versatility and value (physical quantity) assessment of cultivated land [39,40]. For example, the coupling and mutual feedback, spatial and temporal evolution and functional transition of these subsystem components give multiple value attributes to cultivated land resources while forming a fluctuating and self-organized transition in the process of "material-energy-information" exchange/reorganization, "production-ecology-life" functional trade-offs/cooperation and "economy-ecology-society" service value response. Specifically, in the "one-to-one" factor coupling relationship, based on climate, topography, soil conditions, hydrology and biology, the "horizontal structure" and "vertical structure" of the cultivated land-use system are used to find the optimal vertical combination of water, soil, climate and biology and the best suitable interval for crop growth and soil synthesis, forming a sequence of inputs/outputs such as solar radiation, labor, agricultural technology, capital and primary agricultural products, which mainly reflects the spatial pattern of green transition of cultivated land-use. In the "one-to-many" factor coupling relationship, it is mainly the regulation, buffering and self-adaptation of the cultivated land-use system and the external artificial control environment, and different cultivated land-use methods, intensity of use and structural characteristics, with a specific spatial and temporal order and factor ratios to generate a hierarchical composite structure to maintain the material and energy flow exchange, product and value exchange with the external environment. This in turn affects the landscape pattern, soil environment, water environment, air environment, agricultural inputs (fertilizer and pesticide application, irrigation inputs), mechanization level, multiple crop index, crop-soil relationship and cultivated land output, which mainly reflects the evolution of GTCL. In the "many-to-many" factor coupling relationship, throughout the key nodes of cultivated land cultivation, quality improvement, crop maintenance, soil degradation, ecological management, etc., with reference to the source reduction and regulation, process precision and intelligent control, and agile management at the end, focusing on the value of the virtuous cycle of the cultivated land ecosystem, in the process of resource sharing, structural remodeling, functional gain and value response of the cultivated land utilization system, based on the reduced and harmless input/output model, the intensity of material consumption is effectively reduced, soil organic quality is improved, groundwater depletion is slowed down, the intensity of non-point source pollution is reduced and greenhouse gas emissions are reduced, which mainly reflects the system services of GTCL. Throughout the overall process of GTCL, "water" is the "lifeblood", "land" is the "root", "food" is the "core" and "carbon" is the "service".

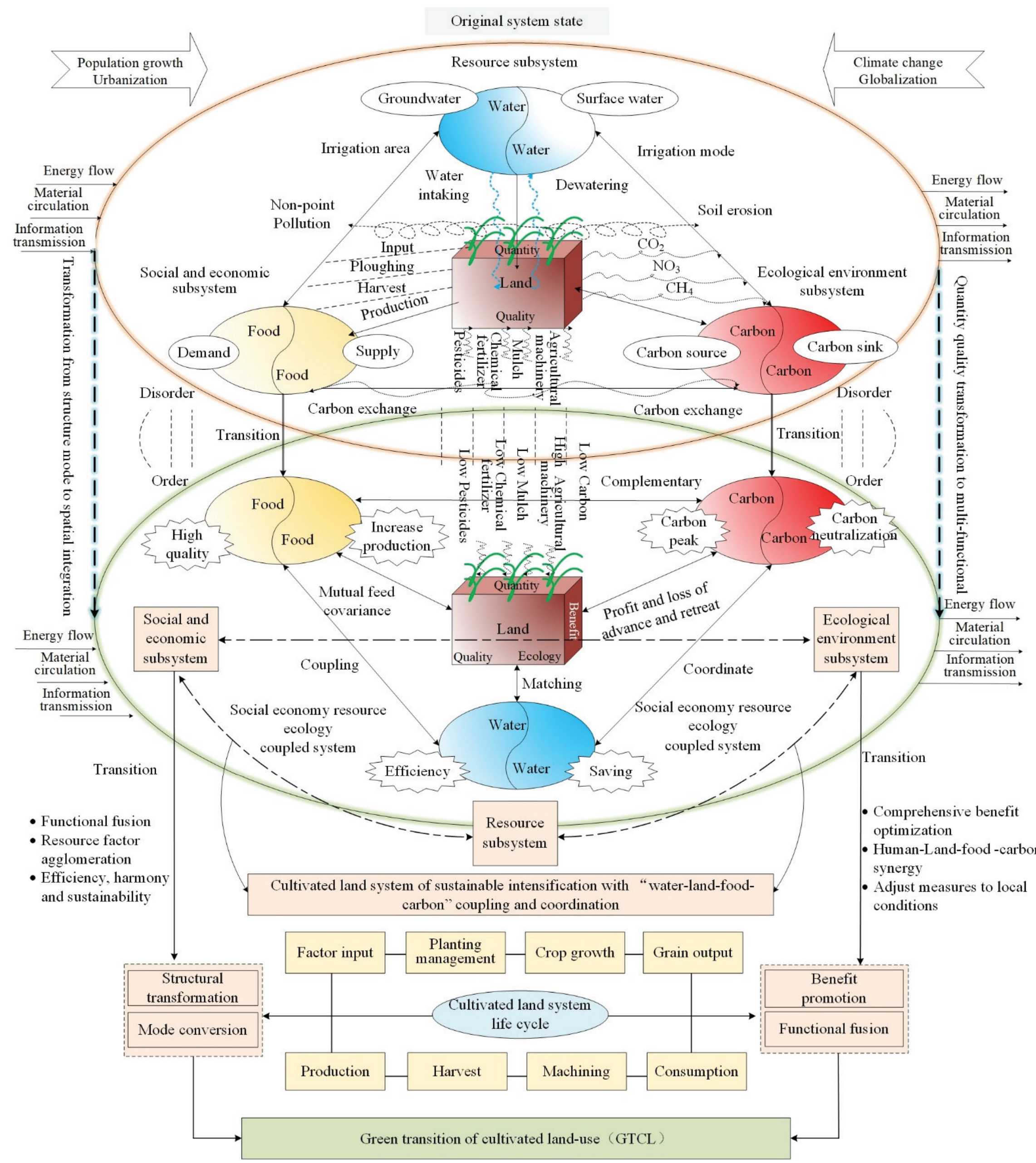


Figure 2. The concept framework of GTCL.

2.3. Evaluation Index System of GTCL

Based on the connotation of GTCL (Figure 2), this paper constructs an evaluation index system of GTCL, including four factor layers and 20 index layers, and the specific indexes are explained in Table 1.

Table 1. Index system of GTCL.

Factor Layers	Index Layers	Unit	Weight	Direction	Index Interpretation
Water	Virtual water self-sufficiency rate	%	0.129	+	Internal self-sufficiency of virtual water/total consumption of virtual water, it reflects the self-sufficiency of food production and the contribution of local water resources in residents' food consumption.
	Effective irrigation area	hm^2	0.065	+	Water source environment reflecting cultivated land resources.
	Virtual water land density	$m^3 \cdot hm^2$	0.098	+	Internal self-sufficiency of virtual water/Grain sowing area, it reflects the water consumption of grain production per unit area.
	Water consumption per unit area	L/hm^2	0.012	-	Agricultural irrigation water consumption/cultivated land area, it reflects the actual water consumption per unit cultivated land area.
Land	Per capita cultivated land area	hm^2/person	0.138	+	Cultivated land area/total population, it reflects the change of cultivated land quantity.
	Land reclamation rate	%	0.035	+	Cultivated land area/total land area, it reflects the degree of cultivated land development.
	Multiple crop index	%	0.033	+	Crop sowing area/cultivated land area, it reflects the degree of cultivated land-use.
	Investment ratio of saving and increasing	/	0.096	+	Total power of agricultural machinery per labor/chemical input per land, that is, labor-saving input/yield increasing input, reflecting the change of cultivated land input structure.
	Non-point source pollution intensity	kg/hm^2	0.010	-	The total loss of fertilizer nitrogen (phosphorus), pesticide and agricultural film reflects the carrying capacity of cultivated land ecological environment.
	Disaster area	hm^2	0.009	-	Reflect the resilience of cultivated land system
Food	Average grain yield	kg/hm^2	0.027	+	Grain crop yield/cultivated land area, reflecting grain production capacity.
	Per capita grain yield	person /kg	0.134		Food crop production/total population, reflecting food production security.
	Proportion of sown area of grain crops	%	0.026	+	Grain crop planting area/cultivated land area, reflecting grain production potential.
	Ratio of food crops to cash crops	%	0.127	+	Grain crop area/cash crop area, reflecting the change of grain structure.
Carbon	Carbon emission from pesticide use	kg/hm^2	0.013	-	Carbon emissions from pesticides, chemical fertilizers, agricultural film, tillage, total power of agricultural machinery and irrigation during the life cycle of cultivated land-use.
	Carbon emission from fertilizer use	kg/hm^2	0.007	-	
	Carbon emission from plastic film use	kg/hm^2	0.004		
	Carbon emission from tillage	kg/hm^2	0.015	-	
	Irrigation carbon emission	kg/hm^2	0.015	-	
	Carbon emission of agricultural machinery	kg/hm^2	0.008	-	

The indexes of the "water" system include the virtual water self-sufficiency rate, effective irrigation area, virtual water land density, and water consumption per unit of cultivated land. Virtual water for major food crops refers to the amount of water required for grain yield [41]. In this paper, five major food crops are selected: rice, wheat, corn, soybeans and potatoes. The virtual water self-sufficiency rate is calculated as follows:

$$I = \frac{IVW}{TVW} \tag{1}$$

$$TVW_{(j,t)} = IVW_{(j,t)} - EVW_{(j,t)} \tag{2}$$

$$IVW_{(j,t)} = VW_{(j,t)} \times \sum\nolimits_{i=1}^{n} G_{(j,t)} \tag{3}$$

$$EVW_{(j,t)} = VW_{(j,t)} \times \sum\nolimits_{t=1}^{n} \Delta A_{(j,t)} \tag{4}$$

In Equations (1)–(4), I is the virtual water self-sufficiency rate, IVW is the internal virtual water self-sufficiency of grain, TVW is the total virtual cultivation land consumption of grain. $EVW_{(j,t)}$ is the external virtual water flow of crop t in the area j, $VW_{(j,t)}$ is the virtual water content of crop t in the area j, $G_{(j,t)}$ is the grain output of crop t in the area j, $\Delta A_{(j,t)}$ is the transport amount of crop t in the area j.

The relevant indexes of the "land" system include per capita cultivated land area, land reclamation rate, multiple crop index, investment ratio of saving and increasing, soil organic matter content, non-point source pollution intensity and affected area. The non-point source pollution of cultivated land is mainly caused by the excessive use of chemical fertilizers, pesticides and agricultural films [42]. Therefore, this paper uses the loss of fertilizer nitrogen (phosphorus), ineffective use of pesticides and agricultural film residues to characterize the pollution level. The average fertilizer, pesticide and plastic film pollution intensity are used to estimate the level of agricultural non-point source pollution, and the calculation equation is as follows:

$$E = \sum E_{ij} = \sum C_{ij} \times \eta_{ij} = \sum T_i \times \rho_{ij} \times \eta_j \tag{5}$$

$$EI = E/AL \tag{6}$$

In Equations (5) and (6), E is the non point source pollution intensity of total fertilizers, pesticides and plastic films, EI is the non point source pollution intensity of average fertilizers (kg/hm^2); AL is the total sown area (hm^2); $\sum E_{ij}$ denotes the total amount of the j th pollutant produced in the area i; C_{ij} denotes the total amount of fertilizers, pesticides and plastic films produced by the j th pollutant in the area i; η_{ij} denotes the loss rate of the j th fertilizer in the area i. T_i is the index statistics of area i; ρ_{ij} indicates the product coefficient of the j th pollutant in the area i. The coefficients of fertilizer loss, pesticide residue and plastic film residue are shown in Table 2.

The relevant indexes of the "food" system include the average grain yield, per capita grain yield, the proportion of sown area of grain crops and the ratio of food crops to cash crops. Among them, oilseeds, cotton, hemp, sugar, tobacco and vegetables are mainly selected as cash crops. The relevant indexes for the "carbon" system include carbon emissions from pesticide use, carbon emissions from fertilizer use, carbon emissions from agricultural film use, carbon emissions from tillage, carbon emissions from irrigation, and carbon emissions from agricultural machinery. The Intergovernmental Panel on Climate Change (IPCC) guidelines were employed to calculate the CO_2 emissions for the available energy consumption (Intergovernmental Panel on Climate Change, 2007), emissions from the consumption of fossil fuels (mainly diesel) by agricultural machinery, indirect emissions from the consumption of electricity (mainly thermal power) by irrigation, and the loss of organic carbon due to tillage [31,44]. With reference to previous studies, carbon emissions are mainly from pesticides, fertilizers, plastic films, tillage, agricultural machinery and irrigation during the life cycle of cropland use (E). The equation for measuring carbon emissions from cropland use is:

$$E = \sum E_i = \sum (G_i \times \delta_i) \tag{7}$$

In Equation (7), E is the total carbon emission from cropland use; E_i is the carbon emission from the i th carbon source; G_i is the original amount of each carbon emission source, and δ_i is the carbon emission coefficient, which are 0.8956 (kg/kg) for fertilizers [45], 4.9341 (kg/kg) for pesticides [46], 5.18 (kg/kg) for plastic films, 0.18 (kg/kW) for agricultural machinery power (kg/kW), 20.476 kg/hm^2 for irrigation [47], and 312.6 (kg/km^2) for tillage [48].

Table 2. List of product factors of pollutants.

	Region	Loss Rate /%	Loss Rate /%	Region	Residual Rate /%	Loss Rate /%
		Nitrogenous fertilizer	Phosphate fertilizer		Plastic film	Pesticide
I	Jiangsu, Beijing	30	7	Inner Mongolia, Shanxi,	17.3	0.13820
II	Tianjin, Guangdong, Zhejiang, Shanghai	30	4	Heilongjiang, Jilin, Liaoning	25.75	0.00768
III	Hubei, Fujian, Shandong	20	7	Tianjin, Beijing, Shandong, Hebei, Henan, Jiangsu	25.65	0.06980
IV	Hebei, Shaanxi, Liaoning, Yunnan, Ningxia, Hunan, Jilin, Inner Mongolia, Guizhou	20	4	Fujian, Guizhou, Hunan, Jiangxi, Yunnan, Sichuan, Chongqing, Guangdong, Guangxi, Hainan	13.3	0.145625
V	Henan, Heilongjiang	10	7	Anhui, Zhejiang, Hubei, Shanghai	22.3667	0.228531
VI	Anhui, Hainan, Xinjiang, Shanxi, Guangxi, Gansu, Sichuan, Jiangxi, Chongqing, Qinghai, Tibet	10	4	Shaanxi, Gansu, Ningxia, Qinghai, Xinjiang, Tibet	34.41667	0.00010

Note: The correlation coefficient mainly adopts the literature research method and the relevant data published by the National Bureau of statistics, with reference to Lai [43] and the first national pollution survey: Manual of fertilizer loss, pesticide loss and film residue coefficient, and the impact of regional gap shall be considered as much as possible in the accounting process.

2.4. Determination of Index Weights

(1) Entropy weight method

This paper applies the entropy weight method to determine the objective weights of each index in Table 1, and reflects the contribution size of the comprehensive index of GTCL as the final weight value of the evaluation index system based on the generated weight structure. The results are shown in Table 1.

The extreme value standardization was used to unify the indexes to [0, 1] in order to eliminate the influence brought about by different index magnitudes.

For positive and negative indexes, the equation below was used:

$$r_{ij} = \frac{X_{ij-}X_{min}}{X_{max} - X_{min}} \quad r_{ij} = \frac{X_{max} - X_{ij}}{X_{max} - X_{min}} \tag{8}$$

Using the entropy weight method for the calculation of index weights, in an evaluation problem with m evaluation indexes and n evaluation objects, the entropy of the i th indicator is defined as:

$$H_i = -k\sum_{j=1}^{n} f_{ij} ln f_{ij} \ i = 1, 2, \cdots, m \tag{9}$$

In Equations (8) and (9): $f_{ij} = \frac{r_{ij}}{\sum_{j=1}^{n} r_{ij}}$, $k = \frac{1}{lnn}$, when $f_{ij} = 0$, make $f_{ij} ln f_{ij} = 0$.

After defining the entropy of the i th index, the entropy weight of the i th index is:

$$w_i = \frac{1 - H_i}{m - \sum_{i=1}^{m} H_i} \tag{10}$$

In Equation (10): $0 \ll w_i \ll 1, \sum_{i=1}^{m} = 1$.

(2) Comprehensive evaluation model

The equation of multidimensional evaluation:

$$F_i = \sum_{j=1}^{n} W_{ij} \times T'_{ij} \tag{11}$$

In Equation (11): F_i is the GTCL index in different dimensions; W_{ij} is the weight of the i th evaluation index; T'_{ij} is the normalized value of the j th of the i index.

(3) Scientific test of index system

$$R^2 = 0.992 \quad R^2 = \frac{\sum_i^n \left(Y_{pi} - Y_m\right)^2}{\sum_i^n \left(Y_i - Y_m\right)^2}$$

$$e = \sqrt{1 - R^2} \approx 0 \tag{12}$$

In Equation (12): The R^2 value is between 0 and 1 to show how close the predicted value Y_{pi} is to the actual value Y_i, Y_m denotes the average value, and n denotes the total number. The closer the residual coefficient e is to 0, the more representative and relevant the index system is.

2.5. Evaluation Methods

(1) Coupling coordination model

$$C = \left\{ \frac{U_1 \times U_2 \times U_3 \times U_4}{\left(\frac{U_1+U_2+U_3+U_4}{4}\right)^4} \right\}^{\frac{1}{4}} \tag{13}$$

$$U_i = \sum_{j=1}^{n} w_j y_{ij} \tag{14}$$

In the Equations (13) and (14): C is the coupling degree value, U_1, U_2, U_3, U_4 represent the four subsystems, i.e., "water, land, food, carbon," respectively, and the value range is [0, 1]. The interval of C represents the degree of interrelationship of subsystems. The higher C value indicates the stronger interrelationship between the subsystems, presenting the trend of orderly evolution; on the contrary, the evolution between the systems shows no trend.

$$D = (C \times T)^{\frac{1}{2}} \tag{15}$$

$$T = a \times U_1 + b \times U_2 + c \times U_3 + d \times U_4 \tag{16}$$

In Equations (15) and (16): D is the value of coupling coordination; T is the comprehensive index of GTCL, a, b, c and d are the weight coefficients of subsystems. The higher D value indicates the higher degree of coordination of the cultivated land composite system, and the level of coupling coordination is classified in Table 3.

Table 3. Classification of coupling coordination degree.

Coupling Coordination Degree	Coordination Level	Coupling Coordination Degree	Coordination Level
(0.80, 1.00]	Highly coordinated	(0.30, 0.40]	Reluctantly coordinate
(0.60, 0.80]	Good coordination	(0.20, 0.30]	Verge of disorder
(0.50, 0.60]	Moderate coordination	(0.10, 0.20]	Moderate disorders
(0.40, 0.50]	Low coordination	[0, 0.10]	Serious disorders

Based on relevant literature [41,44] and the actual situation, this paper uses the natural fracture method to cluster the values of "water-land-food-carbon" internal coordination development degree in the study area with the principle of maximum variance between groups and minimum variance within groups, and classifies the coupling coordination degree into serious disorder ($0 < D \leq 0.10$), moderate disorder ($0.10 < D \leq 0.20$), verge of disorder ($0.20 < D \leq 0.30$), reluctant coordination ($0.30 < D \leq 0.40$), low coordination ($0.40 < D \leq 0.50$), moderate coordination ($0.50 < D \leq 0.60$), good coordination ($0.60 < D \leq 0.80$), and high coordination ($0.80 < D \leq 1.00$) (Table 3), in order to set the internal coordination development discriminatory criteria.

(2) Exploratory Spatial Data Analysis (ESDA)

Exploratory Spatial Data Analysis (ESDA) is a visual analysis of spatial data interactions based on spatial correlation to explore the potential relationships of data distribution. The global spatial autocorrelation analysis can be applied to examine the spatial clustering characteristics of GTCL based on the Global Moran's *I* index, which reflects the similarity of attribute values of spatial neighboring areas.

$$I = \frac{n}{\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}} \times \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}(x_i - \overline{x})(x_j - \overline{x})}{\sum_{i=1}^{n}(x_i - \overline{x})^2} \tag{17}$$

where, x_i, x_j are the cultivated land-use transition indexes in areas i and j, respectively; $\overline{x}$ is the average of GTCL index in each area; W_{ij} is the spatial weight matrix (adjacency of spatial units), but if areas i and j are adjacent, $W_{ij} = 1$, otherwise $W_{ij} = 0$. Global Moran's I index takes values between -1 and 1, and there is no spatial autocorrelation when $I = 0$. There is positive correlation when $I = 0$, and negative correlation when $I < 0$.

2.6. Uncertainties and Shortcomings

This paper preliminarily reveals the WLFC nexus in the evolution process of GTCL and measures the coupling coordination degree between them on this basis. Due to the inconsistency of statistical caliber of data in different provinces, this current research has not well studied the internal development of each subsystem of WLFC. However, the research data timeline for official statistics in this paper is selected according to the Five-Year Plan, which will be beneficial to provide a theoretical and empirical ground for formulation and implementation of cultivated land protection policy.

3. Results

3.1. Spatial and Temporal Patterns of GTCL

3.1.1. Dynamic Evolution Characteristics of Regional Differences

As shown in Figures 3 and 4, the overall GTCL index in all China's provinces, municipalities and autonomous regions shows a "W"-shaped fluctuating uptrend, with the average values of the comprehensive transition index in 2000, 2005, 2010, 2015 and 2020 being 0.202, 0.137, 0.206, 0.147 and 0.237, respectively. The provinces, municipalities and autonomous regions above the average in 2000 were mainly Heilongjiang, Inner Mongolia, Anhui, Henan and Ningxia; in 2005, they were concentrated in Hebei, Jiangsu, Anhui, Shandong, Henan and Chongqing; in 2010, they were mainly in Inner Mongolia, Jilin, Heilongjiang, Anhui, Henan and Ningxia; in 2015, they were concentrated in Heilongjiang, Anhui, Jiangxi, Shandong and Henan; in 2020, they were concentrated in Inner Mongolia, Jilin, Heilongjiang, Jiangsu, Shandong and Henan. From 2000 to 2005, Inner Mongolia had the largest transition rate at −48.23%, Anhui the smallest at −19.29%; from 2005 to 2010, Heilongjiang had the largest transition rate at 169.07% and Beijing the smallest at 17.72%; from 2010 to 2015, Ningxia had the largest transition rate at −46.00% and Shanghai the smallest at 4.44%; from 2015–2020, Inner Mongolia had the largest transition rate at −51.54%, and Shanghai the smallest at −4.23%. In addition, the GTCL in provincial areas is more balanced. The extreme difference of GTCL index is 0.157 in 2000, 0.095 in 2005, 0.301 in 2010, 0.158 in 2015, and 0.673 in 2020, which indicates that the difference of GTCL between provincial areas shows an overall increasing trend.

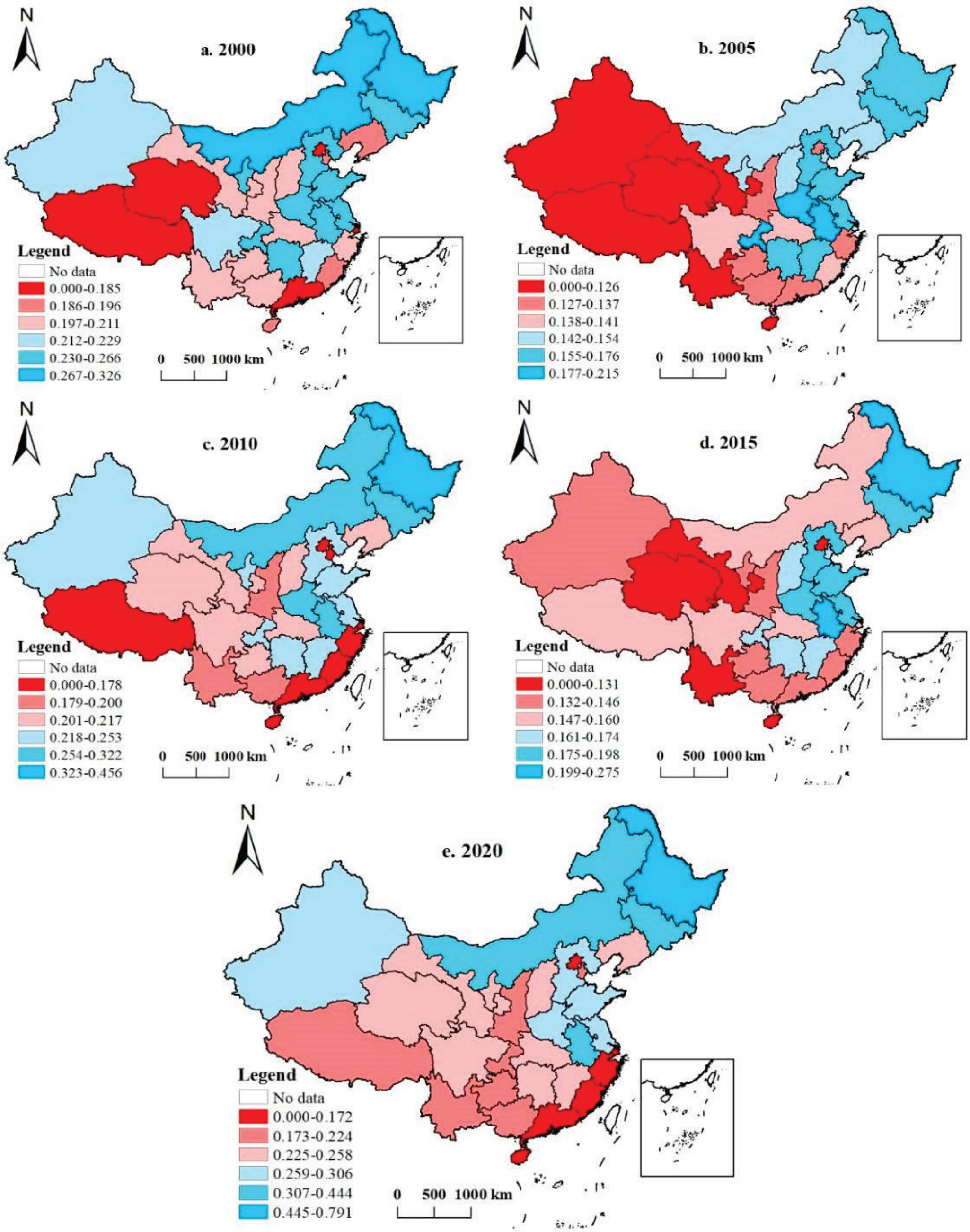
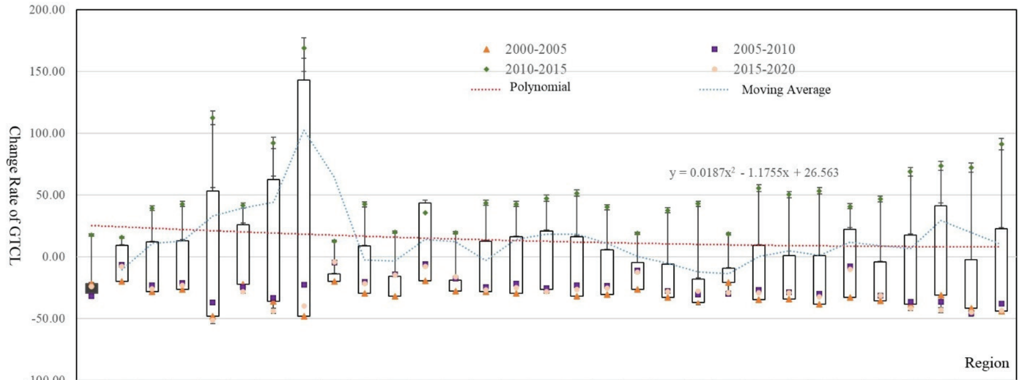


Figure 3. Evolution of spatial pattern of GTCL in China during 2000–2020.



	BJ	TJ	HB	SX	IM	LN	JL	HLJ	SH	JS	ZJ	AH	FJ	JX	SD
▲ 2000-2005	-21.	-19.	-28.	-26.	-48.	-22.	-36.	-47.	-19.	-29.	-31.	-19.	-27.	-28.	-29.
■ 2005-2010	-31.	-6.6	-23.	-21.	-36.	-24.	-33.	-22.	-4.4	-20.	-14.	-5.9	-17.	-24.	-21.
◆ 2010-2015	17.7	15.6	39.3	42.8	112.	41.6	92.3	169.	12.7	42.5	19.9	35.7	19.6	43.6	42.7
● 2015-2020	-24.	-7.8	-25.	-23.	-51.	-28.	-43.	-39.	-4.2	-21.	-14.	-7.7	-16.	-26.	-25.
2000-2020	-29.	9.38	11.9	13.1	53.3	26.0	62.4	143.	-14.	9.04	-15.	43.7	-18.	12.6	16.0

	HEN	HUB	HUN	GD	GX	HAN	CQ	SC	GZ	YN	XZ	SAX	GS	QH	NX	XJ
▲ 2000-2005	-26.	-31.	-30.	-26.	-32.	-37.	-20.	-34.	-34.	-38.	-32.	-35.	-38.	-30.	-41.	-43.
■ 2005-2010	-25.	-23.	-23.	-11.	-27.	-30.	-30.	-26.	-28.	-30.	-7.7	-31.	-36.	-36.	-46.	-38.
◆ 2010-2015	47.5	51.6	40.1	18.9	37.7	42.9	18.4	55.4	50.4	53.4	40.9	46.9	68.6	73.6	72.1	91.2
● 2015-2020	-28.	-26.	-25.	-12.	-28.	-27.	-29.	-29.	-29.	-32.	-9.9	-31.	-41.	-43.	-44.	-43.
2000-2020	20.7	16.1	5.62	-4.7	-6.2	-18.	-9.0	9.18	0.97	0.94	22.4	-4.0	17.6	41.3	-2.2	22.6

Figure 4. Change rate of GTCL in China during 2000–2020.

3.1.2. Global Characteristics of the Evolution of Spatial Pattern

Using the trend analysis tools in ArcGIS 10.2 software, this paper makes a three-dimensional intervisibility analysis on the overall trend of the GTCL in 31 provinces, municipalities and autonomous regions of China from 2000 to 2020 as research units. Taking the GTCL as the Z axis and the X and Y axes as the due east and due north directions, respectively, the spatial visualization results are obtained (Figure 5). The results show that there are significant spatial differences in the distribution of GTCL in China from 2000 to 2020. The overall distribution of cultivated land is basically the same from east to west, high in the north and low in the south.

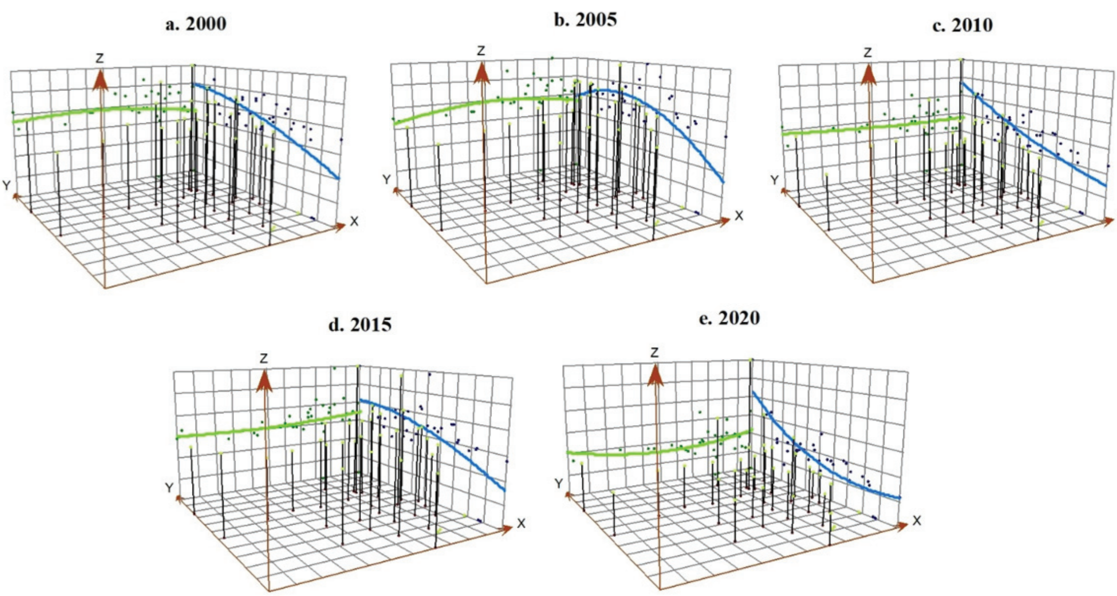


Figure 5. Trend analysis of GTCL in China during 2000–2020.

In GeoDa, a global spatial autocorrelation analysis was conducted for GTCL using Rook's criterion to calculate the Global Moran's I index (Figure 6).

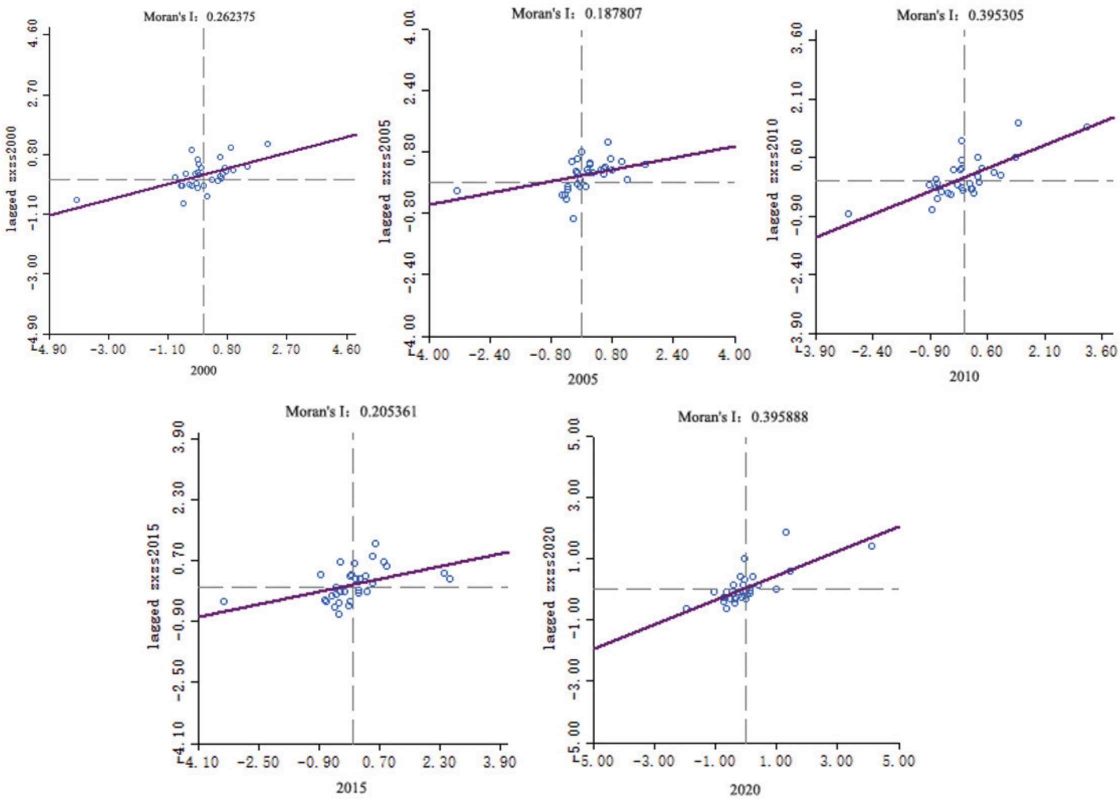


Figure 6. Moran's *I* index value of GTCL.

The global autocorrelation coefficients of Moran's I were all positive: 0.262, 0.188, 0.395, 0.205, and 0.396 from 2000 to 2020, respectively, and were divided into three categories according to the relative magnitude of each year: strong (absolute value $\geq$ 0.5), relatively weak (0.3 $\leq$ absolute value < 0.5), and weak (0 $\leq$ absolute value < 0.3). Overall, GTCL in each province, autonomous region and municipality showed a significant positive correlation between 2000 and 2020, and there were obvious regional clustering characteristics in space. From 2000 to 2005, the Moran's I value decreased, indicating a weak clustering distribution pattern among provinces, municipalities and autonomous regions. Compared with 2005, the Moran's I value increased significantly in 2010, which showed a weak clustering distribution pattern among provinces, municipalities and autonomous regions. Compared with 2015, Moran's I value in 2020 showed a significant increase, but it was still larger than that in 2010, indicating that the correlation of spatial distribution of GTCL among provinces, municipalities and autonomous regions increased in the period of 2015–2020, but the overall spatial differences showed an increasing trend.

3.2. Spatial and Temporal Patterns of "Water, Land, Food and Carbon" Changes

The spatial and temporal patterns of "water, land, food, and carbon" changes in each province, autonomous region and municipality were analyzed based on the evaluation indexes W (w), L (l), F (f), and C (c) (Figures 7 and 8).

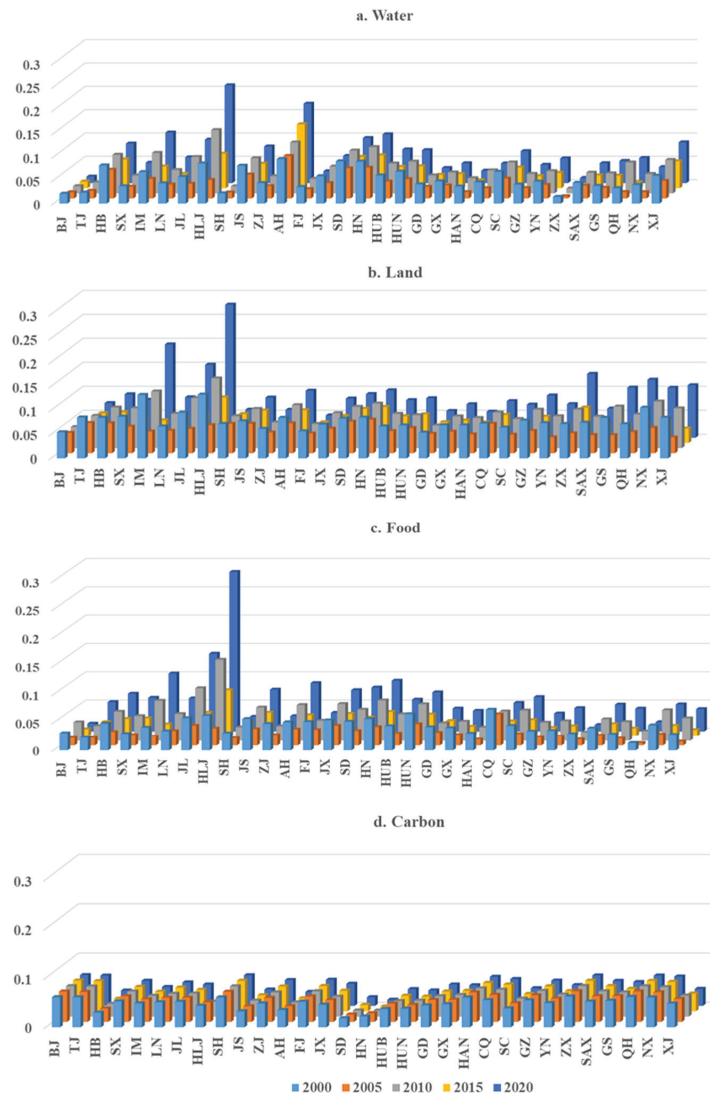


Figure 7. Temporal and spatial distribution of "Water-Land -Food-Carbon".

The water system W (w) evaluation index ranges from 0.0048 to 0.210, with a large fluctuation trend, mainly influenced by the virtual water self-sufficiency rate, effective irrigation area, water consumption per unit area of grain yield and water consumption per unit of cultivated land (Figure 8a). From 2000 to 2005, the highest rates of change in water were in Tibet, Ningxia and Hainan, with −66.82%, −66.37% and −62.34%, respectively, and the lowest was in Anhui, with a reduction of 4.44%, probably related to the reduced contribution of local water resources to the population's food consumption. From 2005 to 2010, the highest rate of water change was in Northwest China, with the largest increases in Qinghai and Ningxia, followed by Heilongjiang and Jilin in Northeast China, and the lowest was in Beijing, with an increase of 16.17%, probably related to the increase in the effective irrigated area. From 2010 to 2015, the trend was decreasing, with the highest rate of change in Qinghai and Ningxia, at 80.54% and 63.05%, followed by Jilin, at −56.63%, and Beijing, at −7.33%. From 2015 to 2020, the largest increases were in Qinghai, Heilongjiang and Inner Mongolia, at 318.96%, 183.63% and 132.31%, with the smallest decrease in Beijing, at 1.29%, which is related to the increase of water consumption per unit of cultivated land.

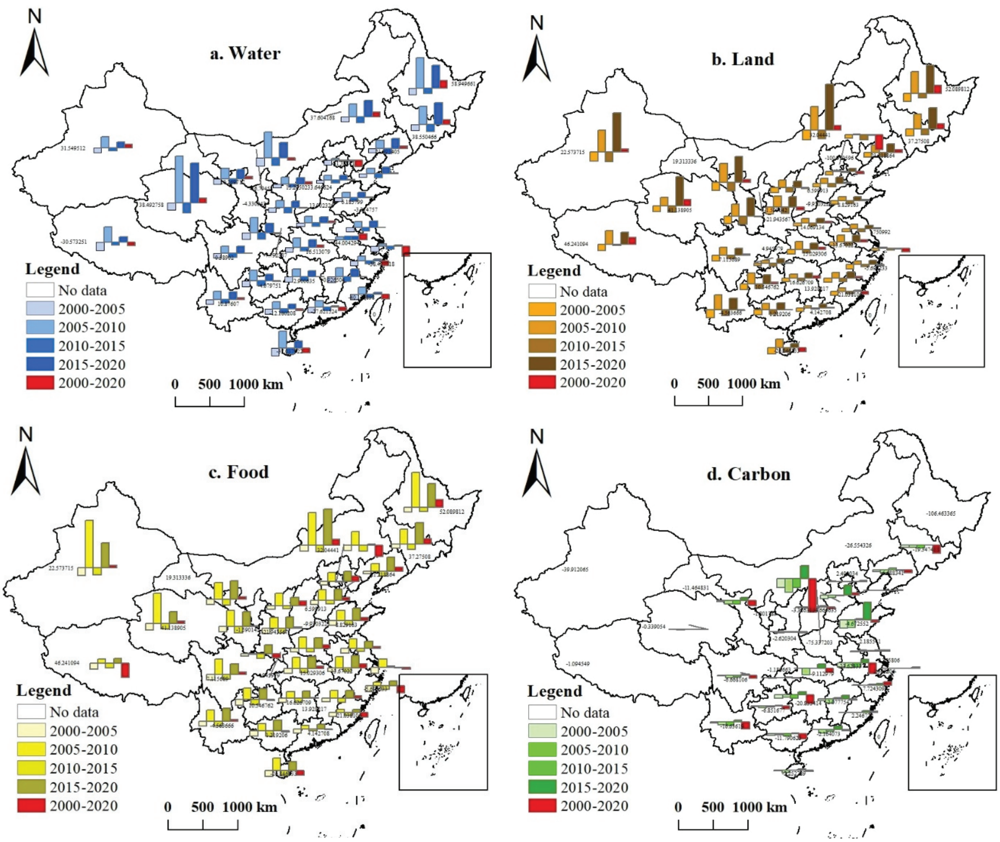


Figure 8. Evolution of spatial pattern of "Water–Land–Food–Carbon".

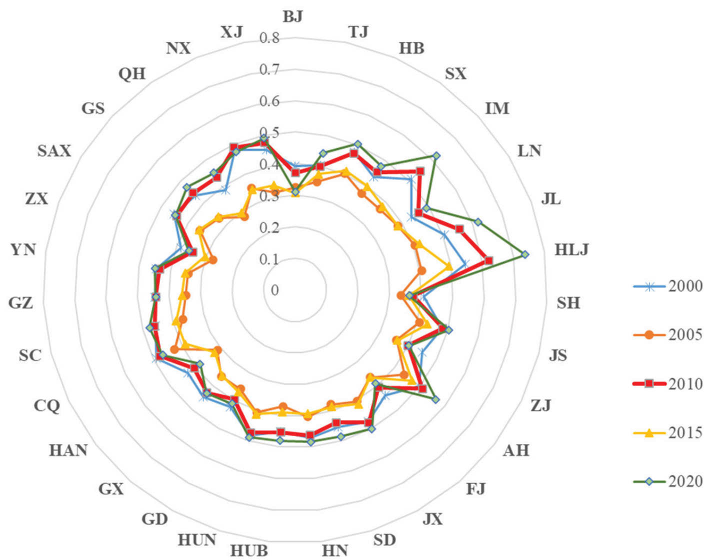
The L (l) evaluation index of the cultivated land system ranges from 0.027 to 0.278, showing a "W"-shaped variation trend, but with small fluctuations (Figure 8b). Moreover, 2000–2005 is the period of decreasing fluctuation, with an average annual change rate of 7.08%, which is related to the decrease of per capita cultivated land area; 2005–2010 is the period of increasing fluctuation, which is related to the increase of multiple crop index, among which the more typical ones are Inner Mongolia, Xinjiang and Heilongjiang, where the multiple crop index increased from 0.758, 0.936 and 0.857 to 0.980, 1.154 and 1.028; the fluctuating-decreasing phase from 2010 to 2015 is related to the increase of land reclamation rate. For example, the land reclamation rate in Shandong, Henan, Jiangsu and Anhui increased from 0.478, 0.475, 0.464 and 0.410 to 0.482, 0.485, 0.427, and 0.420, respectively; in the fluctuation-increasing phase from 2015 to 2020, Inner Mongolia, Xinjiang, Heilongjiang, and Gansu had the largest change rates, with average annual growth rates of 62.86%, 53.52%, 38.44%, and 35.37%, respectively, while Beijing, Shanghai, and Fujian had the smallest change rates. This is related to the per capita cultivated land area and the intensity of non-point source pollution.

The evaluation index of food system F (f) ranged from 0.0042 to 0.282, with a fluctuation growth trend and a more stable fluctuation trend (Figure 8c). The period of 2000–2005 was a decreasing phase, which was closely related to the instability of grain sown area and grain yield; the period of 2005–2010 was a growing phase, especially in Xinjiang, Heilongjiang, Inner Mongolia and Qinghai with annual average growth rates of 99.63%, 72.79%, 68.57% and 63.53%, respectively, mainly influenced by the per capita grain yield, the proportion of sown area of grain crops and the ratio of food crops to cash crops. From 2010–2015 was a fluctuation-decreasing phase, with a relatively stable decrease, averaging 10% per year; 2015–2020 was a fluctuation-increasing trend, mainly influenced by the average grain yield.

The evaluation index of carbon system C (c) ranged from 0.0098 to 0.063, with less fluctuation than the values of the water, cultivated land and food systems, and the increasing trend of the evaluation index was not obvious, basically in a slow growth state, with a mean value of 0.045, which was probably related to the slow increase of carbon emissions from pesticides, fertilizers, agricultural films, tillage, total power of agricultural machinery and irrigation during the use of cultivated land (Figure 8d).

3.3. Water-Land-Food-Carbon" Coupling Coordination Analysis

From Figures 9 and 10, the coupling coordination degree of "water-land-food-carbon" of all provinces, municipalities and autonomous regions in China from 2000 to 2020 showed a trend of decreasing before increasing, and the lag of "water-land-food-carbon" system was improved. The coupling coordination in Northeast China first decreased and then increased, among which, the coupling coordination in Heilongjiang was higher than the other two provinces and changed from moderate coordination (0.55) to good coordination (0.74) with a rate of 35.15%; Jilin changed from low coordination (0.50) to good coordination (0.62); Liaoning changed between low coordination and reluctant coordination (0.44→0.38→0.46→0.38→0.49). In North China, Beijing's coupling coordination changed more steadily, all in a low coordination state; Inner Mongolia was between low and reluctant coordination (0.44→0.38→0.46→0.38→0.49) during 2000–2015, and the coupling coordination was higher than the other four provinces and municipalities in 2020, reaching a good coordination state (0.62). Anhui in East China changed from low coordination (0.50) to good coordination (0.57). Except for Anhui, the areas of Jiangsu, Zhejiang, Jiangxi and Shandong increased on the whole and were basically between low coordination and reluctant coordination, while Shanghai and Fujian decreased on the whole and the coupling coordination changed from low coordination (0.41, 0.44) to reluctant coordination (0.36, 0.39). Henan, Hubei and Hunan in Central China had less changes and were basically in the state of low coordination (0.48, 0.48, 0.49). Guangdong, Guangxi and Hainan in South China developed from low coordination (0.42, 0.45, 0.43) to reluctant coordination (0.36, 0.36, 0.31) from 2000 to 2005; from 2005 to 2020, Guangdong and Guangxi developed into low coordination (0.41, 0.43), and Hainan was still in reluctant coordination, but with a relatively large increase of 11.42%. Shaanxi, Gansu, Ningxia and Xinjiang in Northwest China all changed from low coordination (0.45, 0.43, 0.48, 0.45) to reluctant coordination, and then to low coordination before increasing to low coordination (0.45, 0.47, 0.48, 0.49); Qinghai changes were more volatile, developing from reluctant coordination (0.39) to verge of disorder (0.28, 0.30) before rising to low coordination (0.45). The coupling coordination of Tibet in Southwest China was relatively low, developing from reluctant coordination (0.39) to verge of disorder (0.28) from 2000 to 2005, changing to reluctant coordination (0.36) from 2005 to 2020, and showing an overall decreasing trend (0.39→0.36); Ningxia and Shaanxi showed a decreasing trend but were basically in a low coordination state; Gansu, Qinghai and Yunnan were in low coordination. The "water-land-food-carbon" system showed lagging development.



	BJ	TJ	HB	SX	IM	LN	JL	HLJ	SH	JS	ZJ	AH	FJ	JX	SD
2000	0.39	0.40	0.47	0.44	0.51	0.55	0.50	0.55	0.41	0.48	0.45	0.50	0.44	0.48	0.46
2005	0.32	0.35	0.40	0.37	0.37	0.41	0.41	0.41	0.34	0.41	0.36	0.44	0.36	0.40	0.38
2010	0.37	0.40	0.47	0.46	0.55	0.62	0.56	0.62	0.37	0.48	0.40	0.51	0.41	0.48	0.44
2015	0.31	0.37	0.41	0.40	0.38	0.49	0.42	0.49	0.36	0.43	0.36	0.47	0.36	0.41	0.39
2020	0.32	0.44	0.50	0.48	0.62	0.74	0.62	0.74	0.36	0.50	0.40	0.57	0.39	0.50	0.49

	HN	HUB	HUN	GD	GX	HAN	CQ	SC	GZ	YN	XZ	SAX	GS	QH	NX	XJ
2000	0.47	0.45	0.48	0.42	0.45	0.43	0.49	0.46	0.45	0.45	0.39	0.45	0.43	0.39	0.48	0.45
2005	0.40	0.37	0.41	0.36	0.36	0.31	0.43	0.37	0.35	0.34	0.28	0.36	0.33	0.28	0.35	0.32
2010	0.46	0.45	0.47	0.40	0.43	0.41	0.48	0.46	0.44	0.43	0.35	0.44	0.45	0.43	0.49	0.48
2015	0.39	0.39	0.41	0.37	0.36	0.32	0.39	0.39	0.36	0.35	0.30	0.36	0.34	0.30	0.35	0.34
2020	0.48	0.48	0.49	0.41	0.43	0.38	0.47	0.48	0.44	0.45	0.36	0.45	0.47	0.45	0.48	0.50

0 0.1 0.2 0.3 0.4 0.5 0.6 0.8 1.0

Figure 9. "Water–Land–Food–Carbon" coupling coordination degree. Note: BJ, TJ, HB, SX, IM, LN, JL, HLJ, SH, JS, ZJ, AH, FJ, JX, SD, HEN, HUB, HUN, GD, GX, HAN, CQ, SC, GZ, YN, ZX, SAX, GS, QH, NX, XJ is the abbreviation of Beijing, Tianjin, Hebei, Shanxi, Inner Mongolia, Liaoning, Jilin, Heilongjiang, Shanghai, Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi, Shandong, Henan, Hubei, Hunan, Guangdong, Guangxi, Hainan, Chongqing, Sichuan, Guizhou, Yunnan, Tibet, Shannxi, Gansu, Qinghai, Ningxia, Xinjiang.

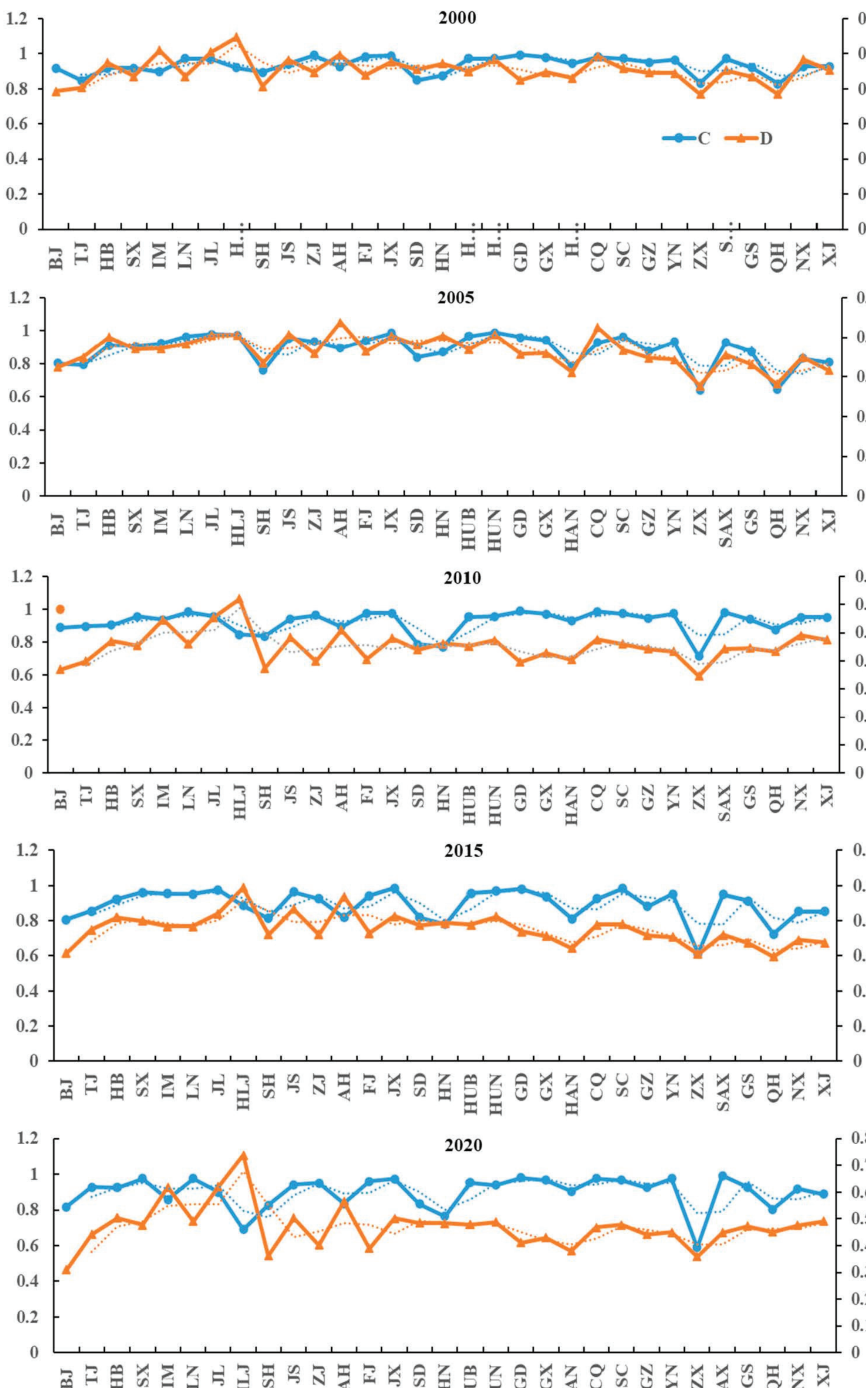


Figure 10. Development trend of coupling degree and coupling coordination degree of "Water–Land–Food–Carbon".

4. Discussion

4.1. Theoretical Implications of GTCL

At present, the Chinese government aims to promote green development and the overall green transition of economic and social development. The purpose of this paper is to realize a green, low-carbon, efficient and intensive spatial pattern of sustainable development of cultivated land-use based on the coupling coordination effect of "water-land-food-carbon" (Figure 2). From the perspective of a geographical pattern, the cultivated land-use system is not only a basic material space for economic and social development, but also an important part of rural habitat. In the process of promoting GTCL, priority shall be given to complex adaptive relationships between the whole and the local (element sharing and system coupling), conservation and development (sustainable use and food security), and equity and well-being (intergenerational balance and ecological welfare). For this reason, there is an urgent need to conduct theoretical and practical research on GTCL from the perspective of resource-factor linkage. GTCL is an inherent requirement for driving regional high-quality development, which refers to the sustainable use of cultivated land gradually shifting away from the dependence on high factor consumption and agro-ecological damage to a green development approach in which economic growth and resource conservation, carbon emission reduction and farmland ecosystem improvement are reinforcing each other. GTCL is not only the essential requirement of the natural properties of land, but also the inevitable requirement of sustainable utilization of resources and ecological civilization construction, as well as the value requirement of realizing the green transition of economic and social development in an all-round way. To promote GTCL, attention must be paid to the conceptual innovation from "independent" means of production to "systematic" resource community, as well as the transition from extensive use and excessive mode to a large-scale, intensive and sustainable way, thus moving towards the unification of value goals from farmers' personal interests to social public interests. Thus, there is a recognition that exploring the WLFC nexus under this framework (Figure 2) is a crucial first step toward effectively implementing its emerging policies for GDCL. For example, policymakers can better formulate legally binding development and protection objectives by analyzing the interaction between WLFC subsystems, and promote the combination of relevant policies and broader socio-economic activities in a timely manner, which will be beneficial to the common realization of the objectives of sustainable use of cultivated land, increase of food production, economic transformation, optimization of resources and environment, and mitigation of climate change.

4.2. Impact of GTCL on the WLFC Nexus

A compelling reason for analyzing GTCL from the "water-land-food-carbon" perspective is that the degree of water-soil matching, cultivated land reuse, grain yield, cultivated land-use and carbon emissions play a crucial role in achieving sustainable cultivated land-use. "Water-land-food-carbon" is the external condition that leads to changes in GTCL; GTCL is the internal basis that influences the synergy of "WLFC", and the external cause works through the internal cause. According to the analysis above, the development strategies in different periods have different emphasis on "WLFC". From 2000 to 2020, industrial pollution caused by the rapidly developing of industrialization had a negative impact on the resources and environment, the modern agricultural construction was started after the abolition of agricultural tax, and urban sprawl in the period of rapid urbanization led to the massive loss of cultivated land. After that, cultivated land protection policies were integrated into a larger natural resources management framework at national level, which improved the coupling coordination degree of WLFC. Furthermore, the in-depth adjustment of the global industrial chain, supply chain and value chain represented by grain trade has produced a transmission effect on many uncertain risks. However, the policy framework of cultivated land protection has been constantly improved, including regulations, policies, subsidies, standards, technical measures, etc. [49]. Overall, the "W"-shaped fluctuating uptrend of GTCL is observed. That is naturally why the average values of the comprehensive transition index exhibit decrease first and then increase with a repeatedly periodic dynamic process. Other compelling reasons include the positive effects of the green transition in soil conservation, soil carbon sequestration, soil organic matter levels, water and nutrient retention, and biodiversity support, especially for farmland and pastures with low productivity or environmental sensitivity. In general, when the degree of soil-water matching is close to the critical range, green use plays a dominant role in controlling grain yield and carbon emissions, e.g., the Xinjiang Uygur Autonomous Region and the Inner Mongolia Autonomous Region in Northwest China (Figures 3e and 6); if GTCL is not properly regulated, then no matter how high the degree of land-water matching is, it cannot further increase grain yield or reduce carbon emissions, e.g., Zhejiang Province and Fujian Province in East China (Figure 8a,b and Figure 9). Since the coupling of "water-land-food-carbon" is complex and involves the overlapping combination of virtual resource flows and remote utilization patterns in the context of cross-food trade, the examination of the coupling coordination between the WLFC subsystems will help to deeply analyze the external effects of GTCL, mainly from two perspectives. First, the cultivated land-use system is a complex giant system with coupling interactions of single or multiple subsystems in the process of green transition, and its transition goal, transition direction, transition path and its internal mechanism are mainly governed by water, land, food and carbon. Second, whether it is the degree of water-land matching, cultivated land reuse and grain yield or carbon emission, they are all influencing factors in the process of GTCL. Based on the spatial and temporal patterns of GTCL and the results of "water-land-food-carbon" coupling coordination analysis, the influence of external factors can be fully reflected by monitoring data. Relying on the macroscopic analysis model established on the basis of the transition mechanism, the "details" of the process that are difficult to quantify can be greatly reduced, thus ensuring the scientific and reasonable research results.

4.3. Ductile Control Strategy Based on WLFC Nexus

In this paper, the K-Medians clustering function of GeoDa was applied to cluster the values of the coupling coordination degree of "water-land-food-carbon" of China's 31 provinces, municipalities and autonomous regions in 2020, to set the criteria of internal coordination development of cultivated land-use. Combined with the level of GTCL (Figures 3–5 and Figure 9), they were divided into five levels, I to V, namely: benefit leading area, quality improvement area, connotation tapping potential area, ductile development area and ecological reserve area (Table 4).

Table 4. Regulation type division.

Category		Region
I	Benefit leading area	HLJ, JL, LN, IM
II	Quality improvement area	HB, SD, HN, AH, JS, ZJ, JX, HUB, HUN
III	Connotation tapping potential area	SX, SAX, BJ, TJ, SH, CQ
IV	Ductile development area	GZ, SC, YN, GD, GX, FJ, HAN
V	Ecological reserve area	XZ, XJ, QH, GS, NX

The benefit leading area (I) includes four regions, namely, Heilongjiang, Jilin, Liaoning and Inner Mongolia, whose cultivated land-use transition development and "water, land, food and carbon" coupling coordination were at a high level, especially in Heilongjiang, where the cultivated land-use transition index was as high as 0.79 in 2020, and the four subsystems were in good coordination (Figures 3, 9 and 10). Therefore, this type needs to give full play to the advantages of resource endowment and guide the cultivated land-use toward the efficient enhancement of ecological, production and living benefits, and promote farmers' income, efficient use of soil and water resources, conservation of agricultural biodiversity, and the maintenance and enhancement of soil fertility. Quality improvement area (II) includes Hebei, Shandong, Henan, Anhui, Jiangsu, Zhejiang, Jiangxi, Hubei and Hunan. The GTCL of these types of provinces was at a medium level, and the four subsystems were in low and moderate coordination (Figures 3, 9 and 10). This type of region was mostly located in the groundwater leakage area of the Huang-huai-hai Plain, and the degradation and pollution of cultivated land due to agricultural production had obvious conflicts with ecological environmental protection and food safety guarantee. Therefore, it is urgent to introduce high-yielding and drought-tolerant food crops, promote the synergistic intensification of labor, capital, and technology to improve grain yield, and ensure food self-sufficiency based on agricultural science and technology. Connotation tapping potential area (III) includes Shanxi, Shaanxi, Beijing, Tianjin, Shanghai and Chongqing. This type of "water, land, food and carbon" coupling coordination was relatively low (Figures 9 and 10), basically in a state of reluctant coordination and low coordination, especially in Beijing, Tianjin and Shanghai, which had more carbon emissions from cultivated land-use but small grain yield. Therefore, special attention should be paid to the reduction of pesticide and chemical fertilizer use, and the implementation of carbon emission reduction and environmental pollution control. Ductile development area (IV) includes Guizhou, Sichuan, Yunnan, Guangdong, Guangxi, Fujian, and Hainan. The green development level of cultivated land-use in this type of region involved was low (Figure 4), with an average level of only 0.2, and the degree of coupling coordination of the four subsystems was also relatively low (Figures 9 and 10). Therefore, it's necessary to explore the development space of intensive use and grain yield potential in the region, and improve the ability of stable growth, efficient use, resistance to disturbance and resource support of cultivated land. In addition, farmers should be better motivated to expand grain sowing area and develop special agriculture and thus increase farmers' income. Ecological reserve area (V) includes Tibet, Xinjiang, Qinghai, Gansu and Ningxia. This type should improve the planting structure, cultivate as appropriate, pay attention to the protection of ecological functions such as water purification, CO_2 regulation, hydrological regulation, biodiversity protection, farming landscape, etc. to ensure food security and ecological safety.

5. Conclusions

The WLFC nexus is crucial to the sustainable development of cultivated land-use and human well-being. In this study, "water, land, food and carbon" is considered as the integration point for exploring GTCL. We constructed a theoretical analysis framework for GTCL based on the WLFC nexus and evaluated the spatial and temporal patterns of GTCL in all provinces (autonomous regions, municipalities) of China from 2000 to 2020. In fact, previous studies mainly focused on the impact of single factor management on cultivated land-use, but often ignored the key role of factor correlation at different levels. This study further determines WLFC nexus in combination with Chinese national conditions on the basis of WEF, and it helps policymakers to reduce the comprehensive cost in the decision-making process under the background of complex system management, which will provide basic support for GTCL research in China. However, due to the novelty of this analysis framework, the data set required for economic, social and ecological analysis has not yet been formed. Relevant statistics on the evolution of groundwater, the mechanism of diet nutrition, the effect of carbon source and sink have not been considered in the scope of this paper, which is also a deficiency of this research.

In addition, we analyzed the spatial and temporal characteristics of "water, land, food and carbon" and their coupling coordination. According to the results, GTCL, the changes of WLFC system and their coupling coordination degrees showed spatial and temporal coincidences with great consistency. From 2000 to 2020, GTCL index in each province (autonomous region, municipality) showed an overall "W"-shaped fluctuating uptrend, and the regional differences showed an overall increasing trend; we found that GTCL in each province (autonomous region, municipality) presented a significant positive correlation with obvious spatial characteristics of regional clustering; in the past five years, GTCL in Northeast China had a higher development level, followed by Central and North China, while South China was at a low level. In addition, the "water, land and food" system showed a more obvious "W"-shaped fluctuation, with the coupling coordination in Northeast China being higher and in good coordination while lower in East and Southwest China. To a certain extent, this trend promoted the green and low-carbon use of cultivated land and the coordinated matching of water, land and food in China. Although there are substantial differences in cultivated land-use among regions, the common challenges drive the sharing and cooperation of similar policy approaches. Moreover, due to common scientific, technological and environmental issues, there will be great opportunities for cross-regional joint research and development and knowledge sharing in the future. It is concluded that this paper proposes a new solution to the GTCL based on theoretical and empirical analysis, which can promote the cooperation among public administration departments, business organizations and civil society when they develop or innovate these measures. Besides that, integrating and resolving the interests and responsibilities of different stakeholders from the institutional level, and taking into account the consistency of policy objectives and the common interests of technical requirements, it will enhance policy effectiveness.

Finally, the "water-land-food-carbon" effect of GTCL and the WLFC-based cultivated-land resilience control strategy were discussed. It should establish the planting system and green production system around green agricultural products and create a recycle agriculture model integrating planting and breeding; it also needs to organize a series of activities such as GTCL-related research for exhibition, public welfare training and digital communication to improve the understanding of stakeholders. At the same time, it is necessary to expand the scope of GTCL management according to the sustainable development standards and formulate the mechanism of GTCL protection and development strategy through the establishment of information sharing, data collection, risk warning and capacity-building, so as to better promote institutional, national and regional international cooperation. In general, this study proposed a comprehensive assessment system for GTCL, which may contribute to the sustainable use of cultivated land in the future. Nevertheless, the continuous and innovative research on GTCL requires a more comprehensive understanding of the interaction mechanism between ground and underground. We should not only pay attention to the internal material circulation in the whole food production chain, but also focus on the influencing mechanism of external factors. For example, how does the cultivated land protection policy affect GTCL? This will be of interest for future research.

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Soybean Production and Spatial Agglomeration in China from 1949 to 2019

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Abstract: By mastering the spatial-temporal evolution of patterns of soybean production, a reference for optimizing a soybean production layout could be provided, ensuring food security. The variation coefficient method, and the comparative advantage and spatial autocorrelation models were used to analyze the spatial divergence regularities of soybean production, sown area and yield, spatial-temporal changes in the comparative advantages of soybean planting efficiency and soybean planting scale, and the spatial agglomeration characteristics in China from 1949 to 2019. The results indicate that (1) from 1949 to 2019, soybean production and yield changes in China remained constant with a fluctuating upwards trend, and soybean sown areas hardly changed, yet experienced a sharp fluctuation. (2) The Northeast China Plain (NECP) was the main soybean-producing area, and its main position was strengthened. In contrast, the main soybean production position of the Huang-Huai-Hai Plain (HHHP) has declined. The Northern arid and semiarid region (NASR), the Sichuan Basin and surrounding areas (SBSR), the Middle-Lower Yangtze Plain (MLYP), and the Yunnan-Guizhou Plateau (YGP) became new soybean production growth poles. (3) The spatial distribution of soybean planting efficiency-related comparative advantages in China extended from northern China to the whole country, and the soybean planting scale-related comparative advantages proceeded through three stages: steady expansion, relative stability, contraction, and stabilization. (4) The spatial agglomeration of soybean planting efficiency-related comparative advantages has weakened, and the spatial agglomeration of the soybean planting scale-related comparative advantages exhibited a strengthening-weakening-strengthening-weakening process. Through our research analysis, we propose a policy resource to fully utilize the soybean planting efficiency-related comparative advantages in southern China (SC), promote grain-soybean rotation patterns in the HHHP and NECP, improve the soybean cultivation subsidy system, and build a soybean industry chain in the NECP.

Keywords: soybean; production pattern; spatial agglomeration; policy implications

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1. Introduction

Soybean is an important crop in regard to global food security and sustainable development due to its dual properties as a protein food ingredient and oilseed [1]. Soybean, a native plant of China and one of its most important crops, has been known to man for over 5000 years [2]. China's meat consumption and demand for soybean are rapidly increasing with a growing population, rising per capita income, and changing dietary preferences [3,4]. As the main soybean producer worldwide, China has transitioned from a net exporter of soybeans to a net importer since 1996, with soybean imports increasing from 1.11 Mt in 1996 to 100.33 Mt in 2020 [5]. China's soybean imports account for 60.57% of the global soybean trade volume, making the country the world's largest soybean importer and highly dependent on imports from countries, such as Brazil, the United States, and Argentina [6,7]. At present, China's soybean consumption heavily depends on international imports; however, the total population in China will peak by approximately 2030, and if the current soybean production and consumption trends persist, the soybean production and demand gap in China will continue to expand in the future [8]. In addition, soybean yields have been projected to decline by 7–19% in 2100 against the backdrop of global warming [9]. Therefore, China must urgently optimize its soybean planting area and increase soybean production to ensure its national food security.

Mastering the spatial-temporal change in soybean planting advantages and their geographical agglomeration patterns is fundamental to optimizing the spatial layout of soybean production and ensuring national food security [1,10]. In terms of soybean planting spatial changes [5,10], Sun et al. [11] studied the spatial-temporal patterns of the soybean sown area in China in response to soybean imports from 1980 to 2012, and the results demonstrate that the soybean sown area decreased in southeastern China while it increased in northwestern China. Regarding the soybean cultivation's influencing factors, Liu et al. [12] analyzed the factors causing farmers to increase soybean production, and the study found that the age of farmers, farm income, land topography, and ease of sale positively influence the behavior of farmers. In addition, soybean imports were identified as another important factor influencing soybean cultivation [11,13–15]. In terms of timing the changes in soybean planting advantages, for political and economic reasons, soybean production in China has lost its competitiveness and has been declining since the early 2000s [15]. In terms of space optimization in soybean planting, land suitability [16], climate suitability [17], and climate production potential [18] have mainly been considered. Most areas of the Sanjiang Plain are suitable for soybean cultivation, except for areas with slopes of $\geq$30% [16]. Zhao et al. [17] determined that the areas of high climatic suitability for soybean planting are mainly located in the northeastern and northern-central regions and that the total area of high suitability covers 1.2988×10^8 ha. In addition, the effects of conservation tillage [19], wheat straw mulching [20], temperature [21], CO_2 [22], and drought [23,24] on soybean yields have been studied. Existing research plays a key role in optimizing the soybean production space and increasing soybean production. However, little research has studied the spatial-temporal changes in patterns of soybean production on a national scale and over a long time series; the spatial difference between the comparative advantages of soybean planting efficiency and soybean planting scale and their spatial agglomeration characteristics remains unclear.

Soybean trade exerts a negative impact on the resources and environments of both importing and exporting countries [25]. Land expansion for soybean production has increased since 2000 by 160% in Brazil and by 57% in Argentina [4], resulting in deforestation [26], greenhouse gas emissions [27], and ecological damage [28]. Across South America, 9% of the forestland lost was converted into soybean planting areas from 2000 to 2016 [4]. Simultaneously, the soybean cultivation space in China is constantly being replaced by land for the cultivation of crops, such as rice, corn, vegetables, and fruit, resulting in irrigation water usage increasing by 96.42% (3.05 km^3), and the application of N fertilizer has increased by 256.65 thousand tons (almost 5 times) [15,25,29]. The optimization of the soybean planting space and enhancement of domestic soybean production to relieve pressure on resources and the environment in China and other soybean-exporting countries require immediate solutions.

With the frequent occurrence of global extreme weather hazards, the trade war between China and the United States, and outstanding structural contradictions in domestic food security, as a country with a large population, China's food security must be firmly controlled at all times. The research of this paper consists of three parts: first, this paper analyzes the spatial-temporal evolution of patterns of soybean production from 1949 to 2019; second, this paper analyzes the spatial-temporal evolution of comparative advantages in soybean production and its spatial agglomeration characteristics; third, this paper provides relevant policy implications based on the research results. The objective of this paper is to provide a means to optimize the layout of soybean production and alleviate the structural contradictions of food security in China.

The remainder of the paper is organized as follows. Section 2 introduces the data sources and methods used. Section 3 describes the spatial-temporal evolution of patterns of soybean production and the spatial-temporal evolution of the comparative advantages of soybean production and its spatial agglomeration characteristics. Section 4 presents a discussion of the results and limitations of this study. Finally, Section 5 provides the research conclusions and policy implications.

2. Data Sources and Methods

2.1. Data Sources

A total of 31 provinces of China were selected as the study area (excluding Hong Kong, Macao, and Taiwan). Statistical and raster data were used. Statistical data used include panel data on soybean and grain crop yields, sown area, and production in 31 provinces in China from 1949 to 2019. Data were drawn from the official website of the National Bureau of Statistics (https://data.stats.gov.cn/index.htm, accessed on 20 December 2020). As raster data, we used data on China's cropland potential productivity (CPP) in 2010 from the Resource and Environment Science and Data Center, Chinese Academy of Sciences (https://www.resdc.cn/data.aspx?DATAID=261, accessed on 22 April 2022). The CPP data are based on China's cultivated land distribution, soil, and DEM data from the Global Agro-Ecological Zones model, comprehensively considering light, temperature, water, CO_2 concentration, pests and diseases, agroclimatic restrictions, soil, terrain, etc. Using 1949 as the starting point, and 10-year intervals, this paper analyzed the characteristics of the spatial-temporal patterns of soybean production and sown areas and the comparative advantages of the planting efficiency and planting scale in China over eight periods.

To measure the differences in patterns of soybean production on a regional scale, China was divided into nine agricultural zones (Figure 1): the Northeast China Plain (NECP, including Heilongjiang, Jilin, and Liaoning), the Northern arid and semiarid region (NASR, including Inner Mongolia, Ningxia, Gansu, and Xinjiang), the Huang-Huai-Hai Plain (HHHP, including Beijing, Tianjin, Hebei, Shandong, and Henan), the Loess Plateau (LP, including Shanxi and Shannxi), the Middle-Lower Yangtze Plain (MLYP, including Shanghai, Jiangsu, Zhejiang, Anhui, Jiangxi, Hubei, and Hunan), the Sichuan Basin and surrounding regions (SBSR, including Chongqing and Sichuan), the Yunnan-Guizhou Plateau (YGP, including Yunnan, Guizhou, and Guangxi), Southern China (SC, including Fujian, Guangdong, and Hainan), and the Qinghai Tibet Plateau (QTP, including Qinghai and Tibet).

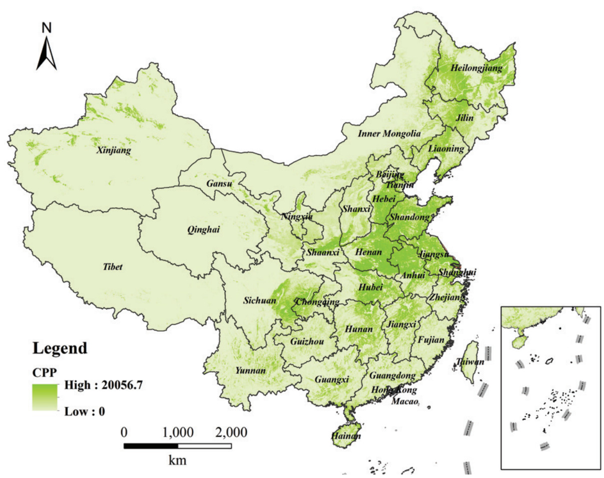

Figure 1. Spatial distribution map of CPP in China.

2.2. Methods

2.2.1. Coefficient of Variation Method

The coefficient of variation method can eliminate the influence of different units and average values on results and is widely used in the analysis of spatial differences within a geographical community [30]. The spatial variations in the soybean yield, production, and sown areas in China were analyzed by calculating the coefficient of variation over different periods. The established equations are given as follows:

$$CV = \frac{\sigma}{\mu} \tag{1}$$

where CV is the coefficient of variation, σ is the standard deviation, and μ is the mean.

2.2.2. Comparative Advantage Model

The soybean yield level and planting area are the results of the interactions between the regional agricultural natural resource endowment, socioeconomic and local conditions, planting system, and market demand. The soybean yield and sown area were chosen as factors of the comparative advantages of soybean cultivation efficiency and scale, respectively, in each province. The established equations are given as follows:

$$SAI_{ij} = \frac{s_{ij}}{s_i} / \frac{s_j}{s} \tag{2}$$

$$EAI_{ij} = \frac{t_{ij}}{t_i} / \frac{t_j}{t} \tag{3}$$

where i and j denote province i and crop j, respectively; S_{ij} and S_j denote the planting area of crop j in province i and China, respectively; S_i and S denote the planting area of all grain crops in province i and China, respectively; t_{ij} and t_j denote the yields of crop j in province i and China, respectively; t_i and t denote the yields of all grain crops in province i and China, respectively; and SAI_{ij} and EAI_{ij} denote the comparative advantages of the planting scale and efficiency, respectively, of crop j in province i.

2.2.3. Spatial Autocorrelation Model

The spatial autocorrelation model usually includes global and local spatial autocorrelation aspects. Global spatial autocorrelation determines whether aggregation exists in the spatial distribution of the comparative advantages of soybean planting scales and the efficiency of various provinces. Local spatial autocorrelation determines the state of the spatial agglomeration or dispersion based on the similarities in values across provinces. The established equations are given as follows:

$$\text{Global Moran's I} = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}(x_i - \overline{x})(x_j - \overline{x})}{S^2 \sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}} \tag{4}$$

$$\text{Local Moran's I} = \frac{n(x_i - \overline{x})\sum_{j=1}^{n} W_{ij}(x_j - \overline{x})}{\sum_{i=1}^{n}(x_i - \overline{x})^2} \tag{5}$$

where Global Moran's I is the global spatial autocorrelation index; Local Moran's I is the local spatial autocorrelation index; n is the number of provinces; x_i and x_j denote the attribute values of a certain element in provinces i and j ($i \neq j$), respectively; and W_{ij} is the spatial weight matrix. The value range of the Global Moran's I index is [−1, 1]. When the significance level is provided, if the Global Moran's I index value is significantly positive, this indicates a spatially significant clustering of regions with large (small) values of the comparative advantages of soybean planting efficiency or comparative advantages of the soybean planting scale. Conversely, if Global Moran's I is significantly negative, this indicates significant spatial differences in the comparative advantages of soybean planting efficiency or soybean planting scale between a specific region and its neighbors. If Global Moran's I = 0, no spatial correlation occurs.

2.2.4. Contribution Model

The interannual variation in soybean production is the result of the combined effect of the interannual variation in the soybean sown area and soybean yield. Therefore, the contribution model is used to determine the contribution of the soybean sown area and yield to production. The established equations are given as follows:

$$A_c = \frac{(A_j - A_i) \cdot Y_i}{P_j - P_i} \tag{6}$$

$$Y_c = \frac{(Y_j - Y_i) \cdot A_i}{P_j - P_i} \tag{7}$$

where A_c is the area contribution (%); Y_c is the yield contribution (%); A_i and A_j represent the soybean sown area in year *i* and *j* ($j > i$), respectively; Y_i and Y_j represent the soybean yield in year *i* and *j*, respectively; and P_i and P_j represent the soybean production in year *i* and *j*, respectively.

3. Results

3.1. Spatial-Temporal Evolution of Production Pattern of Soybean

Changes in the soybean sown area, production, and yield over the past 71 years in China are shown in Figure 2. The soybean yield increased from 614 kg/ha in 1949 to 1937 kg/ha in 2019 at an average annual growth rate of 3.08%. The increase in soybean yield is attributed to improved cultivars, increased application of fertilizers, improved cultural practices, better pest/weed control, and the rapid adoption of technologies by producers [2]. China's soybean production and yield changes remained consistent and exhibited a fluctuating upwards trend over the past 71 years. Soybean total production increased from 5.11 million tons (Mt) in 1949 to 18.08 Mt in 2019, at an average annual growth rate of 3.63%. The soybean sown area grew from 8.32 million hectares (Mha) in 1949 to 9.33 Mha in 2019, but the sown average annual growth rate reached only 0.17%, with dramatic fluctuations. Affected by high-quality and low-priced imported soybeans, the soybean sown area in China rapidly decreased from 9.48 Mha in 2001 to 6.83 Mha in 2015, reaching almost the lowest value in 71 years. To control the rapid decline in the soybean sown area, the Chinese government started pilot projects involving soybean target price subsidies in the NECP and Inner Mongolia in 2014; began to promote the corn–soybean rotation system in the NECP in 2016; and launched a soybean revitalization plan in the NECP, HHHP, and Southwest China in 2019. These policies have increased the willingness of soybean farmers to amplify the soybean sown area, facilitating an expansion in the area [31].

The coefficients of variation of soybean production, sown area, and yield in China from 1949 to 2019 are listed in Table 1. Among the coefficients of variation of the soybean sown area, production, and yield, the soybean sown area was the biggest in 1949, 2009, and 2019; the soybean yield was the biggest in 1959; and soybean production was the biggest in 1969, 1979, 1989 and 1999. This indicates that the spatial differences in the soybean yield, production and sown area in China from 1949 to 2019 experienced a process dominated by an area-yield-production-production-production-production-area-area pattern. The soybean yield rapidly increased amid improved soybean varieties, increased application of chemical fertilizers, and enhanced mechanization levels. Under the cumulated influence of the dual factors of soybean yield and sown area, the spatial differences in soybean cultivation in China experienced a process dominated by production from 1969 to 1999, and the coefficient of variation of soybean production continued to boost. With what can be achieved with the existing level of scientific and technological development, the increase in soybean yield was limited, and the national level relatively remained constant. Under the influence of national soybean support policies, the sown area in the main soybean-producing region has increased rapidly, and the differences among the various provinces of China are significant [32]. Therefore, among the variation coefficients of the soybean sown area, production, and yield, the spatial difference in the soybean sown area was the greatest in 2009 and 2019.

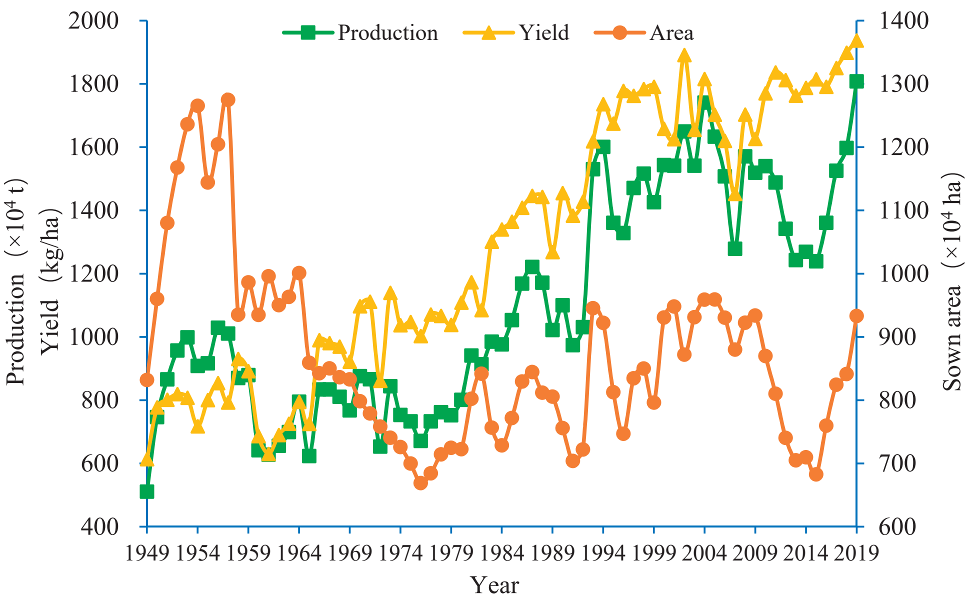

Figure 2. Changes in the soybean sown area, production, and yield in China from 1949 to 2019.

Table 1. Coefficient of variation of soybean production, sown area, and yield in China from 1949 to 2019.

Coefficient of Variation	1949	1959	1969	1979	1989	1999	2009	2019
Production	1.46	1.46	1.46	1.51	1.58	1.73	2.20	2.39
Sown area	1.50	1.29	1.33	1.46	1.57	1.52	2.46	2.54
Yield	0.50	1.61	0.76	0.76	0.47	0.41	0.76	0.52

China's soybean production increased by a net amount of 12.97 Mt from 1949 to 2019, with significant variation across the nine agricultural zones (Figure 3). Soybean production in the NASR, SBSR, and NECP showed rapid growth, with average annual growth rates of 33.54%, 8.23%, and 5.38%, respectively. Soybean production in the YGP and MLYP slowly increased to 0.8 and 2.6 Mt, respectively, and production remained stable. Soybean production in the SC began to nosedive after a gradual increase from 0.09 Mt in 1949 to 0.4 Mt in 1999, decreasing to 0.19 Mt in 2019. Soybean production for the LP, HHHP, and QTP fluctuated at approximately 0.5 Mt, 2 Mt, and 1000 t, respectively.

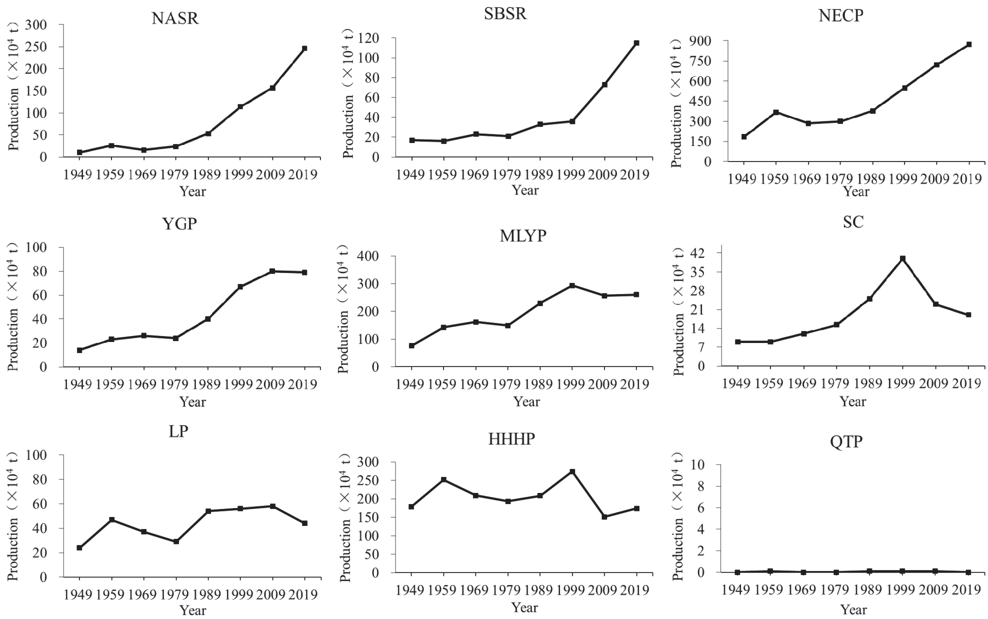

Figure 3. Changes in soybean production in the nine agricultural zones of China from 1949 to 2019.

The soybean sown area in China slowly increased by 1.01 Mha from 1949 to 2019, with significant variation across the nine agricultural zones (Figure 4). The soybean sown area in the NASR, SBSR, NECP, and YGP exhibited positive growth, increasing by 1.13, 0.27, 2.52, and 0.22 Mha, respectively. The NECP remained the main soybean-producing area in China, and the soybean sown area significantly increased with the proportion of the soybean sown area to the total land area of China increasing from 26.28% to 50.45%. At the same time, the soybean sown area in the NASR rapidly expanded at an average annual growth rate of 10.83%. Moreover, the soybean sown area in the YGP underwent a slowly fluctuating upwards trend with an annual growth rate of 1.27%. On the contrary, the soybean sown area in the MLYP, SC, LP, and HHHP exhibited a downward trend, decreasing by 0.1, 0.08, 0.19, and 2.76 Mha, respectively. The soybean sown area of the HHHP dropped at a higher rate, with an average annual growth rate of −1.15%, and the proportion of soybean sown areas in China declined from 41.33% to 7.27%. This downturn can mainly be attributed to the lesser benefits, and more notably, to the extending return gaps than those of corn production [10].

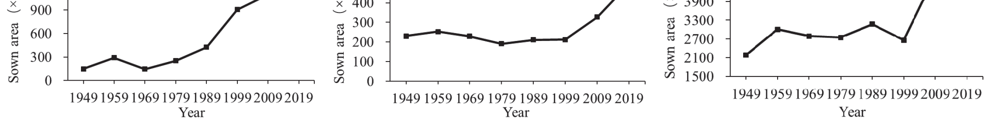

Figure 4. *Cont.*

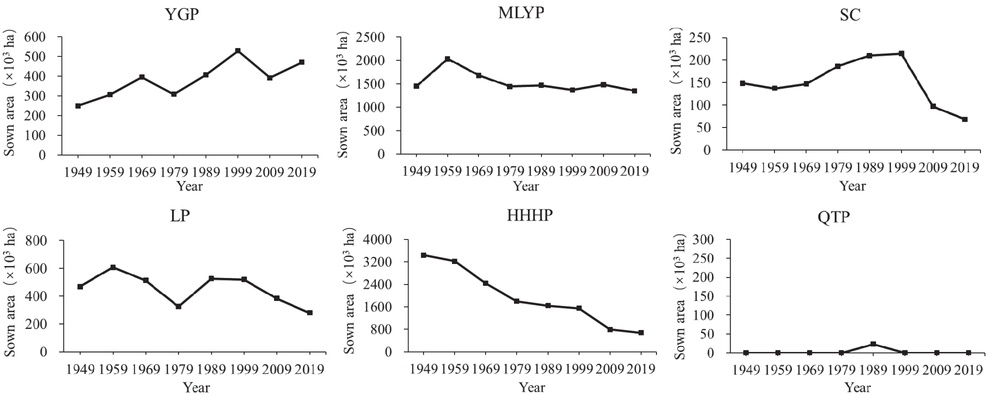

Figure 4. Changes in the soybean sown area in the nine agricultural zones of China from 1949 to 2019.

3.2. Spatial-Temporal Evolution of the Comparative Advantages of Soybean Production and Its Spatial Agglomeration Characteristics

In general, the spatial differentiation characteristics of the comparative advantages of soybean planting efficiency in China from 1949 to 2019 can be divided into three stages: in the first three decades after the founding of new China, provinces with comparative advantages in soybean planting efficiency were concentrated in northern China, mainly distributed in the NECP, NASR, and HHHP (Figure 5a–d). In 1979, the soybean yield in the NECP and HHHP reached as high as 1086.88 and 1072.82 kg/ha, respectively. From 1979 to 1999, the comparative advantages of soybean planting efficiency in Henan, Jiangsu, Zhejiang, Anhui, Fujian, Hubei, and Sichuan experienced a process from scratch, and provinces with comparative advantages in soybean planting efficiency continued to agglomerate in the MLYP and SBSR (Figure 5d–f). The soybean yield in the MLYP and SBSR increased by 107% and 54.45%, respectively, from 1032.57 and 1099.48 kg/ha, respectively, in 1979 to 2141.81 and 1698.11 kg/ha in 1999, respectively. Since 1999, the comparative advantages of soybean planting efficiency have gradually extended across China. All provinces in China, except Jilin, Beijing, Tianjin, Ningxia, Shanxi, Henan, and Anhui achieved comparative advantages in soybean planting efficiency in 2009 (Figure 5g). Only five Chinese provinces, namely, Hubei, Guizhou, Guangxi, Jilin, and Anhui did not achieve comparative advantages in soybean planting efficiency in 2019 (Figure 5h). The soybean yield in the SC and HHHP regions was high, reaching 2794.12 and 2566.37 kg/ha, respectively, reaching levels much higher than the national average of 1937.41 kg/ha.

Provinces with comparative advantages in soybean planting scales in China, from 1949 to 2019, were mainly located in the NECP, HHHP, and MLYP regions (Figure 6). The spatial evolution of the comparative advantages in soybean planting scales can be divided into three stages. From 1949 to 1989, comparative advantages in soybean planting scales in China exhibited the spatial characteristics of steady expansion, spreading from seven provinces in 1949 to nine provinces in 1989 (Figure 6a–e). Heilongjiang, Jilin, and Liaoning in the NECP and Henan in the HHHP have consistently maintained their comparative advantages. The proportion of the soybean sown area in the NECP grew from 26.28% to 39.24% with a net growth increase of 0.98 Mha. From 1989 to 1999, the spatial distribution of the comparative advantages in soybean planting scales in China remained relatively stable (Figure 6e,f). Provinces with comparative advantages in soybean planting scales in 1999 include the NECP, Inner Mongolia, Tianjin, Shanxi, Anhui, and Guangxi. From 1999 to 2019, comparative advantages in soybean planting scales in China contributed to a spatial contraction and stabilization (Figure 6f–h). Liaoning, Tianjin, Shanxi, Guangxi, and Jilin lost their comparative advantages in soybean planting scales. Only four provinces exhibited comparative advantages in soybean planting scales in 2019, i.e., Inner Mongolia, Heilongjiang, Anhui, and Zhejiang, and their spatial distribution tended to remain stable.

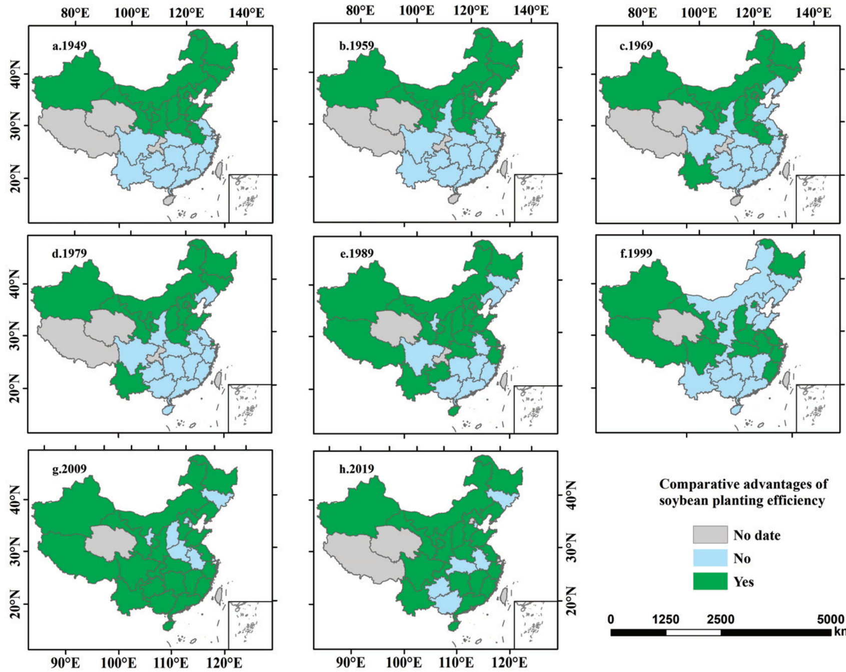

Figure 5. Spatial distribution of the comparative advantages in soybean planting efficiency in China from 1949 to 2019.

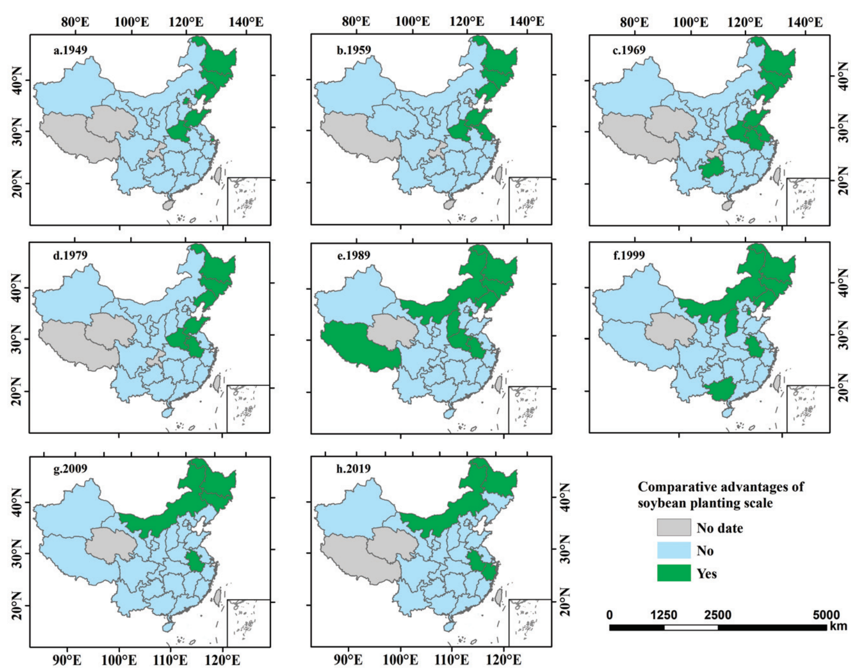

Figure 6. Spatial distribution of comparative advantages in soybean planting scales in China from 1949 to 2019.

To explore the spatial pattern differentiation characteristics of the comparative advantage of soybean cultivation, we used Geoda software to calculate the Global Moran's index. The first step was to create a weight file, the second step was to set the weight file, and the Rook spatial adjacency weight matrix with common boundaries was selected. The third step was to calculate the Global Moran's I index of soybean planting efficiency and scale. The Global Moran's I index and related indicators for the comparative advantages of soybean planting efficiency and scale over the eight periods are shown in Table 2. The Global Moran's I index of soybean planting efficiency in 1949, 1959, 1989, 1999, and 2009 was higher than 0 and satisfies the requirements of the significance level test, indicating that the comparative advantages of soybean planting efficiency during these five periods revealed certain clustering characteristics in terms of spatial distribution. Similarly, the comparative advantages of soybean planting scales for these eight periods were spatially clustered. The Global Moran's I index and Z values underwent an increase-decrease-increase-decrease process, and the comparative advantages of the soybean planting scale saw a spatial agglomeration strengthening-weakening-strengthening-weakening process.

Table 2. Change in the Global Moran's I index of comparative advantages in soybean planting efficiency and scale in China from 1949 to 2019.

Types	Year	Moran's I	Z	*p*	Types	Year	Moran's I	Z	*p*
Comparative advantages of soybean planting efficiency	1949	0.4698	4.0965	0.0010 ***	Comparative advantages of soybean planting scale	1949	0.3312	3.1188	0.0080 ***
	1959	0.3988	3.5324	0.0020 ***		1959	0.4538	4.2601	0.0010 ***
	1969	0.0506	0.9904	0.1420		1969	0.3660	3.4813	0.0030 ***
	1979	0.1498	1.4296	0.0770		1979	0.2153	2.6390	0.0180 **
	1989	0.2017	1.9674	0.0350 **		1989	0.3071	3.5760	0.0010 ***
	1999	0.1592	2.0447	0.0460 **		1999	0.3484	4.0114	0.0010 ***
	2009	0.2091	2.0315	0.0260 **		2009	0.2987	3.8615	0.0030 ***
	2019	−0.1764	−0.2237	0.0990		2019	0.2153	2.6390	0.0180 ***

Note: ** and *** indicate that the Global Moran's I index is significant at the 5% and 1% levels, respectively.

According to the spatial distribution map of the comparative advantages of soybean planting efficiency (Figure 7), the high–high spatial aggregation areas in 1949 occurred in the NECP, LP, NASR, and HHHP, i.e., Heilongjiang, Jilin, Liaoning, Inner Mongolia, Ningxia, Gansu, Shaanxi, Shanxi, and Hebei. The low–low spatial aggregation areas included Yunnan and Guizhou in the YGP and Hunan (Figure 7a). The spatial distribution of low–low aggregation areas in 1959 is consistent with that in 1949, while the high–high aggregation areas included the NECP and Inner Mongolia (Figure 7b). In 1989, Xinjiang was a high–high aggregation area, while low–low areas shifted from the YGP to the MLYP, including Yunnan, Hubei, and Hunan (Figure 7c). In 1999, the soybean planting efficiency cluster exhibited aggregation with high–high aggregation areas remaining in Xinjiang, low–low aggregation areas remaining in Hunan, and Beijing becoming a high–low aggregation area (Figure 7d). In 2009, Fujian was a high–high aggregation area, and Tibet was a low–high aggregation area (Figure 7e).

According to the spatial distribution map of the comparative advantages of the soybean planting scale (Figure 8), the spatial distribution of the comparative advantages of the soybean planting scale from 1949 to 1979 was relatively similar, with the high–high aggregation areas mainly occurring in Heilongjiang and Jilin; low–high aggregation areas remaining in Inner Mongolia; low–low aggregation areas, which were largely located in Xinjiang, Sichuan, Guizhou, and Hunan (Figure 8a–d). In 1989, the high–high aggregation areas included Heilongjiang, Jilin, and Inner Mongolia while Tibet became a high–low aggregation area and only Guizhou was a low–low aggregation area (Figure 8e). High–high aggregation areas in 1999 were the same as those in 1989, while the low–low aggregation areas included Xinjiang, Tibet, and Sichuan (Figure 8f). Aggregation areas in 2009 and 2019 remained consistent, with Heilongjiang and Jilin identified as high–high aggregation areas and Xinjiang was identified as a low–low aggregation area (Figure 8g,h), indicating that the aggregation areas of the comparative advantages of soybean planting scales basically formed a highly stable state in recent years.

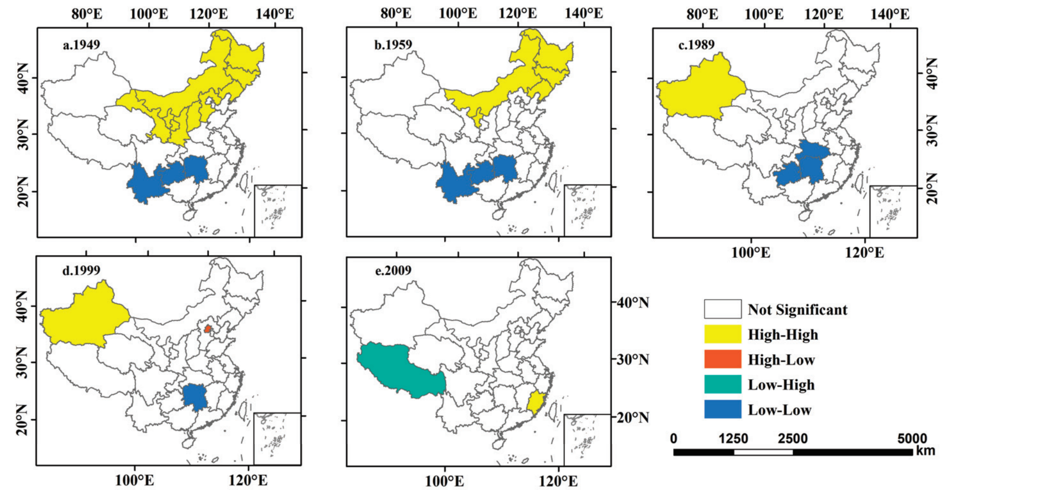

Figure 7. Local indicator of spatial association (LISA) aggregation map of the comparative advantages of soybean planting efficiency in China.

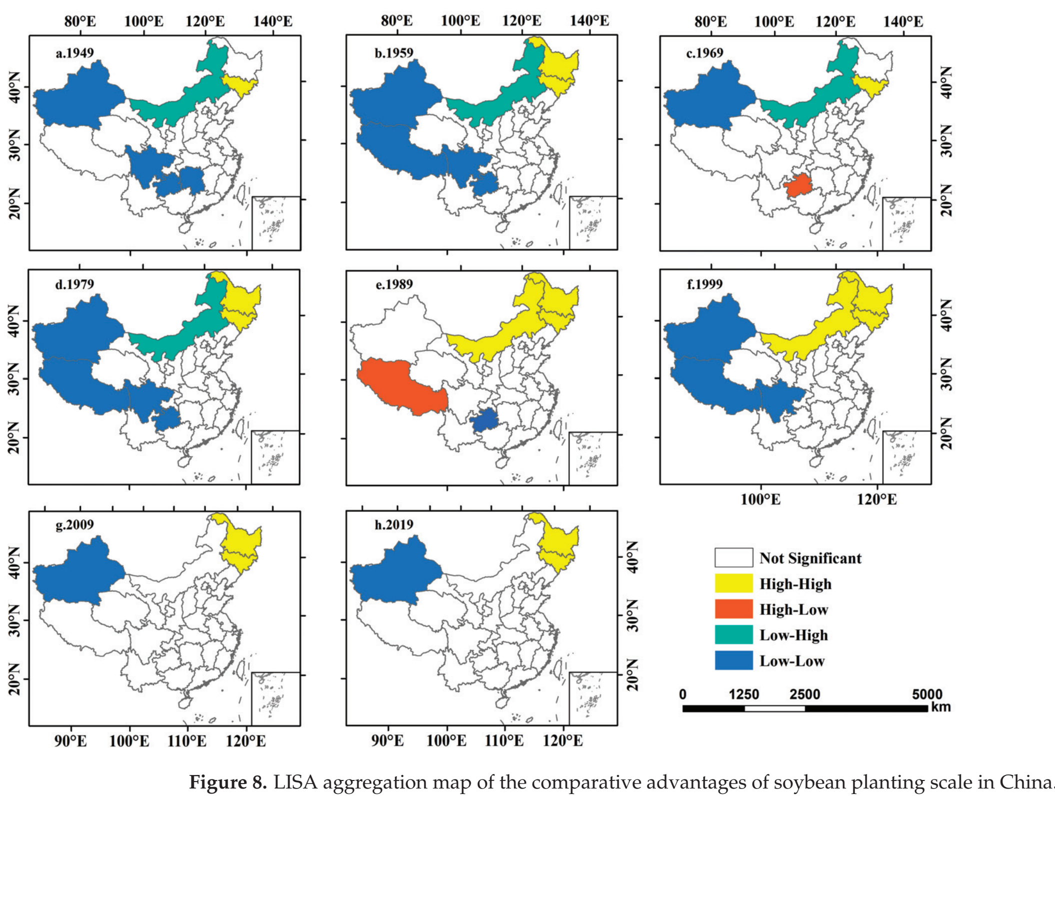

Figure 8. LISA aggregation map of the comparative advantages of soybean planting scale in China.

4. Discussion

The soybean yield is the main contributor to soybean production. From 1949 to 2019, soybean production in China was mainly affected by soybean yields; the contribution of the soybean yield was as high as 95.21%, and the contribution of the soybean sown area was only 4.79% (Table 3). However, there were differences in the dominant contributors to soybean production in different periods. In 1959–1979 and 1999–2009, the soybean sown area was the dominant contributor to soybean production; in 1949–1959, 1979–1999, and 2009–2019, the soybean yield was the dominant contributor to soybean production. According to USDA data, soybean yields in the United States and Brazil reached 3190 kg/ha and 3480 kg/ha, respectively, in 2019, however, China's soybean yield was only 1937 kg/ha in 2019. In the future, China needs to further improve soybean breeding technology, the quality of soybean fields, and farmland infrastructure to boost soybean yields and continue to narrow the yield gap between China and major soybean-producing countries [12].

Table 3. Contributions of soybean sown area and yield to soybean production from 1949 to 2019.

Time	1949–1959	1959–1969	1969–1979	1979–1989	1989–1999	1999–2009	2009–2019	1949–2019
Area contribution (%)	25.71	122.65	636.69	31.18	−2.98	265.20	−0.39	4.79
Yield contribution (%)	74.29	−22.65	−536.69	68.82	102.98	−165.20	100.39	95.21

The patterns of soybean production are affected by multiple factors, such as natural resource endowments, economic development levels, soybean imports, and national policies. Soybean crops are highly adaptable to the natural environment, however natural conditions, such as climate, temperature, and soil conditions have a profound impact on the yield and quality of soybeans [33]. The NECP and HHHP present obvious comprehensive advantages in soybean production. The rapid development of the economy, the optimization of the dietary structure of urban and rural residents, and the increasing demand for meat, eggs, and milk have led to an acceleration in the consumption of feed grains, and such consumption has had a positive effect on soybean production [1]. Soybean yield in China is far lower than the levels in the United States and Brazil. Amid rising prices of agricultural production factors, domestic soybeans have no price advantage in the international market; the enthusiasm of farmers to plant soybean crops has dimmed; and the soybean planting area has been superseded by crops yielding more income, such as corn and rice [6]. In general, the soybean sown area in China is negatively related to soybean imports. In addition, national policies also affect patterns of soybean production. China has formulated a series of policies, including a soybean revitalization plan, however, it focuses on the NECP, HHHP, and southwestern China, resulting in an accumulation of soybean production space in these areas [34]. Therefore, the influencing factors of patterns of soybean production vary in different periods.

Grain imports have caused a deterioration of ecological environments, both for importing and exporting countries. To promote global sustainable development, grain importing countries can alleviate domestic grain shortages as well as exporting countries' resourcing and environmental problems by optimizing the spatial distribution of domestic grain to increase production and reduce resource and environmental consumption. This paper only qualitatively analyzed the influencing factors of patterns of soybean production, and quantitative analysis should be conducted in the future. In addition, county-scale soybean production data should be obtained to conduct more refined research in the future.

5. Conclusions and Policy Implications

5.1. Conclusions

The soybean sown area has not varied considerably, however, spatial patterns of soybean planting underwent tremendous changes from 1949 to 2019. The NECP is the main soybean-producing area, and its main position has strengthened. The NASR, SBSR, MLYP, and YGP regions have become new growth poles in terms of total soybean production, and soybean production in the HHHP region has decreased.

The spatial-temporal differentiation characteristics of the comparative advantages of soybean planting efficiency over the past 71 years can be divided into three stages: those concentrated in northern China from 1949 to 1979, those concentrated in the MLYP region from 1979 to 1999, and those spread across China from 1999 to 2019. The spatial-temporal differentiation characteristics of the comparative advantages in soybean planting scale over the past 71 years can also be divided into three stages: steady expansion from 1949 to 1989, relatively stable spatial distribution from 1989 to 1999, and spatial contraction and stabilization from 1999 to 2019.

The spatial distribution of the comparative advantages in soybean planting efficiency in 1949, 1959, 1989, 1999, and 2009 exhibited the characteristics of agglomeration. From 1949 to 2019, comparative advantages in soybean planting scales showed characteristics of spatial agglomeration, which involved a dynamic strengthening-decreasing-strengthening-decreasing change process. Currently, Heilongjiang and Jilin, in the NECP region, are high–high aggregation areas with comparative advantages in their soybean planting scales, and Xinjiang is a low–low aggregation area.

This paper illustrates the spatial-temporal evolution of the patterns of soybean production and the spatial-temporal evolution of the comparative advantages in soybean production and its spatial agglomeration characteristics. The results can guide China in formulating a food security strategy. Optimizing the spatial layout of soybean planting according to the comparative advantages of soybean planting efficiency; determining key areas for soybean planting subsidies based on the comparative advantage of the soybean planting scale; considering the spatial distribution of China's soybean industry chain according to the agglomeration characteristics of the comparative advantage in soybean planting scale, thus, alleviating the national soybean shortage problem. This paper can also guide China in formulating grain security strategies in the context of the COVID-19 pandemic, major power games, and extreme climate disasters.

5.2. Policy Implications

The comparative advantages of soybean planting efficiency in SC and MLYP should be fully exploited. Li et al. [35] calculated the rate of cultivated land abandonment in mountainous counties in China from 2014 to 2015, which reached 14.32%, with abandonment rates reaching 34.03% in Jiangxi; 20–30% in Sichuan, Zhejiang, and Hunan; and 10–20% in Fujian, Guangdong, and Hainan. More than 30% of all plots have been abandoned in southwestern China since 1992 [36], 10.45% of all cropland in the Guizhou-Guangxi karst mountain area has been abandoned since 2001 [37], and 5.35% of all croplands have been abandoned in Sichuan Province [38]. Cropland abandonment totalled approximately 43.12 Mha and mainly occurred in the Northern China Plain and Sichuan Plain during the 1990–2010 period [39]. Zhang et al. [40] reported that counties with cropland abandonment from 1992 to 2017 were concentrated in SC. Provinces with high rates of cropland abandonment in China are high-value areas in terms of soybean yield and achieve comparative advantages in soybean planting efficiency. However, the current agricultural planting structure ignores the remarkable potential to achieve increased soybean production on abandoned cropland in SC and MLYP. Therefore, it is necessary to fully utilize the abandoned croplands in SC and MLYP to grow soybeans, obtain regional comparative advantages in soybean planting efficiency, expand the soybean sowing area, and develop the MLYP as a new growth pole for soybean production, centered in Anhui and Jiangsu; thereby increasing soybean production and self-sufficiency in China.

Grain–soybean rotation should be promoted in the HHHP and NECP. The HHHP was historically the main soybean-producing region in China. From 1949 to 1979, Shandong and Henan exhibited comparative advantages in soybean planting scales. However, with the increasing sown area for wheat and corn, the proportion of the soybean sown area in the HHHP region decreased from 41.33% to 7.27%, while soybean production fell from 34.99%

to 9.62% in China between 1949 and 2019. The HHHP has no longer exhibited comparative advantages in scale since 1999 but remains a high-value area in terms of soybean yield and exhibits comparative advantages in soybean planting efficiency, with water resources being the main restraint on food production in the region [41,42]. Within the context of fallow cropland, the sown area of water-consuming crops, such as wheat, should be trimmed down and replaced with soybean or corn–soybean rotation cultivation land, in accordance with local conditions [43–45], to gradually restore the main soybean production area, reduce groundwater consumption in the region and fully utilize the comparative advantages in soybean planting efficiency in the HHHP region. The black soil layer in the Northeast Plain has been skimmed for more than 71 years since reclamation [46], and the organic matter content has decreased by 4–7% below the levels at the beginning of reclamation. With the rapid expansion of rice cultivation [29], water scarcity has also alarmingly emerged, posing a serious threat to food security in China [47]. From 2009–2019, Heilongjiang and Liaoning in the NECP region exhibited comparative advantages in soybean planting efficiency. In the future, corn–soybean rotation in the NECP should be vigorously promoted to exploit the comparative efficiency of regional soybean cultivation and the role of soybean crops in nitrogen fixation. Simultaneously, the application of cropland quality improvement projects in the region should be encouraged to progressively improve soil fertility and increase the supply of high-quality soybean crops.

The soybean planting subsidy system should be reinforced. To become a World Trade Organization (WTO) member, China reduced tariffs on imported soybeans from 130% to 3% in 1995 [48]. Since domestic soybeans did not have a price advantage over foreign high-quality and inexpensive genetically modified soybeans, the domestic soybean market has been continuously occupied by imported soybeans [49]. To this end, the *No. 1 Central Document* of 2014 reported that a pilot project of soybean target price subsidies in the NECP and Inner Mongolia was launched. However, with the rise in the price of soybean production factors and the high cost of domestic soybean production, the actual profits of soybean planting lowered from 435.44 yuan in 2012 to 157.46 yuan in 2018. When considering labour and land costs, the net profit of soybean planting in 2018 reached −192.04 yuan. In addition, soybean production suffers negative impacts from extreme climate hazards and crop pests [50,51]. In 2019, the soybean planting area in Heilongjiang, Inner Mongolia, and Anhui accounted for 57.17% of the total area of China, and soybean production accounted for 61.01% of the total production in China. In addition, Heilongjiang and Inner Mongolia exhibited comparative advantages in soybean planting efficiency and scale. Therefore, it is necessary to focus on increasing subsidies for soybean planting in the region, increasing subsidies for agricultural insurance premiums, and increasing the amount of insurance compensation to enhance incomes; therefore, encouraging farmers to plant soybean crops and stabilize the planting area and production of the main soybean-producing region in China.

A complete soybean industry chain should be created in areas with comparative advantages in soybean planting scale abilities. From 1949 to 2019, the center of soybean production moved 335.89 km along the direction of 89.59° northeast, and the center of gravity of the soybean sown area moved 467.21 km along the direction of 77.41° northeast. At present, Heilongjiang and Jilin form a high–high cluster area with comparative advantages in the soybean planting scale, and it is necessary to fully utilize these advantages to implement major joint soybean research, accelerate the application of biotechnology to soybean breeding, and upgrade the breeding capacity of soybean seeds. Moderate-scale operation activities of soybean crops in the region should be accelerated with a focus on cultivating and supporting a number of soybean planting cooperatives, large producers, family farms, and other new business entities to promote large-scale operations. A soybean industry chain integrating soybean breeding, production, processing, and marketing should be established in the NECP region, Inner Mongolia, and Anhui to raise the market competitiveness of Chinese soybeans.

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Spatiotemporal Evolution of Crop Planting Structure in the Black Soil Region of Northeast China: A Case Study in Hailun County

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Abstract: Detailed characteristics of crop planting structure (CPS) evolution can inform the optimization of the crop yield proportion in the black soil region of Northeast China (BSRNC). Choosing Hailun County as an example, this study sought to analyze the geographic characteristics of CPS evolution from 2000 to 2020. Our analysis produced new spatiotemporal information based on the remote-sensing interpretation data, namely, Landsat4-5 TM, Landsat7 ETM+, and Landsat8 OLI images. The study characterized the temporal and spatial dynamics of CPS. Our results showed the following: (1) Soybean and maize were the main crops, with a total land area of 70%; they alternated as the most dominant crop. (2) The distribution breadth and aggregation intensity of soybean and maize were spatially complementary; rice had the smallest distribution range but strong water aggregation. (3) The evolution pattern of CPS was the interconversion between a single type of soybean and maize. Our results indicate that the future CPS adjustment of BSRNC needs to consider the county-level optimization of crop area proportion and crop spatial distribution. This context has excellent implications in geographically informing policymaking to adjust county-level CPS of BSRNC, thus safeguarding food security.

Keywords: spatiotemporal changes; crop planting structure; black soil region; Northeast China; county-level; geographic characteristics

1. Introduction

Recently, diet shifts have threatened global food security [1]. As the Food and Agriculture Organization of the United Nations reported, nearly 12% of the worldwide population faced severe food insecurity in 2020. The percentage is likely to rise in the coming decades [2]. Hence, implementing suitable agricultural adaptation to diet shifts is challenging for ensuring food security [3]. According to this aim, an essential measure of this adaptation is to reach a food balance between supply and demand [4]. The rationalization of the crop planting structure (CPS) contributes to optimizing the crop yield proportion to achieve this balance [5].

The CPS rationalization refers to the appropriate adaptation of crop composition and spatial distribution for agricultural development [6]. This adaptation is different from one country to another. For example, the main crops in the United States are soybean and maize [7]. Additionally, agriculture in Brazil and China have main crops of soybean and maize, respectively [8,9]. This situation showed that these two crops represented an essential share of international trade. The interdependence of food trade intercountry ensures global food security [10]. However, irregular CPS evolution has been a significant obstacle to national food security, notably in China [11]. Previous studies show that this obstacle is mainly manifested in the irrational proportion of food yield [12]. Specifically, wheat, rice, and maize self-sufficiency have reached 95%, while soybean faces production shortages in China [13]. Consequently, the Chinese agricultural principal contradiction has shifted from an insufficient total output to a structural contradiction [14]. This situation results from China's market economy and the interference of the natural environment [15]. Hence, the Chinese government has undertaken policymaking to address this contradiction nationwide [16,17]. Geographic information about the spatiotemporal changes of the CPS is an essential basis for such policymaking [9]. Therefore, the study of CPS plays a strategic role in optimizing CPS and safeguarding national food security.

Previous studies on CPS have focused on two main aspects. The first was to analyze the interactions between CPS and other elements. The second extracts information on crops' spatial distribution and suggests the optimization of CPS. The study of interactions between CPS and other components involves several disciplines, including climatology [18], hydrology [19], ecology [20], and geography. The scholars have conducted research primarily in geography. They focused on the interaction between CPS with latitude, population density, and geographical location [21,22]. In extracting crop-distribution information and CPS optimization, scholars have mainly explored the spatiotemporal changes of CPS on national [23,24] and regional scales [25,26]. In China, researchers have conducted studies on different scales, such as the entirety of China [9], North China [27], Sanjiang Plain [5], Hunan Province [28], etc. These studies have promoted the optimization of China's CPS to safeguard national food security. However, research on the black soil region of Northeast China (BSRNC), which is an essential commercial grain production base, is lacking. In addition, most of these studies focused on characterizing the CPS for the entire study area through multiple counties [29]. They concerned a large region, and few studies investigated the geographic characteristics of the CPS within a small geographical entity such as Hailun County. For this reason, we seek to understand the aspects of CPS in BSRNC on a small scale.

Small-scale acquisition of CPS features specialized methods and data. Surveys, statistics, and remote-sensing image interpretation are the three primary methods for obtaining CPS information. Survey data are accurate, but obtaining CPS information for long time series is challenging [30]. Statistical data are available for accessing long time series of crop information. Restrictedly, statistics fail to reflect spatial heterogeneity [31]. With the advancement of remote-sensing technology, acquiring high-resolution, long-term series of remote-sensing images is possible [32]. Remote-sensing image interpretation provides rapid access to small-scale spatial crop information with long time series [33]. Furthermore, high-, medium-, and low-spatial-resolution images are employed for remote-sensing image interpretation. High-spatial-resolution remote-sensing images, such as SPOT, enable the accurate extraction of crop information. However, image interpretation based on such data requires a long access period and a large workload due to the low temporal resolution [34,35]. Low-spatial-resolution remote-sensing images such as MODIS provide a broader coverage area and higher temporal resolution. Nevertheless, it is difficult to guarantee the accuracy of extraction results [36,37]. Medium-spatial-resolution remote-sensing images, such as Landsat, enable the rapid and accurate acquisition of crop information [38,39]. Overall, remote-sensing interpretation at medium spatial resolution is preferred to obtain CPS of BSRNC on a small scale.

The BSRNC covers an area of 1.09 million square kilometers and contains 264 counties [40]. The BSRNC is a significant supplier of soybean, maize, and rice in China and contributes a quarter of the national food yield [41]. Nevertheless, the irrational crop yield proportion has hindered agricultural development in this region. This hindrance is shown by a significant decline in soybean yield and increased maize and rice yield [42]. In addition to the unit yield, the crop yield changes are mainly due to the CPS adjustment [43]. From this fact, the CPS evolutionary study contributes to a new round of CPS policymaking in BSRNC, thus optimizing the food yield proportion. Furthermore, the adjustment policy of large-scale CPS needs to be practiced in small regions. Therefore, this study selected Hailun County as an example and aimed to summarize the geographical characteristics of CPS spatiotemporal dynamics from 2000 to 2020. Specifically, the objectives of this study are: (1) to analyze the temporal dynamics of crop area, (2) to analyze the spatial dynamics of crop distribution, and (3) to seek to determine CPS type and analyze CPS distribution characteristics. These findings can geographically inform county-level CPS adjustment in BSRNC to ensure regional food security.

2. Materials and Methods

2.1. Study Area

Hailun County is located between latitudes of 46°58′–47°52′ N and longitudes of 126°14′–127°45′ E, in the central part of BSRNC [44]. The regional landform is characterized by southwestern plains and northeastern hilly, with an average elevation of 239 m. The northeastern most hilly area is mainly covered with forests. Hailun County has a humid continental climate, with an average annual temperature of 2.48 °C. The average yearly precipitation is 550 mm/year. The main rivers and reservoirs distributed in the territory are Tongkeng River, Zhayin River, Hailun River, Dongfanghong Reservoir, Lianfeng Reservoir, etc., (Figure 1).

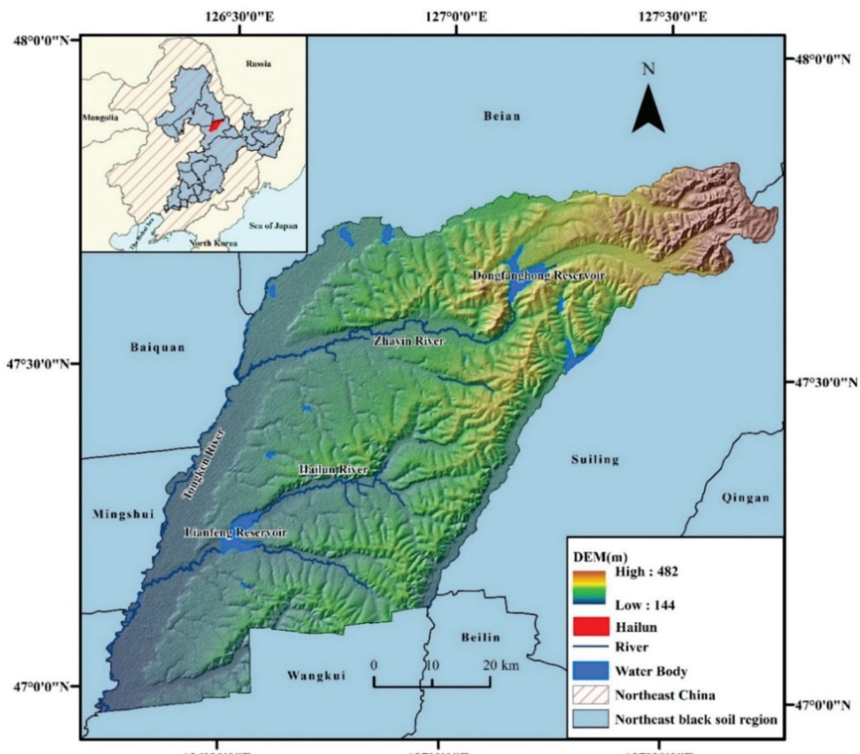

Figure 1. Study area.

Hailun County is a nationally renowned grain-producing county. The cultivated land area is about 310,000 hectares, accounting for 63.3% of the total land area. The principal crops are soybean, maize, and rice. In 2020, Hailun County's food yield reached

132,500 tons, and its agricultural income was 65% of the county's gross domestic product, which indicates that agriculture is the leading industry [45].

Black soil is the primary soil type in Hailun County, accounting for 63.4% of the total land area. This soil features excellent permeability and water retention, as well as great fertility potential, which provides favorable conditions for crop growth. To conduct observations and studies on black soil agriculture, the Chinese Academy of Sciences has established research stations in Hailun County [46]. In addition, the Chinese government has implemented relevant policies (Guidance on the Structural Adjustment of Maize in the "Sickle Bend" Area, etc.,) to adjust Hailun County's maize area. To optimize the planting structure of soybean and maize, Hailun County was also listed as a pilot area of the national crop rotation fallow system in 2017 [11]. Therefore, Hailun County is a typical area for studying the CPS of BSRNC.

2.2. Data Resources

The crop phenology features one crop per annum in the study area. At the transplanting and tillering stages, the rice showed significant spectral differences in the remote-sensing images from May to June. Hence, we chose these images for identifying rice. From mid-late July to mid-August, soybean is in the stage of podding to maturity, and the plants begin to turn yellow. Meanwhile, maize is in the milky ripeness stage, and the plant greenness is still high. Therefore, we chose images from this period to distinguish between soybean and maize [47].

We collected Landsat4-5 TM, Landsat7 ETM+, and Landsat8 OLI remote-sensing images with a spatial resolution of 30 m for five years (2000, 2005, 2010, 2015, and 2020) (Table 1). In addition, we collected the administrative division vector data and DEM data of Hailun County. These data were sourced from the Geospatial Data Cloud Platform (https://www.gscloud.cn/home, accessed on 15 May 2020).

Table 1. Details of satellite imageries.

Times		Image Types	Cloud Proportions (%)	Identified Crops
2000	06-06	Landsat4-5 TM	0.00	Rice
	08-17	Landsat7 ETM+	0.22	Soybean, Maize
2005	06-28	Landsat7 ETM+	0.48	Rice
	08-07	Landsat4-5 TM	0.00	Soybean, Maize
2010	06-10	Landsat7 ETM+	0.00	Rice
	08-24	Landsat4-5 TM	3.07	Soybean, Maize
2015	06-16	Landsat8 OLI	3.13	Rice
	09-04	Landsat8 OLI	1.07	Soybean, Maize
2020	05-28	Landsat8 OLI	0.66	Rice
	07-15	Landsat8 OLI	2.92	Soybean, Maize

2.3. Methods

2.3.1. Crop Classification

This study used ENVI and ArcGIS for crop classification. First, we geometrically corrected the remote-sensing images based on DEM. After preprocessing remote-sensing images, we created a mask to crop images using the cropland vector data. Next, we performed a Landsat TM/ETM+ 453 RGB band composite and Landsat OLI 564 RGB band composite. According to crop spectral characteristics, we established the interpretation keys of soybean, maize, and rice by visual identification. Finally, we corrected the supervised classification results by visual interpretation to obtain crop information.

We assessed the accuracy of classification results through the confusion matrix and field survey. Taking the crop confusion matrix in 2020 as an example, the overall accuracy of crop classification was 91.5%, the Kappa coefficient was 0.89, and the user accuracies of soybean, maize, rice, and other crops were 86.36%, 96.36%, 100%, and 85.71%, respectively. Taking the crop field survey in 2020 as an example, the overall survey accuracy was 93%, and the field survey accuracies of soybean, maize, rice, and other crops were 92%, 88%, 98%, and 94%, respectively. The classification results met the requirements of the subsequent analysis.

2.3.2. Temporal Dynamics of Crops

This section revealed the area dynamics of soybean, maize, and rice through the dynamic degree model and transition matrix.

We introduced the land use dynamic degree model to analyze the crop area change characteristics, which can quantify the change rate of the crop area. The expression is as follows [48]:

$$K = \frac{U_b - U_a}{U_a} \times \frac{1}{T} \times 100\% \quad (1)$$

where K is the dynamic degree of crop area during the study period; U_a and U_b represent the crop area at the beginning and end of the study, respectively; and T is the time interval of the study.

We introduced the land-use transition matrix to analyze the crop area conversion characteristics. The transition matrix reflects the transferred-out area at the initial period and the transferred-in area at the end period. The form of the transition matrix is as follows [49,50]:

$$S_{ij} = \begin{bmatrix} S_{11} & S_{12} & \ldots & S_{1n} \\ S_{21} & S_{22} & \ldots & S_{2n} \\ \ldots & \ldots & \ldots & \ldots \\ S_{n1} & S_{n2} & \ldots & S_{nn} \end{bmatrix} \quad (2)$$

where n represents the number of crop types before and after the transfer; i, j (i, j 1, 2 . . . , n) represent the crop type before and after the transfer, respectively; S_{ij} represents the area of type-i crop before conversion to type-j crop after conversion.

2.3.3. Spatial Dynamics of Crops

We introduced the crop kernel density to analyze crops' spatial aggregation and spatial dynamics [51]. Kernel density estimation reflects the spatial distribution density and changing trend of point groups. Before the kernel density estimation, all soybean, maize, and rice pixels were converted to points that were then algorithmically output to represent crop density. Suppose that (x_1, ... , x_n) is a series of n identically and independently distributed observations; the kernel estimator of the x density is given by [52,53]:

$$f_n(x) = \frac{1}{nh}\sum_{i=1}^{n} K(\frac{x - x_i}{h}) \quad (3)$$

where K is the kernel function and h is a smoothing parameter called bandwidth. The bandwidth h is calculated as follows [54]:

$$h = 0.9 * \min\left(SD, \sqrt{\frac{1}{\ln(2)} * D_m}\right) * n^{-0.2} \quad (4)$$

where SD is the standard distance, D_m is the distance from the mean center for all points, and n is the number of points.

In addition, we defined the kernel density levels as follows: kernel density values between 0 and 400 frequency/km^2 are "low level", kernel density values between 401 and 800 frequency/km^2 are "medium level", and kernel density values between 801 and 1200 frequency/km^2 are "high level".

2.3.4. Determination and Spatial Characterization of CPS

The CPS type is determined based on one crop area as a percentage of the total area. Given previous studies in Northeast China [5,55], there are usually no more than three crops in a CPS type. The CPS type is determined as follows: if only a specific crop area accounts for more than 30% of the total crop area in the county, the CPS is the single type of this crop; if there are two or three types of crop areas accounting for more than 30% of the total crop area, the CPS is a combination of these crops; if all crop areas account for less than 30% of the total crop area, the CPS is a combination of the top three crops. Considering the spatial variation of CPS, we further calculated the variation in CPS types on the 900 × 900 m unit.

3. Results

3.1. Temporal Dynamics of Crops

3.1.1. Area Changes in Crops

Soybean and maize were the main crops with over 70% of the total area from 2000 to 2020. They alternated as the crops with the most area. Rice and other crops accounted for less than 30% of the area (Table 2).

Table 2. Area of major crops in Hailun County.

Years		Crop Types/Values			
		Soybean	Maize	Rice	Other Crops
2000	Area (10^4 hm^2)	10.3	14.5	3.3	7.2
	Proportion (%)	29.2	41.1	9.3	20.4
2005	Area (10^4 hm^2)	21.5	8.7	2.1	3.0
	Proportion (%)	60.9	24.7	5.9	8.5
2010	Area (10^4 hm^2)	20.9	6.0	2.0	6.4
	Proportion (%)	59.2	17.0	5.7	18.1
2015	Area (10^4 hm^2)	10.3	18.0	4.8	2.3
	Proportion (%)	29.1	50.8	13.6	6.5
2020	Area (10^4 hm^2)	17.7	9.9	6.1	1.7
	Proportion (%)	50.0	28.0	17.2	4.8

From 2000 to 2020, rice showed a significant relative increase in area (over 80%). The second-largest relative increase in area was for soybean (71.8%). In contrast, the area of maize and other crops decreased by 31.7% and 76.4%, respectively. In addition, the relative area change of major crops varies over the period. The area changes in soybean and maize were the most pronounced across periods (Table 3).

Table 3. Area changes of major crops in Hailun County.

Periods		Crop Types/Values			
		Soybean	Maize	Rice	Other Crops
2000–2005	Relative change(%)	+108.7	−40.0	−36.4	−58.3
	Dynamic degree(%)	+21.7	−8.0	−7.3	−11.7
2005–2010	Relative change(%)	−2.8	−31.0	−4.8	+113.3
	Dynamic degree(%)	−0.6	−6.2	−1.0	+22.7
2010–2015	Relative change(%)	−50.7	+200.0	+140.0	−64.1
	Dynamic degree(%)	−10.1	+40.0	+28.0	−12.8
2015–2020	Relative change(%)	+71.8	−45.0	+27.1	−26.1
	Dynamic degree(%)	+14.4	−9.0	+5.4	−5.2
2000–2020	Relative change(%)	+71.8	−31.7	+84.8	−76.4
	Dynamic degree(%)	+3.6	−1.6	+4.2	−3.8

(+) represents the increase in rate; (−) represents the decrease in rate.

3.1.2. Area Conversion among Crops

Specifically, the area interconversion featured differently across stages. From 2000 to 2005 (Figure 2a), soybean had the most significant area increase, while maize was the crop with the most considerable area decrease. The gain area of soybean was 13.83 × 10^4 hm^2, and the lost area of maize was 10.35 × 10^4 hm^2. For soybean, 52% of the gain area came from the maize, and 40% was translated from other crops. For maize, 70% of the lost area translated to soybean and 17% to other crops. From 2005 to 2010 (Figure 2b), maize was the crop with the most area reduction. The area loss of maize was 6.68 × 10^4 hm^2. A total of 55% of the lost area was converted to soybean and 28% to other crops. From 2010 to 2015 (Figure 2c), maize was the crop with the most significant area increase, and soybean was the crop with the most significant area decrease. The gain area of maize was 14.82 × 10^4 hm^2, and the lost area of soybean was 14.72 × 10^4 hm^2. Specifically, 79% of the gained area of maize came from soybean conversion, and 79% of the lost soybean area was converted to maize. From 2015 to 2020 (Figure 2d), the soybean area had the most significant increase, and the maize area had the largest decrease. The soybean gain area was 12.01 × 10^4 hm^2, and the maize loss area was 13.41 × 10^4 hm^2. For soybean, 81% of the gain area came from the maize conversion. For maize, 72% of the lost area was converted to soybean.

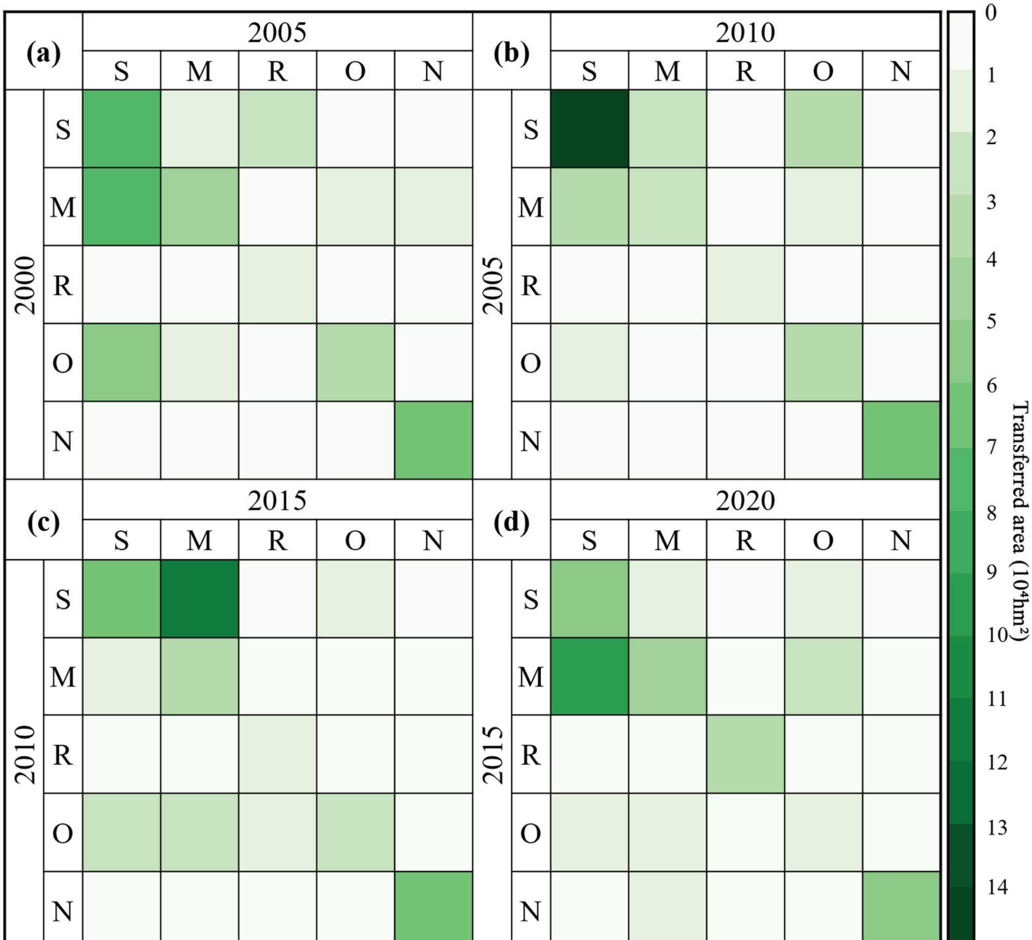

Figure 2. Transition matrix of crops 2000–2005, 2005–2010, 2010–2015 and 2015–2020 (**a**–**d**) (S for soybean; M for maize; R for rice; O for other crops; N for non-cultivated land).

Overall, the area interconversion was concentrated between soybean and maize. The interconverted area between paddy and dryland was almost negligible.

3.2. Spatial Dynamics of Crops

Specifically, crops' distribution ranges and aggregation characteristics differed significantly. According to Figure 3a–e, soybean was the most widely distributed and featured different aggregations. In 2005, 2010, and 2020, soybean was widely distributed and showed strong spatial aggregation. The frequency percentages of soybean kernel density at "high level" were about 30%. In 2000 and 2015, the spatial aggregation of soybean was weaker, with the frequency percentages of kernel density at a "high level" of about 4%. According to Figure 3f–j, maize was mainly distributed in the south-central part of Hailun County. In 2000 and 2015, the maize distribution was more widespread and aggregated. The frequency percentages of the maize kernel density at "high level" were 7.14% and 21.69%, respectively. In 2005, 2010, and 2020, the distribution and aggregation of maize were small, with some maize distributed along the Tongken River. According to Figure 3k–o, rice was the least widespread of the major crops. It was characterized by aggregation mainly near water sources, with the most pronounced spatial aggregation in the Tongken River and Zhayin River. In 2015 and 2020, rice showed more robust water aggregation than in other years.

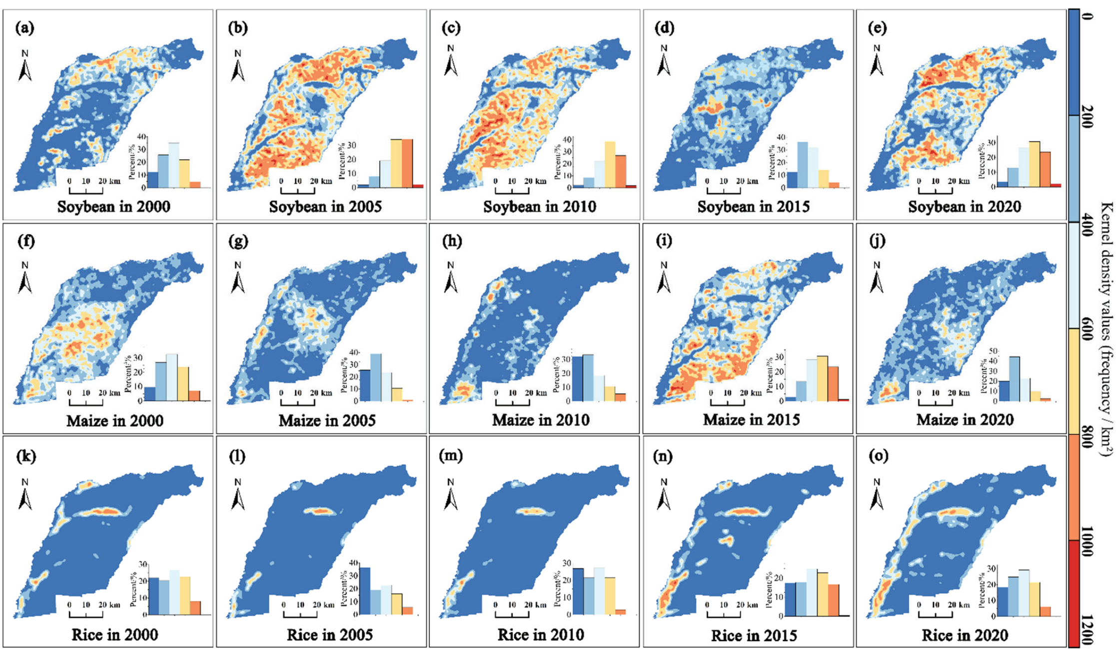

Figure 3. Kernel density of soybean (**a**–**e**); maize (**f**–**j**); rice (**k**–**o**) in 2000, 2005, 2010, 2015, and 2020.

Overall, soybean and maize were spatially complementary in distribution and aggregation. In 2005, 2010, and 2020, soybean's distribution breadth and aggregation intensity far exceeded maize's. Conversely, maize's distribution breadth and aggregation intensity far exceeded soybean's in 2000 and 2015. Moreover, the aggregation centers of soybean and maize did not overlap and complemented each other.

3.3. Determination and Spatial Characterization of CPS

We obtained the CPS types for the past 20 years in Hailun County based on the CPS determination criteria. The results were "single type of maize" (2000), "single type of soybean" (2005), "single type of soybean" (2010), "single type of maize" (2015), and "single type of soybean" (2020), respectively. In addition, the CPS evolution pattern was the interconversion between a single type of soybean and maize.

The CPS spatial distribution based on 900 m × 900 m units is determined by the crop spatial distribution based on 30 m × 30 m units. Therefore, they shared similar spatial distribution characteristics. According to Figure 4, a "single type of soybean" and "single type of maize" were the main CPS types, accounting for more than 40% of the total area. A "single type of soybean" was distributed throughout the territory, and a "single type of maize" was mainly distributed in the south-central part of the study area. The area proportion of a "single type of rice" was about 10%, which was mainly distributed near water sources, especially near the Tongken River and Zhayin River. "Mixed type of soybean–maize" was the largest area of mixed types, but the area was much smaller than that of a single type. "Mixed type of soybean–maize" was mainly distributed in the central and northern parts of Hailun County. The other "mixed types of two crops" were the non-dominant CPS types, and irregularities characterized their spatial distribution. The area of "mixed types of three crops" was almost negligible.

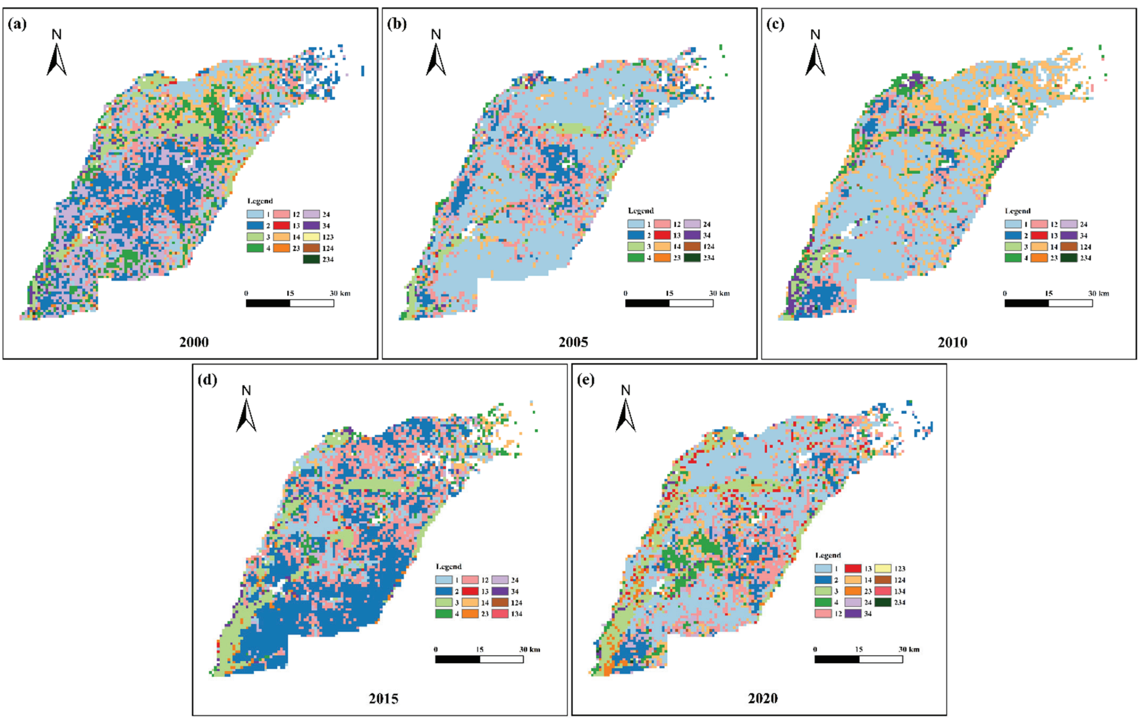

Figure 4. Spatial distribution of CPS based on 900 m × 900 m units in 2000, 2005, 2010, 2015, and 2020 (**a**–**e**) (1: single type of soybean; 2: single type of maize; 3: single type of rice; 4: single type of other crops; 12: mixed type of soybean–maize; 13: mixed type of soybean–rice; 14: mixed type of soybean–other crops; 23: mixed type of maize–rice; 24: mixed type of maize–other crops; 34: mixed type of rice–other crops; 123: mixed type of soybean–maize–rice; 124: mixed type of soybean–maize–other crops; 134: mixed type of soybean–rice–other crops; 234: mixed type of maize–rice–other crops).

4. Discussion

4.1. Explanation for Geospatial Distribution of Crops in Hailun County

Soybean, maize, and rice showed significant differences in spatial distribution characteristics from 2000 to 2020 in Hailun County. The spatial distribution of regional crops is mainly influenced by natural conditions, socio-economic, and agricultural policies [56]. For soybean, Hailun County is blessed with widespread black soil and climatic conditions suitable for growing soybean. This county is also well experienced in growing soybean [57].

As a result, soybean is the main crop and is distributed throughout the territory. For maize, the yield and quality are higher in plains than in hilly areas. Farmers preferred to grow maize in the plains for higher economic benefits [58]. Therefore, maize in Hailun County is mainly distributed in the central and southern plains. For rice, it is concentrated near water sources due to its high water demand. From 2010 to 2014, China raised the minimum rice purchase price for five consecutive years [59]. During this period, more farmers preferred to grow rice. Some dry fields along the Tongken River were converted to paddy fields. As a result, rice's distribution breadth and aggregation intensity along the Tongken River increased after 2015.

For soybean and maize, rotation improves the physicochemical properties of black soil to increase crop yield [60]. BSRNC has been rotating soybean and maize for the past 20 years. In 2016, the "Pilot Program for Exploring the Implementation of Cultivated Land Rotation and Fallowing System" proposed to conduct a pilot rotational fallowing system in Northeast China, and Hailun County was listed [11]. Therefore, the soybean and maize distributional breadth and aggregation intensity were complementary spatially across years.

4.2. Crop Planting Structure and Food Security

The Chinese agricultural conflict has shifted from an insufficient crop yield to an irrational crop structure in recent decades. To optimize this structure, China's food security strategy aims to balance the food supply and demand [61]. Rational CPS adjustment contributes to optimizing the crop yield proportion to achieve this balance. Most relevant studies have found that state macro-regulation and changes in farmers' cropping concept are the two primary measures to ensure food security from the CPS perspective [9,42].

One is the macro-control of the state. The CPS evolution is closely related to China's food security policy. " National mid-to long-term food security plan (2008–2020)" has set the goal of stabilizing the food self-sufficiency rate above 95% by 2020 [62]. At present, rice, wheat, and maize yields basically meet the demand for self-sufficiency. Due to imported soybean's low price and high quality, China still accounts for more than 60% of global soybean imports [10]. The BSRNC contributes to 40% of China's total soybean yield and plays a vital role in the national soybean supply [63]. Therefore, a new round of county-based regulation of CPS in BSRNC helps to realign the crop yield proportion, thus guaranteeing food security.

The other is the change in farmers' cropping concept. According to the "Agricultural Supply-side Structural Reform," the CPS optimization requires a shift in farmers' cropping concept [64]. Food prices and planting subsidies directly influence farmers' cropping concept. From 2000 to 2005, the soybean price in Hailun County was about 1.5–2-times higher than that of maize. The subsidies for growing soybean were also much higher than for growing maize. As a result, the CPS transformed from a "single type of maize" to a "single type of soybean." Overall, the optimization of CPS in BSRNC requires reasonable adjustment by the state and changes in farmers' cropping concepts to safeguard food security.

4.3. Crop Planting Structure and Policy Implementation

China has implemented policies to optimize the CPS of BSRNC at three levels. On overall policies, the "Outline of the Medium and Long-term National Food Security Plan (2008–2020)" and "National Agricultural Sustainable Development Plan (2015–2030)" called for rational optimization of agricultural production layout to reach a food balance between supply and demand [62]. On specific policies, "Agricultural Supply-side Structural Reform" and " National Planting Structural Adjustment Plan (2016–2020)" required the rational CPS adjustment to achieve a reasonable crop yield proportion [17,65]. More specifically, "Guiding Opinions on the Adjustment of Maize Structure in the 'Sickle' Region" is required to reduce the excessive maize area, restore the shrinking soybean area, and achieve a proper crop rotation in BSRNC.

According to our results, the CPS adjustment over the past 20 years has largely met the requirements of these policies. However, there were still some deviations in the implementation of the policy. For example, the maize area far exceeded the soybean area in 2015. In this case, the new round of CPS adjustment in BSRNC should prioritize policy implementation at the county scale. The county-level geographic characteristics of CPS evolution in BSRNC contribute to monitoring the performance of these policies and guiding the direction of CPS adjustments.

We revealed the geographic characteristics of CPS dynamics in Hailun City from both temporal and spatial perspectives. Due to the limitations in data availability and precision, we did not perform a comprehensive and detailed CPS analysis. However, the geographic characteristics of CPS are both the result of spatiotemporal evolution and the prerequisite for CPS adjustment. Therefore, we will conduct longer time series and more detailed analyses of spatio-temporal characteristics and influencing factors to provide BSRNC with detailed CPS optimization recommendations in future studies.

5. Conclusions

This research attempted to systematically characterize the crop area dynamics and crop distribution dynamics and determine the CPS types in Hailun County. The main findings are as follows: From 2000 to 2020, soybean and maize had the largest area and alternated as the most dominant crop. The area of rice and other crops was tiny. The area interconversion was mainly concentrated between soybean and maize. Relatively, soybean was the most widely distributed and aggregated crop. The soybean and maize distribution breadth and aggregation intensity were spatially complementary in different years. Rice had the smallest distribution range but showed a substantial aggregation of water sources. In addition, the CPS types were a single type of soybean or maize in 2000, 2005, 2010, 2015, and 2020. The CPS evolution pattern was the interconversion between a single type of soybean and maize. The CPS spatial distribution had similar characteristics to the crop spatial distribution.

This study provides a new perspective for CPS research in BSRNC: the spatio-temporal analysis based on county-level geographic characteristics. The results suggest a future CPS adjustment of the BSRNC is necessary, and such an adjustment requires a county-level optimization of the crop-area proportion and crop spatial aggregation. These findings inform the Chinese government's new round of CPS adjustments for BSRNC to safeguard food security.

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Article

Is There Herd Effect in Farmers' Land Transfer Behavior?

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Abstract: China's rural land transfer market has been plagued by issues including poor information transmission, limited scale, and an incoherent structure. In this context, this study collected the data of 337 farmers in Qufu City, Shandong Province, and incorporated into the analysis the acquaintance-based nature of rural society that includes strong geographic ties. Taking the herd effect as the starting point, this paper it considers how farmers in the same geo-network affect the land transfer behavior of individual farmers, and adopts the Probit model to analyze the impact of geo-networks to verify the function of the herd effect in farmers' land transfer behavior. Then, the IV-Probit model is applied to solve the endogenous problem of the herd effect. The results show that: (1) Farmers imitate the land transfer behavior of other farmers in the same geo-network. Geo-networks positively impact the land transfer behavior of farmers, and the herd effect is apparent in farmers' land transfer behavior. (2) Farmers' family background, resource endowment, and cognitive features are key factors that influencing farmers' land transfer behavior. (3) Farmers' land transfer behavior is more significantly influenced in groups with low and middle agricultural income than in groups with high agricultural income. This study aims to assist the government in giving full play to the positive role of the herd effect, promoting the leading role of village cadres as leader sheep, and smoothing the transmission of land transfer information. Governments should place more emphasis on developing land transfer platforms and invest more in the construction of farmland infrastructure. This paper may serve as a reference to achieve large-scale agriculture operation via land transfer and promote the prosperity of the land transfer market.

Keywords: farmers' land transfer behavior; herd effect; geo-network

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1. Introduction

During recent decades, China has seen rapid urbanization as well as intensified crises including farmland abandonment, deficiency of rural land use, and rural decline [1–3]. Since the massive outward rural migration due to rapid urbanization, rural land use has been dramatically affected, especially in cases of farmland abandonment [4,5]. Due to the household contract responsibility system in place in China, even though the rural migrants left the agricultural industry and abandoned their land in the countryside, they could not sell the rural land nor could other farming households obtain more rural land [6]. Under the household contract responsibility system, all residents of a village collective own all the rural land within the village, and the amount of land any household can own depends on its historical numbers of household family members [7]. In fact, this household contract responsibility system stipulates that farming households cannot sell their contracted land even if they intend to leave the countryside permanently, as the farming households only have contractual and usage rights to the contracted land, but not the ownership rights. As a result, the household contract responsibility system increased the levels of farmland abandonment and rural land use deficiency in rural China [1,7]. Thus, land transfer was proposed to solve the rural land use problem in rural areas through the promulgated "separating three property rights" reform [8]. Thanks to the "separating three property rights" reform, the contractual and usage rights of rural land are divided into non-tradable contractual rights and tradable usage rights, which make it possible for farmers who cease engaging in agricultural industry to transfer outward the land usage rights to others, and it also makes it possible for farmers remaining in agricultural industry to transfer inward more rural land to enlarge the scale of their farming operations [9]. Land transfer refers to this inward and outward transfer of rural land usage rights, and is used with that meaning in this study.

Land transfer is nowadays the route one must take to revitalize abandoned rural land resources and develop moderate-scale operations in rural areas in China [10,11]. Reasonable land transfer is vital for developing modern agriculture, to address problems in rural areas [6,7]. The 18th, 19th, and 20th National Congresses of the Communist Party of China all urged efforts to implement the tasks and requirements of land transfer reform, and to obtain rural revitalization through optimal allocation of land elements [12–14]. At present, despite legal protection and central government support, the rural land transfer market still suffers from ineffective information transmission, small scale, and uncoordinated structures [15,16]. Further attempts are required to facilitate rural land transfer and allocate land resources appropriately to support rural economic progress and revitalization. These are key to promoting reform of rural land systems and actualizing agricultural scale management in the new era.

For famers, obtaining land transfer information is fundamental to the land transfer process. With limited information channels broadcasting government policies, instead of spending more time, cost, and energy collecting and interpreting land transfer information, farming households are more inclined to refer to and imitate the behavior of other farmers in their social networks when making decisions on land transfer, showing a herd effect [17,18]. Herd effect refers to the behavior of individuals extracting information from other people's behaviors and imitating them to maximize utility when information is asymmetric or insufficient due to imitations of information-discrimination ability [19]. Although farmers have a general tendency to pursue the maximization of economic benefits and utility, behavioral economics research shows that farmers' individual willingness and behavior are also influenced by the willingness and behavior of other individuals in their groups [20].

As the most important subjective factor, the group psychology of farmers affected by the herd effect plays a key role in the process of land transfer. Due to group psychology, there may be a big difference between an individual's response in the group environment and their response in the independent environment [21–23]. Farmers' land transfer decision-making behavior shows conformity, and in order to avoid being isolated or treated differently by other farmers, they choose to imitate the land transfer behavior of other farmers [24,25]. At the same time, due to the narrow channels of information transmission, farmers tend to rely on decision-making information obtained from other farmers such as acquaintances, relatives, and friends as active reference when obtaining land transfer information [26]. Therefore, in the process of land transfer, due to incompleteness and difficulty in obtaining information, farmers rely on public information when making decisions affecting land transfer behavior, which leads to a herd effect in farmers' land transfer behavior [20–26].

Since land transfer is now protected and recognized by the law, numerous academics have started to investigate the costs, obstacles, and issues regarding land transfer and have put forward helpful policy proposals. In China, farmers live together in villages relying on land resources and maintaining geo-network relationships [18], but little focus has been placed on the geo-network characteristics of the acquaintance society in rural areas, where farmers have few options for getting information about land transfer policies and therefore frequently follow the land transfer behavior of the majority when unsure how to proceed. To examine how geo-networks affect land transfer behavior, this study considers the herd effect, which reflects the actions of people in a group. Therefore, this paper takes herd effect as the starting point, considers the influence on farmers' land transfer behavior of herd effect caused by group psychology, analyze the mechanism of the herd effect in farmers' land transfer behavior, puts forward a research hypothesis, and verifies it through micro-investigation data, to obtain an effective theoretical and empirical basis for guiding land transfer practice.

The remainder of this paper is structured as follows: Section 2 reviews the existing literature and Section 3 proposes the research objective and research hypotheses. Section 4 displays the data and methodology. Section 5 presents the results of empirical analysis and the discussion of this research. Section 6 presents the conclusions.

2. Review of Literature

Recently, many studies have performed extensive research on the external factors influencing land transfer behavior, such as the size of the farming household, resource endowment, household income status, the size of the household labor force, agricultural machinery level, awareness of property rights, land transfer policies, the external environment, and so on [1,6,10,13,14,27–32]. It can be seen from the existing literature that there are various factors affecting farmers' land transfer behavior, but the existing studies have paid little attention to the effect of group psychology on farmers' land transfer behavior. China's rural society is characterized by acquaintance society formed by geographic ties, and group psychology is held to have a significant impact on farmers' land use behavior [33]. In reality, access to land transfer information and direction is related largely to farmers' social networks [34]. According to available studies, social networks can significantly influence farmers' decisions on allocating production factors, especially land resources, and may even change a farmer's land transfer transaction mode and lead to lower land transfer prices [35,36]. Furthermore, land transfer relies heavily on invisible commitments made by members of the kin society. To be specific, the transferor reduces or waives rents in exchange for favorable assistance from the transferee, so land transfer is more likely to occur among friends and relatives, featuring low transfer prices or even zero rents [37,38]. Meanwhile, some scholars have found that in areas where farmers have no strong willingness to transfer land, or social networks play a major part, most farmers access land transfer information through communicating with others in their social networks, revealing that the social network mechanism of farmers promotes the development of land transfer to some degree [39,40].

As stated above, China's rural areas are home to an acquaintance-based society with geographic ties [33]. Such a society boasts the advantages of information symmetry and social network access [41], so land transfer information can be transmitted smoothly among acquaintances. Farmers in the same region basically know each other well. Hence, when a farmer is unable to access land transfer information effectively, he tends to consult his acquaintances and farmers in the same group, within the same village, who are experienced in land transfer. If he follows their actions without fully considering his resource endowments and limitations, his land transfer behavior is thus affected by the herd effect [21,22,42,43]. The herd effect has distinct functions of information transfer and demonstration [22,42]. It is an efficient way to transmit information that impacts individual decision-making while also enabling individuals to change their behavior based on information obtained from other subjects in a group [21,42], hence its vital role in disseminating land transfer information. Scholars have previously focused on the herd effect in the stock market, financial investment, securities market, agricultural production, and rural land use [17,18,23,42,44]. This current paper takes into account the specificity of rural geo-networks, links the herd effect with farmers' land transfer behavior, considers the information transmission and demonstration function of the herd effect, and analyzes how the herd effect influences farmers' land transfer practices.

In this research, we focused on geo-networks to observe the herd effect, because Chinese farmers tend to live together in villages where they maintain geo-network relationships [18]. Geo-networks are considered the contractual basis of rural society [45]. Because rural residents live together in villages, they form interpersonal relationships through mutual social activities and exchanges, leading to close ties between farmers in contexts of politics, economy, culture, customs, socializing, and agricultural production. In China's rural areas, geo-network relationships have long affected economic development and the establishment of new structures [45]. It is precisely because of the existence of geo-networks that villagers in the same village have form general rules for long-term production and life processes, which indirectly affect farmers' land use behavior. Therefore, this study applied the concept of geo-networks to assess the herd effect in farmers' land transfer behavior.

3. Research Objective and Hypotheses

For its research objective, this study begins with the herd effect, integrates the features of acquaintance society with geographic ties in China's rural areas, and considers the influence of group psychology on individual farmers' land transfer behavior. By taking farmers themselves as the channel of disseminating land transfer information, to explore how the geo-network, exerting the herd effect, impacts farmers' individual land transfer behavior. In this research, the IV-Probit model was employed to verify the herd effect of farmers' land transfer behavior. The herd effect based on geo-networks may act as a scientific reference for shareholders to further normalize and direct orderly rural land transfer, solve the problem of fragmented arable land, and facilitate large-scale farming operations.

In order to verify whether there is herd effect in farmers' land transfer behavior, we put forward hypotheses based on theoretical analysis.

In terms of land transfer, the herd effect supports information transfer and provides an example for farmers in the same geo-network to copy [46]. On the one hand, collecting information about land transfer can prove costly, and the traditional land transfer market can fail to match efficiently demand with supply, and as a result, many potential land transfer transactions cannot be realized [1]. Social networks, by contrast, greatly reduce the costs of farmers' information searches [33]. Farmers with abundant social network resources can acquire more useful information quicker and at lower cost that those with less social networks resources. They can also spread land transfer information more effectively and reach land transfer deals more easily [47]. On the other hand, the more that individual farmers identify with the group they belong to in their geo-network, the greater their decision making is influenced by the other farmers in the geo-network. The closer their relationship with the geo-network they belong to, the more likely it is that their decision-making on land transfer is influenced by the group's opinions [23,47]. Therefore, farmers who are unable to acquire land transfer information in advance, cannot make decisions on their own and must instead refer to other land transfer behaviors to decide whether to transfer their land. In this process, farmers' inclination to transfer land is inevitably influenced by the actions of their peers in the same geo-networks, thereby exhibiting the herd effect [22].

According to existing studies, village collectives are function as the main channels for the spread of land transfer information, having the innate advantages of releasing land transfer information, and their functions and effects have been recognized by farmers and academics [28,35,37]. There remains a necessity for developing new channels for land transfer information dissemination in rural areas. To this end, this paper examines the interplay between the land transfer behaviors of farmers in a group based on a collective geo-network, and dissects the land transfer behavior of individual farmers with the aid of the information transmission and demonstration functions of the herd effect. This paper proposes the following research hypotheses:

H1. *Geo-networks positively impact farmers' land transfer behavior*.

H2. *Farmers imitate the land transfer behavior of other farmers in the same geo-network, and a herd effect exists*.

4. Data and Methodology

4.1. Data Source and Variables

4.1.1. Data Source

In recent years, land transfer in Shandong Province has been at the forefront of China's advancements in this field. However, a mature transfer-market mechanism has not yet been formed throughout the province, and all levels of local government lack in-depth understanding of land transfer needs from the perspectives of both supply and demand, and communications platforms for land transfer information are in need of improvement. As one of the prefecture-level cities in Shandong Province, the construction of the land transfer platform for Qufu City started late, and the spread of land transfer information was asymmetric and irregular. Due to the low education levels of farmers, and their lack of awareness of land transfer policies, farmers usually transfer land by oral confirmation. Among acquaintances, even if a land transfer contract is signed between the transferor and the transferee, the terms agreed in the contract are often not clear enough, the land transfer procedures are not complete, and there is no uniform standard for the land transfer price, frequently leading to land transfer disputes and bringing severe challenges to the large-scale management of land in Qufu City. Thus, we conducted the investigation in Qufu City, Shandong Province.

The data used in this paper were gathered from a questionnaire-based survey of farmers in Qufu City, conducted by the author's research group in August 2020. Based on the preliminary investigation and demonstration, the research group took into full account the natural resources, socioeconomic situation, agricultural development, and land transfer practices among towns in Qufu City, and found that Wucun, Shimenshan and Xizou, three typical agricultural towns, are representative in terms of agricultural production and land transfer [48]. Hence these three towns were selected as the research areas. The investigators were assigned four randomly chosen villages in each of the three towns, and a number of farmers in the villages were randomly selected for face-to-face questionnaire-based interviews. The investigators on site were responsible for filling out questionnaires according to the interviews. A total of 359 farmers were surveyed. By reviewing and screening out invalid questionnaires, a total of 337 valid answer sets were obtained, at a survey response rate of 93.8%. The questionnaires covered such aspects as family composition, family livelihood, family contracted land and its transfer, rural land transfer policy cognition, and so on, to reflect fully every farming household's land transfer and land use status.

4.1.2. Variables

- Dependent variable

The dependent variable in this paper is farmers' land transfer behavior (Y), including inward transfer and outward transfer. It was considered whether or not farmers had performed land transfer behavior, be it transferring the land outward to a transferee or inward from a transferor. Assigned values were 1 for "transfer", and 0 for "no transfer".

- Core independent variables

The core independent variables of this study were intended to characterize scientifically the farmers' geo-networks. By referring to existing research [18,49] and considering data availability, this study used the number of farmers in the same village making land transfers (X1) and the number of village cadres in the same village making land transfers (X2) as the core independent variables to reflect the characteristics of the geo-network.

- Instrumental variable

Farmers' land transfer behavior is causally related to the behavior of their peers in the same geo-network, i.e., the endogeneity of the herd effect may occur during estimation. In order to control the estimation bias caused by such endogeneity, the area where farmers are located (IV) was used as an instrumental variable for the number of farmers in the same village making land transfers.

- Control variables

For more accurate estimates of the model, this study included control variables in the model representing farmers' family features, resource endowment features, and cognitive features, with reference to current literature [1,16,17,22,26,28,30]. Variables reflecting farmers' family features included age of the householder (X3), gender of the householder (X4), educational attainment of the householder (X5), and occupation of the householder (X6). Variables for resource endowment features were arable land area (X7), number of land plots (X9), agricultural income (X8), agricultural input–output ratio (X10), changes of unit grain yield in the past five years (X11), and living expenses (X12). Farmers' cognitive features comprise their perception of life and their understanding of policies and regulations. Farmers' perception of life included two variables, their way of accessing information in the village (X13) and their satisfaction with farmland infrastructure (X14), whereas farmers' cognition of policies involved three variables, whether they think contracted land can be inherited by their children (X15), whether farmers are sure that the confirmation and registration of the right to contracted management of rural land are performed in their villages (X16), and farmers' understanding of farmland protection policies (X17). Table 1 describes the symbols and descriptions of the variables.

Table 1. Variables and their symbols and descriptions.

Symbol	Variable	Description	Mean	Standard Deviation
Y	Land transfer behavior	Transfer = 1, No transfer = 0	0.49	0.51
X1	Number of farmers in the same village making land transfers	Proportion of farmers in the same village making land transfer, (30%,40%] = 1, (40%,50%] = 2, (50%,60%] = 3, >60% = 4	2.14	1.16
X2	Number of village cadres in the same village making land transfers	Proportion of village cadres in the same village making land transfer, (0,50%] = 0, >50% = 1,	0.06	0.23
X3	Age of the householder	Age of the householder	60.43	10.83
X4	Gender of the householder	Male = 1, Female = 2	1.07	0.25
X5	Educational attainment of the householder	Uneducated = 0, Primary school = 1, Junior middle school = 2, Senior middle school = 3, Technical secondary school/vocational high school = 4, Junior college and above = 5	1.77	0.95
X6	Occupation of the householder	Farming = 1, Farming with by-business = 2, Non-farming with by-business = 3, Non-farm employment = 4, Unemployed = 5	2.09	1.36
X7	Arable land area	Unit: *mu*, [0,10] = 0, (10,20] = 1, (20,30] = 2, (30,50] = 3, (50,100] = 4, >100 = 5	0.50	1.13
X8	Agricultural income	Agricultural earnings (RMB 10,000)	2.97	9.63
X9	Number of land plots	Number of land plots operated by farmers	3.21	4.78

Table 1. *Cont.*

Symbol	Variable	Description	Mean	Standard Deviation
X10	Agricultural input–output ratio	Input-output ratio	0.65	0.56
X11	Changes of unit grain yield in the past five years	Decrease = 0, Increase = 1, Unchanged = 2	1.39	0.79
X12	Life expenses	Life expenses (RMB 10,000)	0.69	1.13
X13	Farmers' method of accessing information in the village	Broadcasting = 1, Bulletin board = 2, Villages' meeting = 3, Communication with people = 4, Others = 5	1.45	0.96
X14	Farmers' satisfaction with farmland infrastructure	Highly satisfied = 1, Satisfied = 2, Average = 3, Unsatisfied = 4, Highly unsatisfied = 5	2.03	0.81
X15	Whether farmers think contracted land can be inherited by their children	No = 0, Yes = 1, No idea = 2	0.94	0.65
X16	Whether farmers are sure the confirmation and registration of the right to contracted management of rural land are performed in their village	No = 0, Yes = 1, No idea = 2	0.97	0.16
X17	Farmers' understanding of farmland protection policies	Full = 1, Little = 2, Heard but no idea = 3, Never heard = 4	3.01	1.05
IV	The area where farmers are located	By reference to "same village and same town", same village of the same town = 1, different villages of the same town = 2, different villages of different towns = 3	2.64	0.59

4.2. Methodology

As the dependent variable, farmers' land transfer behavior, is a dichotomous choice, this paper employs a Probit model for regression analysis. Also, endogeneity is likely to arise in the analysis of the herd effect in farmers' land transfer behavior. For one thing, environmental factors may cause farmers to perform similar land transfer behaviors against the same backgrounds, resulting in the overestimation of the herd effect. For another, farmers will interact, because when impacted by group behavior they will influence the group behavior, hence invoking mutual causality. Therefore, the herd effect of farmers' land transfer behavior cannot be inferred simply from the fact that farmers' land transfer behavior is influenced by group behavior; the endogeneity issue should be solved first. Based on available research results, the instrumental variable approach was administered to address endogeneity in the model [18]. Considering the dichotomy of the response variable, the IV-Probit model was developed to solve the endogeneity of the herd effect. The formula is:

$$\text{Probit}(Y) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \sum_{n=1}^{n} X_n + \mu + \varepsilon \tag{1}$$

$$X_i = \gamma_0 + \gamma_1 IV + \gamma_2 \sum_{n=1}^{n} \beta_n X_n + \mu + \omega \tag{2}$$

$$\text{IV} - \text{Probit}(\text{Y}) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_2 IV + \sum_{n=1}^{n} \beta_n D_n + \varepsilon \tag{3}$$

In Formulas (1) to (3), Probit (Y) denotes farmers' land transfer behavior. X_1 and X_2 represent the number of farmers in the same village making land transfers and the number of village cadres in the same village making land transfers, respectively, and these two are jointly employed as geo-network variables affecting farmers' land transfer behavior. X_i (i = 3, 4, ... , n) denotes a control variable reflecting farmers' family features, resource endowment features, or cognitive features. IV means an instrumental variable. β_0 is a constant, β_1 is the core coefficient, and ω and ε represent error terms.

5. Results and Discussion

5.1. Results

5.1.1. Farmers' Land Transfer Features

Table 2 details the respondents' land transfer features. In this study, a number of farmers in 12 administrative villages were randomly selected for survey.

Table 2. Land transfer features of respondents.

Town	Village	Number of Respondents	Number and Proportion of Farmers Making Land Transfers	Transfer Price (RMB)	Transfer Period (Year)	Number and Proportion of Transfer Recipients Selection
Shimenshan	Dongzhuang South	21	18 (85.71%)	535.71	2.59	2 (72.22%), 3 (16.67%), 4 (16.67%)
	Linjiawa	27	13 (48.15%)	406	1.67	2 (75%), 3 (16.67%), 1 (16.67%)
	Hedong	26	15 (57.69%)	261.98	1.63	2 (58.33%), 1 (33.33%), 5 (8.33%),
	Dongzhuang North	25	16 (64.00%)	489.58	2.00	3 (50%), 2 (33.33%), 4 (16.67%)
Wucun	Zhangzhuang	33	16 (48.48%)	232.14	1.69	2 (81.81%), 1 (36.36%), 3 (9.09%)
	Wucun	27	14 (51.85%)	260.42	1.47	2 (81.81%), 1 (9.09%), 3 (9.09%)
	Zhongxin	28	12 (42.86%)	363.25	1.29	2 (57.14), 1 (28.57%), 3 (14.29%)
	Liuzhuang	26	9 (34.62%)	387.5	1.50	2 (66.67%), 1 (33.33%), 3 (16.67%)
Xizou	Jiangxiahou	32	11 (34.38%)	232	1.60	2 (57.14%), 1 (28.57%), 3 (14.29%)
	Bujiazhuang	31	12 (38.71%)	224	1.60	2 (33.33%), 1 (33.33%), 3 (33.33%)
	Beixiasong	32	10 (31.25%)	275	4.40	1 (60%), 2 (40%)
	Beiyuantuan	29	19 (65.52%)	595	1.20	2 (50%), 3 (30%), 1 (10%)

Note: Options for transfer recipients include: 1. relatives, 2. other individuals in the same village, 3. groups in the village, 4. individuals from other villages, 5. groups from other villages, 6. others. This question about selection transfer recipients was a multiple choice question, so the total proportions are not always equal to 100%. Numbers inside the parentheses represent the proportion.

The results reveal that there were similarities and differences between villages in terms of the numbers and proportions of farmers making land transfers, transfer price, transfer period, and selection of transfer recipients. Concretely, in terms of the numbers and proportion of farmers involved in land transfer, Dongzhuang South and Beiyuantuan villages had more farmers making land transfers, accounting for 85.71% and 65.52% respectively, while Liuzhuang, Jiangxiahou, Bujiazhuang, and Beixiasong villages had fewer farmers involved in land transfer, with less than 40% in each. In regard to transfer price, land transfer prices varied considerably between villages. In terms of average land transfer price, Beiyuantuan took the first spot, with RMB 595/*mu* (1 *mu* = 0.667 hectare), while Bujiazhuang came in last with RMB 224/*mu*, a gap of around RMB 370/*mu*. This implies a nonnormalized mechanism of land transfer price in the research areas, and arbitrary price setting. Beixiasong village had the longest average transfer period of 4.40 years, whereas Beiyuantuan had the shortest, 1.20 years. The average transfer periods of the remaining villages ranged from 1 to 3 years. With regard to transfer recipients, except for Dongzhuang South and Beixiasong, the remaining 10 villages comprised 81.81% of the total, with most of their farmers transferring their land to individuals in the same village. In addition, some farmers transferred their land to relatives and groups in the same village, but few transferred their land to individuals and groups in other villages, confirming that the recipients of farmers' land transfers were often acquaintances.

5.1.2. Impact of Geo-Networks on Farmers' Land Transfer Behavior

With the aid of the Probit model, we performed regression analysis of the number of farmers in the same village making land transfers (X1), the number of village cadres in the same village making land transfers (X2), farmers' family features (X3–X6), resource endowment (X7–X12), and cognitive features (X13–X17). Prior to regression analysis, these variables were tested for possible multicollinearity. Only if the variance inflation factor (VIF) value is less than 10 can it be considered that no multicollinearity exists between the variables. The test results confirmed that the explanatory variables all had a VIF of less than 10, thus satisfying the independence principle. The regression results are shown in Table 3.

Table 3. Summary of model fitting results.

Name of Variables	Coefficient	Exp(B)	Name of Variables	Coefficient	Exp(B)
X1	0.358 *** (5.15)	1.102	X9	−0.026 (−0.76)	2.984
X2	1.649 *** (3.33)	1.129	X10	−0.003 (−0.03)	1.098
X3	−0.015 * (−1.83)	1.497	X11	−0.090 (−0.92)	1.047
X4	−0.732 ** (−2.20)	1.110	X12	−0.141 (−1.55)	1.166
X5	−0.148 (−1.55)	1.418	X13	0.139 (1.64)	1.126
X6	0.050 (0.85)	1.189	X14	0.189 ** (1.89)	1.186
X7	0.594 *** (4.33)	2.800	X15	−0.140 (−1.19)	1.057
X8	−0.021 (−1.43)	2.696			

Note: ***, ** and * denote significance at 1%, 5% and 10% respectively. Numbers inside the parentheses represent the standard error, the same below.

- Geo-networks positively impact farmers' land transfer behavior

According to the regression results of the Probit model, the number of farmers making land transfer in the same village (X1) was positively significant at 1% with a coefficient of 0.358, showing increasing marginal effects. For each unit increase in the number of farmers in the same village making land transfers, farmers' land transfer behavior was 1.102 times its original value, demonstrating that the number of farmers making land transfer in the same village positively affected farmers' land transfer behavior. The reason for this is that farmers in the same village are in the same geo-networks that a farmer typically interacts with most frequently, and they are crucial in transmitting information about land transfer. Individual farmers may also imitate the land transfer behavior of other farmers in the same village, because these individuals, uncertain about their judgments, tend to follow the majority. Hence, the probability of farmers making land transfers increases as more land transfer occurs in the village, affirming the herd effect in farmers' land transfer behavior.

The number of village cadres in the same village making land transfers (X2) was positively significant at 1% with a coefficient of 1.649, presenting increasing marginal effects. For each unit increase in the number of village cadres making land transfers, farmers' land transfer behavior was 1.129 times its original value. This means that the number of village cadres making land transfers positively affected the land transfer behavior of farmers in the same village. This is because the village cadres are the organizers and leaders of the villagers in their respective villages, and they access more information about land transfer policies and information, hence taking the role of releasing and disseminating information. Village cadres are highly respected by farmers and provide them with support; their decisions often direct farmers' actions. The number of farmers in the same village making land transfers and the number of village cadres in the same village making land transfers, as two geo-network variables, positively influenced farmers' land transfer behavior. Hence, hypothesis H1 is verified.

- Impact of control variables on farmers' land transfer behavior

The age and gender of the householder, the area of arable land operated by farmers, and farmers' satisfaction with farmland infrastructure were all related to farmers' land transfer behavior. Specifically, the age of the householder (X3) was negatively significant at 10% with a coefficient of −0.015, showing decreasing marginal effects. This denotes that the younger the householder, the higher is the probability of land transfer. The gender of the householder (X4) was negatively significant at 5% with a coefficient of −0.502, showing decreasing marginal effects. This indicates that male householders are more likely than female individuals to transfer their land.

The arable land area (X7) was positively significant at 1%, with a coefficient of 0.541, and farmers' land transfer behavior was raised 2.603 times its original value for each unit increase in arable land area, showing increasing marginal effects. This may be attributed to the fact that increased cultivated land areas require a longer operating cycle, and more economic inputs lead to higher earnings. Farmers continue transferring land inward to enlarge their farming scale for financial gain, hence the probability of land inward transfer grows. Meanwhile, as the arable land area continues to enlarge, economic inputs are positively proportional to the risks facing cultivated land. In other words, the more economic inputs, the greater are the risks involved, hence the increased possibility of outward land transfer.

Farmers' satisfaction with farmland infrastructure (X14) is positively significant at 5%, with a coefficient of 0.189, suggesting increasing marginal effects. Increased satisfaction among farmers with farmland infrastructure was associated with greater probability of land transfer. This indicates that farmers' satisfaction with farmland infrastructure positively affects farmers' land transfer behavior. The better the farmland infrastructure, the more favorable it is for agricultural production. Farmers conducting land transfer tend to have better farmland infrastructure and thus earn more rent, and those who transfer land inward can benefit from upgraded farmland infrastructure, which will raise agricultural output and allow additional land transfer activities.

5.1.3. Verification of Herd Effect in Farmers' Land Transfer Behavior

Probit regression cannot effectively address the correlation effect and reflexivity when identifying the herd effect [18]. In order to overcome possible endogeneity in the Probit model, this study developed the IV-Probit model for regression analysis of the sample data and tested the validity of the instrumental variable of the area where farmers are located (IV) using weak instruments. The regression results are tabulated in Table 4. The first-stage F statistic of the IV-Probit was 11.43, greater than the empirical value of 10. The weak identification shows that the *p*-values of the Anderson–Rubin and Wald tests are positively significant at 5%, demonstrating that the instrumental variable selected in this paper was not a weak instrument. This proves that farmers' land transfer behavior imitates the behavior of those in the same group within a geo-network, and the herd effect exists. Hence, hypothesis H2 is verified.

Table 4. Herd effect in farmers' land transfer behavior: IV Results.

Variables	Number of Farmers' Land Transfers
The area where farmers are located (IV)	0.407 *** (3.26)
Farmers' family features	control
Resource endowment features	control
Farmers' cognitive features	control

Note: *** denotes positive significance at 1%.

5.1.4. Difference in Herd Effect between Agricultural Income Groups

In order to better examine the herd effect in farmers' land transfer behavior, this paper divides farmers into three groups according to their agricultural income, viz. low, middle, and high agricultural income groups. Regression analysis was carried out to investigate whether the impact of the number of farmers in the same village making land transfers on farmers' land transfer behavior differed between the three groups, and Table 5 summarizes the regression results.

Table 5. Results of model fitting for various agricultural income groups.

Name of Variables	Low Agricultural Income		Middle Agricultural Income		High Agricultural Income	
	Coefficient	Exp(B)	Coefficient	Exp(B)	Coefficient	Exp(B)
X1	0.30 *** (2.72)	1.176	0.52 *** (3.73)	1.323	0.32 ** (2.09)	1.266
Farmers' family features	Control	Control	Control	Control	Control	Control
Resource endowment features	Control	Control	Control	Control	Control	Control
Farmers' cognitive features	Control	Control	Control	Control	Control	Control

Note: *** and ** denote significance at 1% and 10% respectively.

According to the analysis, the number of farmers in the same village making land transfers was positively significant at 1% in low- and middle-income groups. The number of farmers in the same village making land transfers was significant at 5% in the high-income group. This indicates that the herd effect is more noticeable in the land transfer behavior of farmers in the low- and middle-income groups. The reason may be that farmers in low- and middle-income groups, in contrast to those in the high-income group, may have no other income sources except the land, so their likelihood of inward land transferring increases in order to raise agricultural earnings and facilitate cultivation and harvesting using large machinery. Furthermore, farmers in the low-income and middle-income may tend to transfer land outwards to others and work for an employer, hence earning much less from the land, and the likelihood of outward land transfer increases.

5.2. Discussion

5.2.1. Contribution of Research

This study suggests that farmers' family features, resource endowment, and cognitive features have a major influence on farmers' land transfer behavior, which corresponds with current research findings, especially regarding the impact on farmers' land transfer behavior of age and gender of the householder, arable land area, and farmers' satisfaction with farmland infrastructure [1,6,17,18,27].

However, among these existing studies few have focused on the impact of group psychology on farmers' land transfer behavior. The current research verifies that the herd effect does exert an influence on farmers' land transfer behavior. On the one hand, there are close social networks linked by geography in rural China. With the development of urbanization, large numbers of young people go to work in cities. Most of those who stay in rural areas are farmers with generally low levels of education. They face high costs in collecting, interpreting, and utilizing the land transfer policy information provided by the government. Therefore, in this suboptimal situation of information asymmetry, farmers tend to trust the behaviors of other farmers in the same geo-network, including relatives, friends, acquaintances, or village cadres, resulting in a herd effect. On the other hand, when it is not clear whether the land transfer behavior can bring benefits, farmers will imitate other farmers' decision-making behavior, and the process of referring to other farmers' decision-making information is bound to have an impact on farmers' own decision-making behavior. Thus, farmers follow others to make the same land transfer decisions, resulting in an obvious herd effect in the land transfer behavior. Hence, this study enriches the research focusing on the impact of group psychology on farmers' land transfer behavior, and offers a reference for applying the herd effect in research into farmers' land use behavior.

5.2.2. Limitation and Future Perspectives

This research concludes that there is a herd effect in farmers' land transfer behavior, and that the herd effect can encourage rural land transfer and support extensive land management. Farmers' experience of the land transfer process can be separated into three stages. Firstly, individual farmers incentivized by land transfer information develop their willingness to transfer land, referred to as land transfer willingness. Secondly, farmers transfer their land by utilizing the useful information accessed from other farmers, referred to as land transfer behavior. Finally, they set a rational land transfer price for transferring land based on the price information obtained from other farmers, referred to as the land transfer outcome. It remains unknown whether the herd effect is exerted during all these stages, and the function of the herd effect on the formatting of land transfer price has not been analyzed. Thus, further exploration is required to overcome the failings in this study's examination of how the herd effect impacts all stages of the land transfer process and its outcome.

6. Conclusions

According to the results, the number of farmers in the same village making land transfers and the number of village cadres in the same village making land transfers, reflecting the geo-network and indicating the herd effect, positively impact farmers' land transfer behavior. Farmers imitate the land transfer behavior of other farmers in the same geo-network, so a herd effect exists in farmers' land transfer behavior. Farmers' family features, resource endowment, and cognitive features are key factors influencing their land transfer behavior. Farmers' land transfer behavior is more significantly influenced in groups with low and middle agricultural income than in groups with high agricultural incomes.

In view of the above results, if land transfer information can be effectively disseminated among farmers within a geo-network, the possibility of their involvement in land transfer will rise prominently, and the information transfer function of the herd effect will promote land transfer. If individual farmers prefer to access information from other farmers in the same geo-network rather than consulting related land transfer policies when deciding whether to transfer their land, the demonstration function of the herd effect significantly affects their land transfer behaviors. This study provides the following policy suggestions:

1. During land transfer, attention should be paid to the positive role of the herd effect. Since a geo-network is positively associated with farmers' land transfer behavior, farmers and village cadres in the same village are conducive to spreading land transfer information. Therefore, the government should focus specifically on farmers' geo-networks when promoting land transfer, to give full play to the role of capable farmers, major farmers, and village cadres among the geo-networks, and guide farmers in carrying out land transfer to enable large-scale agricultural operation.
2. More efforts are required to develop platforms for land transfer information and to standardize related procedures. The study found that most recipients of land transfer are farmers in the same village, relatives or friends, and land transfers are made based on mutual trust, featuring problems such as imperfect pricing systems. Hence, when developing platforms for land transfer information, emphasis should be placed on standardizing the release of land transfer information, supervising the execution

of land transfer contracts, enhancing the protection of land transfer contracts, and promoting real-name registration for land transfer, with a view to improving land transfer services and management, and expanding the scale of land transfer.

3. Greater investment in construction of farmland infrastructure are needed to encourage land transfer among farmers. According to the study, farmers' satisfaction with farmland infrastructure plays a key role in their land transfer behavior. Excellent farmland infrastructure conditions are positive contributors to increased land transfer prices and favorable agricultural production conditions for farmers. Hence, further research is essential for raising investments in farmland infrastructure and upscaling land transfer.

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Article

How Does the Heterogeneity of Family Structure Affect the Area of Land Transferred Out in the Context of Rural Revitalization?—Experience from CHIP 2013

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Abstract: Using the sample data of rural households in China's income survey (CHIP 2013), this paper divides the family structure into elite and incomplete families and analyzes the impact of family structure's heterogeneity on land transferred out. The Tobit and Ordinary Least Squares (OLS) models are applied to achieve the study's objectives. The results show that the elite family has a significant positive impact on the paid land subcontract area, while the incomplete family is not significant. After further refining the elite families, it is found that the influence of the families with the political status of Party members (non-grassroots cadres) on the land transfer area is more significant, while the influence of the families with the status of grassroots cadres on the land transfer area is less significant. Then, the formation mechanism of the difference between these two is discussed, which may be explained by the heterogeneity of their endowment structure, functions, and livelihood attributes. After a series of robustness tests, the results still show that elite families significantly positively impact the area of land transferred out. Finally, based on the differences in land transfer areas and the consequences of different resource endowments, the corresponding countermeasures and suggestions are put forward from the aspects of strengthening grassroots governance, legal awareness, and establishing and improving the protection mechanism of vulnerable rural groups.

Keywords: family structure; heterogeneity; area of land transfer; Tobit model

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1. Introduction

A significant challenge to mankind in this era is food security [1,2]. A report from FSIN (2018) indicates that 51 countries globally (approximately 124 million people) are encountering the issue of food insecurity as of 2017 [3]. The United Nations Sustainable Development Goals' (SDGs) first and second concerns emphasize eradicating extreme levels of poverty through unrestricted access to sustainable food and nutrition for good health and well-being [4]. However, one needs agricultural land to produce food for sustainable development and ensure food security. Therefore, the relevance of accessing the determinants of land transfer, a booster of proper land use, has been a concern for scholars in agricultural economics and geography in developing nations such as China [5–8].

In the past few years, under the background of the reform of the rural property rights system, land transfer has developed fast in much countryside of China and has become an important factor activating rural lands of China and improving the revenue of peasants. This shows that China's rural land transfer institution has made phased achievements. According to the Ministry of Agriculture, by the end of 2016, the area of rural land transfer in China has achieved 471 million mu. The No.1 document of the Central Committee in 2019 emphasized: "improving the standardized management system of land transfer and developing various forms of moderate-scale agricultural operations". Predictably, with the in-depth promotion of the rural revitalization strategy and the acceleration of the pace of national agricultural modernization, the status of land fragmentation management can no longer meet the development needs of scalable, modern, and intelligent agriculture. Undoubtedly, the scale of land transfer will expand continually in the future. In the context of the continuous introduction of various favorable policies for benefiting peasants at the central and local levels, more and more peasants have realized the value of the land.

On the one hand, wealthy families can reach scalable management by land transfer and benefit from land appreciation. On the other hand, rural families with relatively low human capital can transfer their free land to obtain some rent. Thus, what impact will the heterogeneity of family structure have on land transfer? Based on the view of supply and demand of land transfer, some scholars found that land transfer may result in widening income disparities within rural areas [9–11]. Some scholars have specifically analyzed the influence of political capital on the willingness of rural land transformation and found that village cadres have more power advantages in the process of rural land transfer [12,13]. Land transferred out is the front-end link of land transfer; the discussion of all related issues, including the "elite capture" of land transfer, inevitably needs to be placed in the land transferred out link; however, the impact of family structure heterogeneity on the area of land transferred out as the front end of land transfer is one of the more core issues. This paper focuses on the following two research questions. First, in the process of rural land transfer, are elite families more likely to transfer out of the land compared to non-elite families? Will it further aggravate the "Matthew effect" between the rich and the poor in rural areas? Second, within the rural elite families, is there heterogeneity between party members and grassroots cadres that then affect the area of land transfer? Undoubtedly, in the context of rural revitalization, with the combination of various types of capital and the land, research on the effect of family structure heterogeneity on land transfer area and the conclusions are conducive to better grasping the front-end of land transfer, maintaining the stability of the order of land transfer, helping local governments to resolve various contradictions and disputes caused by land transfer, maintaining local harmony and stability, and, thus, maintaining the economic and social achievements of building a well-off society in an all-round way.

2. Literature Review

In domestic and foreign scholars' studies on land transfer, the relevant influencing factors are mainly investigated in three sequential dimensions: before-during-after. Regarding the "before land transfer" scenario, the studies mainly focus on the impact of individual endowment differences of farmers or households in different regions on willingness to transfer land or the area of the transfer or transfer out deadline. Regarding the "during land transfer" scenario, the studies mainly focus on the consideration of the transaction method or the form of land transfer. Regarding the "after land transfer" scenario, the studies mainly focus on the impact of land transfers on the changes in the welfare of the transferee.

Many scholars have conducted relevant research on the impact of family, regional, and individual endowment differences on land transfer willingness, decision-making, or transfer area. In terms of family endowment differences, the employment situation of family members is one of the important factors affecting the willingness to transfer land in rural areas. Research shows that if a family member can obtain a stable non-agricultural job in urban areas, it will promote the decision-making of family land transfer, and the member will have the greatest power in decision-making [14–17]. Further, the stronger the willingness of farmers to seek non-agricultural jobs in cities, the more inclined they are to long-term land transfer [18]. At the same time, the family income structure also has an impact on land transfer. The higher the proportion of migrant workers' labor income in the total household income, the more likely farmers are to choose land transfer or abandonment [19]. From the perspective of regional differences, scholars used a panel dataset of 171 Chinese cities that developed high-speed rail infrastructure from 2005 to 2012 and applied the SEM model to find that the expansion of the high-speed rail network had a significant impact on the circulation of agricultural land, and the impact of high-speed rail on the circulation of agricultural land in the western region is five times that in the eastern region [20]. Specific to the differences in various rural location factors, the study found that rural site resources have a significant impact on the circulation of agricultural land. Communities with good infrastructure, that are close to towns, with sufficient labor force, and with high economic input and output do not rely on agricultural land, but natural conditions and well-connected communities rely more on agriculture [21]. From the perspective of individual endowment differences among farmers, the level of financial knowledge possessed by farmers obviously affects land circulation, and financial literacy has a greater impact on land inflow than outflow [22]. Based on the survey data of 8031 households with 27 identities in China in 2014, scholars found that the experience of famine in the early years impacted land circulation [23]. In addition, the older the household head is, the stronger the attachment to the land, and the less likely the household head is to transfer land [24]. In addition, the conclusions of academic research are relatively consistent where the degree of risk perception and attitude, the land property rights system, and the degree of awareness of land policy also significantly affect farmers' willingness to transfer land [25–27].

Secondly, with consideration of the form of land transformation transaction or land transferred out, some scholars have found that land cooperatives promote farmers' land transfer [28]. Meanwhile, some scholars found that when comparing the land stock co-operation mode with rural cooperatives as the main body, against the land leaseback and re-contract mode with "village collective + planting leading firm" as the primary management body, the improvement of farmers' livelihood capital was more evident [29].

Finally, in terms of the impact on the welfare of land transferees after transferring, one study found that the welfare effect of the transferred-out farmers was higher than that of the transferred-in farmers [30]. In contrast, one research shows that the subjective welfare of farmers who transfer farmland will not increase. Further analysis shows that the subjective welfare of farmers who trade with acquaintances is higher than that of farmers who trade with non-acquaintances [31].

In summary, most previous studies have focused on the factors influencing willingness in each link before-during-after land transfer, the transaction transfer mode, and the subsequent net welfare value; especially, the literature focusing on farmers' willingness to transfer their land based on their endowment characteristics is fruitful and has formed a useful reference for subsequent studies. However, there is limited literature on the effect of heterogeneity of endowments on the area of land transferred out based on different household structures, and this is where this paper is expected to make a marginal contribution.

3. Materials and Methods

3.1. Research Hypothesis

Traditionally, family structures mainly include nuclear, joint, main, single-parent, and broken families, and different family structures have prominent heterogeneity in resource endowment. Different household structures related to different household life cycles and different household life cycles influence the relevant decision of the family, such as entrepreneurship, land transfer, land scale operation, household consumption, and labor supply [32–35]. Further, households are divided into elite households and handicapped households, and ordinary households. Generally, elite households are relatively rich in various resources. They tend to have more advantages in household decision-making. Still, they then may capture some national policy dividends and then become "elite capture," and "elite capture" exists mainly in resource allocation and precise poverty alleviation in rural areas of China [36–38]. For other households, especially broken families, the existence of "elite capture" may lead to a more serious policy deviation. Based on the above principles, this paper focuses on whether the heterogeneity of family structure affects land transfer area from the actual land transfer area. Moreover, this paper divides rural households into elite, broken, ordinary households based on existing studies, and focuses on the different influences of elite family and broken family on land transfer, and then explores whether there is a "crowding out effect" in China due to the heterogeneity of family structure in the size of the land transferred out. Based on relevant studies, this paper proposes the following hypotheses.

Hypothesis 1. *Elite households have an advantage in land transfer and are more likely to transfer land.*

In this paper, the rural elite households are defined as political elite households, divided into households with party members and households with grassroots cadres. There is little literature on the effect of the two households on the difference in their land transfer area. The existing studies generally generalize the two households as political capital. However, in real life, for party members and grassroots cadres in rural areas, there are indeed some differences between them. Party members (non-grassroots cadres) in rural areas are mostly engaged in non-agricultural work and have a looser attachment to the land, so they are able to grasp the policy dividend of land transfer and are more likely to transfer their family land for rent. For grassroots cadres, their main workplaces are in rural areas, and they are more or less engaged in agriculture-related work and more closely connected with the land. Based on the status, hypotheses 2 and 3 are proposed as follows.

Hypothesis 2. *Party households have an advantage in land transfer and may transfer a larger land area.*

Hypothesis 3. *The advantage of grassroots cadres' families in land transfer is not obvious, and they are more closely connected with the land, which has no significant effect on land transfer area.*

3.2. Data Resource

This paper uses data from the 2014 survey of the China Household Income Project (CHIP). In July and August 2014, the China family income project (CHIP) conducted the fifth survey. As the main information collected in the survey is related to the income and expenditure in 2013, it is named CHIP 2013, which is consistent with the previous four surveys. This survey is supported by the National Natural Science Foundation of China and the National Bureau of Statistics (NBS) and organized by the China Income Distribution Institute of Beijing Normal University. The survey was conducted by the National Bureau of statistics. The CHIP 2013 sample is from the annual integrated household survey conducted by the National Bureau of statistics in 2013, which includes 160,000 households in 31 provinces. These samples were screened in the eastern, central, and western regions by a systematic sampling method, involving 15 provinces, 126 cities, 234 counties, 18,948 households, 64,777 people, 7175 urban households, 11,013 rural households, and 760 peasant households. CHIP is considered as one of the best public data sources on household income and expenditure in China [39].

All in all, CHIP 2013 is a nationally representative rural household registration survey data sample, and the data are the latest data source of the database. In addition, in the past three years, studies have shown that under the background of China's vigorous implementation of targeted Poverty Alleviation Policies, the phenomenon of "political elites being captured" still exists in rural areas [40]. Therefore, it can be reasonably speculated that most of the rural areas in China have the national conditions of "elite capture". Therefore, the data of CHIP 2013 used in this paper are timely and representative, and also conform to the current situation of rural areas in China.

3.3. Variable Description

3.3.1. Dependent Variable

The dependent variable in this paper is the area of land subcontracted to individuals for a fee. Land transfer is divided into transfer-in and transfer-out, and the CHIP2013 data also mention both transfer-out and take-over in the section of management rights flow. For inward contracting, only the total area of inward contracting and the average price per mu of inward contracting were asked, while for outward contracting, the area, price, and destination of outward contracting were asked in detail. The destination of subcontracted land was asked separately for the area of land subcontracted to individuals with compensation, the area of land subcontracted to individuals without compensation, the area of land subcontracted to enterprises or large agricultural households, and the area subcontracted to village collectives with or without compensation. In conjunction with the research theme, this paper focuses on the effect of household structure on the area of land subcontracted to individuals with compensation. There are two main reasons for this: first, most of the subcontracting without compensation belongs to the subcontracting between neighbors and relatives, and there are fewer interests; secondly, the subcontracting to enterprises or large agricultural households and village collectives is not an individual and family decision, but more of an overall regional planning, and the subcontracting area and price are roughly the same as the situation in the region, so the influence of family structure is not obvious. Based on this, the dependent variable of this paper is the area of land subcontracted to individuals for a fee.

3.3.2. Independent Variable

The independent variable in this paper is family structure. According to different family labor and political capital, this paper classifies family structure into elite and incomplete families. Some scholars define the elite as the household with family members who are local village cadres or the household with relatives who are local village cadres [41]. While elite families mean that they have more abundant social capital in the local area, this definition is not comprehensive. Based on this, this paper defines households with party members or cadres as elite households. Except for ordinary households, elite households correspond to broken households or a disintegration of social structure family. In general, behaviors tend to change family structures and gradually begin to disintegrate into incomplete families, such as having a family member with chronic illness, divorce, incarceration, HIV infection, and disputes with neighbors [33]. Based on this, this paper defines households with an incomplete person, divorced householder, or poor health status of the householder as incomplete households. Thus, elite and incomplete households are dummy variables (elite households = 1; non-elite households = 0; incomplete households = 1; non-incomplete households = 0). In addition, the variables were also replaced by the degree of elite and the degree of disability for the analysis, with the degree of elite and the degree of disability being continuous variables.

3.3.3. Control Variable

In addition to household structure, other variables of individual characteristics and household characteristics also affect land transfer. Variables of individual characteristics include gender, age, education, ethnicity, and health status of the householder, while variables of household characteristics include the logarithm of household income, household land area, labor ratio, and participation in professional cooperatives. Household characteristics also affect land transfer. Variables of individual characteristics include gender, age, education, and ethnicity.

Table 1 shows the mean statistics of the variables used in this paper. Column (1) is the mean statistics of the full sample; column (2) is the mean statistics of the variables related to the elite household; column (3) is the mean statistics of the variables related to non-elite households. In the full sample, the mean of the area of land subcontracted to farmers for compensation is 0.563 mu, while for elite households, the mean of the area of land subcontracted to farmers for compensation is 0.762 mu. Compared with 0.523 mu of non-elite households, it is 0.239 Mu higher. The descriptive results also show that the percentage of elite households in the total sample is 16.6% and the percentage of incomplete households is 8.2%. The mean of other variables can be accessed from Table 1 and is not repeated here.

Table 1. Descriptive statistics of variables.

Variables	Variables Description	Total Sample (1)		Elite Family (2)		Non-Elite Family (3)	
		Obs	Mean	Obs	Mean	Obs	Mean
Land Out	Land area subcontracted to individuals for compensation.	3834	0.563	636	0.762	3198	0.523
FM_str1	Dummy variable, Surrogate indicators for elite families (elite households = 1; non-elite households = 0).	3834	0.166	636	-	3198	-
FM_str0	Dummy variable, Surrogate indicators for incomplete families (incomplete households = 1; non-incomplete households = 0)	3834	0.082	636	0.099	3198	0.079
Party	Does the family have party members (1 = yes, 0 = no)	3828	0.106	636	0.637	3192	0.001
Cadre	Does the family have village cadres (1 = yes, 0 = no)	3817	0.044	636	0.264	3181	0.000
Gender	Gender of the sampled group (1 = Male, 0 = Female)	3834	0.907	636	0.890	3198	0.910
Age	Age of the householder	3834	53.402	636	55.115	3198	53.061
Marriage	Is the householder married (1 = yes, 0 = no)	3834	0.987	636	0.998	3198	0.985
Education	Education years of the householder	3763	7.248	629	8.039	3134	7.090
Ethnicity	Is the householder Han nationality (yes = 1, no = 0)	3834	0.930	636	0.925	3198	0.932
Health_condition	Health status of the householder (1 = excellent, 2 = good, 3 = general, 4 = bad, 5 = Incapacity to work)	3828	3.845	632	3.943	3196	3.826
Ln_income	Logarithm of total household income	3798	10.412	632	10.577	3166	10.379
Ratiolabor	Labor force (Family members aged 16 to 60)/Total number of families	3834	0.580	636	0.581	3198	0.580
Pension_insurance	Whether to participate in pension insurance (1 = yes, 0 = no)	3829	0.874	636	0.912	3193	0.867

3.3.4. Model Building

The subject of this paper is the effect of family structure heterogeneity on land transfer area to investigate whether elite households differ from incomplete households in land transfer. With the help of existing studies, family structure is set as the main explanatory variable, land transfer area as the explained variable, and individual characteristics and household characteristics as control variables. According to the research hypotheses, the following models are set-up in this paper.

$$\text{Land outi} = \alpha + \beta 1\text{FM\_st1} + \gamma i\chi i + \varepsilon i \quad (1)$$

$$\text{Land outi} = \alpha + \beta 1\text{FM\_st0} + \gamma i\chi i + \varepsilon i \quad (2)$$

$$\text{Land outi} = \alpha + \beta 1\ \text{FM\_st1} + \beta 2\text{FM\_st0} + \gamma i\chi i + \varepsilon i \quad (3)$$

The above-explained model variables are all land area subcontracted to individuals for a fee, and the main explanatory variable in model (1) is elite households; the main explanatory variable in model (2) is incomplete households; model (3) is a full-variance model, and, at the same time, the two variables of elite family and whether it is an incomplete family are added. Land out in models (1)–(3) means land area subcontracted to individuals for compensation. FM__strl in the above model is a proxy for elite households, FM_ str0 is a proxy for incomplete households, and χi are control variables. In the empirical analysis and robustness test sections, the independent variable measures are replaced in order to analyze the influence mechanism and test the robustness of the results.

4. Results and Discussion

4.1. Impact of Elite Households on the Area of Land Transferred Out

The explained variable in models (1)–(3) are all land areas subcontracted to individuals for a fee, and the values are continuous variables. In order to avoid the influence of outliers, the key continuous variables in this paper are all made to shrink the tails (Winsor2), and the dependent variables take most of the values of 0. Therefore, Tobit model regression is mainly used. In order to test the existence of multicollinearity, OLS regression was also attempted and all models had variance inflation factors (VIF) less than 2, so the existence of multicollinearity was excluded.

Table 2 shows the results of the hypothesis for elite households and the area of land transferred out, with the key explanatory variable in model (1) being "whether or not the household is elite", and does not control whether it is a disabled family. The key explanatory variable in model (2) is "whether or not the household is incomplete" and does not control for whether or not the household is elite; Model (3) contains "whether or not the household is elite" and "whether or not the household is incomplete". Model (3) contains two dummy variables, "whether elite" and "whether incomplete".

Table 2. Benchmark regression results.

Variables	(1)	(2)	(3)
FM_str1	0.242 ***		0.240 ***
	(0.064)		(0.064)
FM_str0		0.068	0.052
		(0.090)	(0.090)
Gender	−0.011	−0.027	−0.013
	(0.082)	(0.083)	(0.082)
Age	−0.004	−0.002	−0.004
	(0.002)	(0.002)	(0.002)
Marriage	−0.156	−0.145	−0.155
	(0.215)	(0.216)	(0.215)
Education	−0.002	0.004	−0.002
	(0.010)	(0.010)	(0.010)
Ethnicity	0.050	0.038	0.051
	(0.092)	(0.093)	(0.092)
Health_condition	−0.061 **	−0.052 *	−0.057 **
	(0.027)	(0.028)	(0.028)
Ln_income	0.005	0.018	0.006
	(0.033)	(0.033)	(0.033)
Ratiolabor	−0.108	−0.104	−0.103
	(0.079)	(0.079)	(0.079)
Pension_insurance	0.083	0.094	0.082
	(0.070)	(0.070)	(0.070)
Constant	1.023 **	0.772 *	0.986 **
	(0.425)	(0.427)	(0.430)
Observations	3720	3720	3720
Pseudo R^2	0.00129	0.00129	0.00129

Note: Robust standard errors in parentheses. *** represents $p < 0.01$; ** represents $p < 0.05$; * represents $p < 0.1$.

From model (1) in Table 2, we can see that the coefficient corresponding to whether it is an elite household is 0.242 and is significant at the 1% level, which statistically indicates that elite households significantly increase the area of land subcontracted to individuals for a fee. In contrast to model (2), replacing the variable of elite households with incomplete households changes the coefficient to 0.068 and the coefficient is no longer significant, indicating that incomplete households do not have a significant effect on increasing the area of land subcontracted to individuals for compensation. The sample in model (1) may be both elite and incomplete households (for example, a household with a party member and an incomplete person), but not controlling for incomplete households leads to some bias in the results obtained. Hence, model (3) further controls for incomplete households based on model (1), and the results are basically consistent with model (1), with a coefficient of 0.240 for elite households and significant at the 1% level. From the results of models (1)–(3) in Table 2, it can be verified that elite households contribute significantly in the area of land subcontracted to individuals for a fee, and research hypothesis 1 is verified. This result indicates that the less privileged households are mostly at a disadvantage in terms of area of land subcontracted to individuals for compensation as these elite households may use your power to influence the land rental market. This gives a clear indication that China's agenda to eradicate poverty through rural revitalization should be strengthened in favor of less privileged households to make them self-sufficient to partake in the land rental market.

4.2. Mechanism Inquiry

Table 2 presents the effect of elite households on the area of land subcontracted for a fee but does not explore the inner influence mechanism. As mentioned earlier, this paper defines elite households as households with party members or village cadres in the household, which are dummy variables in the baseline regression. Exploring the influence mechanism of elite households on land transfer can be further divided into elite households, and groups with party members in the household, village cadres in the household, and households with a college education or above are included in different regression models to observe their influence on the area of land transferred out. Table 3 shows the estimation results after dividing the independent variables; the main explanatory variable of model (1) is whether the household has party members, the main explanatory variable of model (2) is whether the household has village cadres, the main explanatory variable of model (3) is whether the household has members with a college education or above, and the Tobit model is still used for estimation because the dependent variable 0 takes more values. The results are shown in Table 3.

Model (1) shows that households with party members will significantly increase the area of land subcontracted for compensation, while model (2) shows that households with village cadres do not affect the land transfer area significantly. Model (3) controls for the variable "whether the household has village cadres" based on model (1), the results still show that households with party membership significantly increase the area of land transfer, and research hypothesis 2 is verified. Party members and village cadres with political status indicate that their households are in the elite class of rural society, which may lead to the problem of monopoly in the price of "land transfer" compared with incomplete households or even ordinary households. In the context of rural revitalization in China, the willingness of grassroots cadres to transfer land has increased significantly, but will the area of land transferred also increase significantly in reality? The result of this paper is "no", so research hypothesis 3 is verified, which indicates that there are certain differences between party members and village cadres when they are faced with the decision of subcontracting land to individuals for a fee. The mechanism may be like this. Party members are mostly part-time farmers and have more social capital and relationships in certain regions. Their main business is mostly not related to agriculture, so they have a stronger willingness to transfer land because of the relatively strong social capital. It is helpful for them to gain an advantageous position in land transferring negotiation, thus forming a "seller's market" pattern of land transfer, and then further improve their willingness of expanding the land transfer area. For grass cadres, they are rooted in rural areas, forming a close interest linkage mechanism with rural production and management activities and grassroots governance. On the one hand, they are conscientiously engaged in grassroots governance; on the other hand, most of their work is also related to agriculture, and they are more closely connected with land resources and have more emotion with land and form a hard constraint, coupled with the heavy section of rural grassroots affairs embedded layer by layer, resulting in them, compared to party members (non-grassroots cadres), paying more attention to the social security function and the "livelihood support" function of land, so they are unwilling and dare not easily transfer their land on a large scale. As grassroots cadres, they naturally hope to realize scalable land transfer for better local development, but this may be only their good intention but not their ultimate practical action due to their identity, job responsibilities, and personal characteristics.

Table 3. Mechanism analysis.

Variables	(1)	(2)	(3)
Party	0.251 ***		0.274 ***
	(0.077)		(0.084)
Cadre		0.092	−0.070
		(0.114)	(0.124)
Gender	−0.027	−0.026	−0.026
	(0.082)	(0.083)	(0.082)
Age	−0.004	−0.002	−0.004
	(0.002)	(0.002)	(0.002)
Marriage	−0.155	−0.148	−0.159
	(0.215)	(0.216)	(0.215)
Education	−0.002	0.003	−0.003
	(0.010)	(0.010)	(0.010)
Ethnicity	0.042	0.035	0.042
	(0.092)	(0.093)	(0.092)
Health_condition	−0.061 **	−0.056 **	−0.060 **
	(0.027)	(0.027)	(0.027)
Ln_income	0.011	0.018	0.015
	(0.033)	(0.033)	(0.033)
Ratiolabor	−0.107	−0.107	−0.100
	(0.079)	(0.079)	(0.079)
Pension_insurance	0.083	0.092	0.083
	(0.070)	(0.070)	(0.070)
Constant	0.990 **	0.811 *	0.940 **
	(0.425)	(0.425)	(0.427)
Observations	3717	3707	3705
Pseudo R^2	0.00156	0.00156	0.00156

Note: Robust standard errors in parentheses. *** represents $p < 0.01$; ** represents $p < 0.05$; * represents $p < 0.1$. In this part of the regression, in order to obtain the net effect of party members and village cadres on the dependent variable, models (1) and (2) were repeated. In the repeated model (1), the samples whose family members had village cadres were excluded. Model (2) excludes the regression of samples whose family members have party members, and the results are consistent with the above table. Due to space reasons, it is not reported.

4.3. Robustness Test

Benchmark regression shows that elite households will significantly increase the area of land subcontracted to individuals for a fee. To demonstrate that the results of this paper are robust, a series of robustness tests are conducted below, including replacing the measures, transforming the estimation model, and changing the estimation sample.

4.3.1. Replacement of Measurement Index

In the baseline regression section, the explanatory variables are dummy variables, and households with party members, cadres, or university and higher education in the household are defined as elite households (FM_str1). In the robustness test section, the explanatory variables are replaced with continuous variables, and elite households (FM_str1) are replaced with elite degree (Elite). Similarly, the incomplete family (FM_str0) is replaced by the incomplete degree (Incomplete). The obtained results are shown in Table 4 below. In Table 4, model (3) is the full variables result, model (1) is the result without the variable of degree of incomplete relative to model (3), and model (2) is the result without the variable of degree of elite relative to model (3). Other control variables were added to all models in Table 4, and the control variable results are generally consistent with the baseline regressions; therefore, the results are not reported. In Table 4 below, the coefficient corresponding to the degree of elite remains significant at the 1% level, indicating that as a household's degree of elite increases, it significantly increases the area of land subcontracted to individuals by that household for compensation, which is consistent with the research hypothesis and the results of baseline regression in this paper, including that the findings are relatively robust.

Table 4. Substitute explanatory variable metrics results.

Variables	(1)	(2)	(3)
Elite	0.103 ***		0.102 ***
	(0.039)		(0.039)
Incomplete		0.039	0.032
		(0.060)	(0.060)
Control var	Y	Y	Y
Constant	0.969 **	0.778 *	0.934 **
Constant	(0.426)	(0.427)	(0.431)
Observations	3720	3720	3720
Pseudo R^2	0.00129	0.00129	0.00129

Note: Robust standard errors in parentheses. *** represents $p < 0.01$; ** represents $p < 0.05$; * represents $p < 0.1$.

4.3.2. Transformation Estimation Method

In the above, Tobit models were used for estimation in all cases due to the presence of broken tails. However, for a continuous variable such as the area of land transferred out, the least squares (OLS) method is also used as a succinct method. In order to investigate whether the estimation results of this paper may change depending on the estimation method, the stability of the results of this paper is analyzed using different estimation methods. Table 5 shows the results of least squares estimation, and the coefficients and significance of the results are completely consistent with Table 2, indicating that the results estimated in this paper do not change, due to the change in estimation methods, and the results are robust and reliable. In addition, to explore whether there is multicollinearity, the posterior multicollinearity inflation factors (VIF) of the estimated results of models (1)–(3) are all between 1.01 and 1.39, so there is no multicollinearity.

Table 5. Transform Estimation Method Results.

Variables	(1)	(2)	(3)
FM_str1	0.242 ***		0.240 ***
	(0.064)		(0.064)
FM_str0		0.068	0.052
		(0.090)	(0.090)
Control var	Y	Y	Y
Constant	1.023 **	0.772 *	0.986 **
	(0.426)	(0.427)	(0.431)
Observations	3720	3720	3720
R^2	0.006	0.003	0.007

Note: In parentheses are the robust standard errors; *** represents $p < 0.01$; ** represents $p < 0.05$; * represents $p < 0.1$.

4.3.3. Changing the Estimation Sample

Although the baseline regression and model (3) in the robustness test section control for the variable "whether or not the household is incomplete", this is not as intuitive as directly using the sample with incomplete households excluded. For this reason, the samples used in the next regressions in this paper are directly excluded from the sample of incomplete households and analyzed using the Tobit model used in the baseline regression. The results in Table 6 show that the coefficient corresponding to elite households is 0.224, which is significant at the 1% level, and its results are basically consistent with the baseline regression, once again proving that the regression results in this paper are robust and reliable, and will not change due to the sample transformation.

Table 6. Transform Estimation Sample Results.

Variables	(1)	(2)
FM_str1	0.224 ***	
	(0.067)	
FM_str0		0.021
		(0.097)
Control var	Y	Y
Constant	0.939 **	0.919 **
	(0.447)	(0.444)
Observations	3414	3097
Pseudo R^2	0.000978	0.000978

Note: In parentheses are the robust standard errors; *** represents $p < 0.01$; ** represents $p < 0.05$.

Based on different ways of robustness testing, the result of this paper is stable. Elite households significantly increase paid subcontracted land area.

5. Conclusions

5.1. Simple Conclusions

Whiles many are abandoning farmland for non-farm activities, many nations such as China are putting down strategies to ensure sustainable agricultural development, hence projecting a land transfer agenda. To help policymakers in their decision, this paper empirically analyzes the effect of family structure heterogeneity on the area of land transferred out in the current land transfer process in China, using Tobit regression, OLS regression, and a series of robustness tests, based on the conceptual definition and categorization of family structure, with data from the China Household Income Survey (CHIP)2013. Further, this paper discusses the effect of intra-elite household differentiation on land transfer area by subdividing elite rural households into those with party member status (non-grassroots cadres) and those with grassroots cadre status and finds that households with party member status have a significantly more individual land area in paid subcontracting, while households with grassroots cadre status do not have a significant effect on land transfer area. The possible explanation is that many party members (non-grassroots cadres) are part-time farmers who enjoy more social capital and more social relationships in a certain area and are more engaged in non-farm work, so they are more willing to transfer their contracted land. In addition, because of their relatively strong social capital, they have an advantageous position in the negotiation of land transfer prices and form a "seller's market" pattern of land transfer, and then want to expand the area of land transfer strongly. Meanwhile, grassroots cadres are more tied to the land and their reliance on the land is more obvious due to the social security and livelihood, and they are reluctant to easily transfer the extra land compared to the families with party membership.

5.2. Policy Implications

The above findings suggest that in the context of rural revitalization, as the frequency and intensity of land transfer activities increase, it is more important to pay attention to the crowding out effect of elite households on non-elite households, especially on incomplete households.

In particular, it is necessary to pay attention to the possible price monopoly advantage of households with party member status (non-grassroots cadres) in the seller market pattern of land transfer and to prevent the price negotiation advantage that they may form due to the large area of land transfer and their endowment advantages, which may lead to the problem of "elite capture" of land transfer. The existence of excessive rents may disrupt the normal order of land transfer in the region and may also lead to "mistakes" in the implementation of policies in specific regions, further forming the "Matthew effect" of polarization between elite and non-elite rural households. Therefore, the land rental market may need vivid attention in order to achieve the nation's zero hunger and rural development or revitalization goals through land use intensification.

5.3. Recommendations

In the process of land transfer, the principles of the market economy and legal system should be upheld, and the bargaining power of both supply and demand sides should be fully respected. In accordance with the law of supply and demand in the land transfer market, the unlawful act of coaxing up land rents should be severely cracked down, the blocking behavior of elite families to non-elite families in various disguises of normal land transferred out should be severely cracked down, and the collusion between elite families and land transfer subjects should be prevented from low prices or undercutting of land transfer rents of non-elite families.

The relevant departments should vigorously publicize the newly revised "Rural Land Contract Law" and the newly revised "Measures for the Management of Rural Land Management Rights Transfer" through various flexible ways for the rural grassroots. On the one hand, the relevant departments need to fully respect the principle of "voluntary, paid and legal" land transfer, and let farmers know the basic meaning of the relevant laws through familiar ways and how to defend their legitimate rights and interests by legal means. On the other hand, it is also necessary to establish a fair and reasonable price negotiation mechanism between the transferor party and the transferee party within the legal framework to ensure that both elite and non-elite farm families have the right to enjoy equal opportunities for land transfer and reasonable price transactions.

First, the relevant departments should establish a modern agricultural technology training system for the disadvantaged groups in rural areas so that they can transform into "new professional farmers", who are educated, who know technology, who are good at management, and who realize the organic connection between small farmers and modern agriculture, and learn to use laws and regulations and other means to protect their rights and interests. Secondly, we should improve the educational endowment structure of disadvantaged rural families, and pay attention to the education status of the "second generation of farmers" and "third generation of farmers". In the new era, we will expand the multi-dimensional space of "knowledge changes destiny".

The study has some limitations as well. First, we only focused on family structures and how they impact China's land transfer system. However, other factors may be associated with land transfer conditions. Future studies can consider other factors and their impact on the outcome variable. Secondly, the study is narrowed or focused on China, and its results leave much to be desired; however, we believe that the discussed topic could be examined on the example of several countries. Therefore, we encourage forthcoming studies to carry on a cross-country analysis to see if they may have different or similar conclusions.

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Article

Analysis of the Difference in Changes to Farmers' Livelihood Capital under Different Land Transfer Modes—A Case Study of Manas County, Xinjiang, China

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Abstract: Farmers' livelihoods alter as a direct result of land transfer. This study examined the impacts of land transfer on several indicators of farmers' livelihood capital, as well as variations in the effects of different land transfer methods on farmers' capital, in an effort more effectively to enhance farmers' livelihoods. To compare the changes in farmers' livelihood capital under four different modes—the farmers' spontaneous model, centralized and continuous, joint-stock cooperative, and leaseback and re-contracting—this study calculated farmers' livelihood capital index based on 600 questionnaires in accordance with the sustainable livelihood capital framework. The study's findings indicate the following outcomes: (1) Farmers' livelihood capital is significantly impacted favorably by land transfers. (2) Different types of farmers experienced different changes in their livelihood capital after land transfer: purely agricultural farmers' livelihood capital value increased by 0.138, primarily due to an increase in physical capital; agricultural part-time farmers' livelihood capital value increased by 0.105; non-agricultural part-time farmers' livelihood capital value increased by 0.081; and non-agricultural farmers' livelihood capital value increased by 0.081. (3) The most efficient strategy to increase livelihood capital was to use the leaseback and recontracting model with "village collective + planting leadership company" as the primary business organization. The results provide practical guidance for land transfer in Manas County, and valuable suggestions for improving farmers' livelihoods in arid areas.

Keywords: different modes; land transfer; livelihood capital; difference-in-differences model

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1. Introduction

Rural areas currently have inadequate land income, low land use efficiency, and some farmers have even left their farms [1–3]. As a result, appropriate and organized use of land has become crucial [4,5]. The transfer of land use rights is referred to as a land transfer. Improved land use efficiency and higher land revenue are the goals of legally transferring a farmer's land to other farmers or commercial groups while keeping contracting and usage rights. Land transfer is an efficient way to support rural economic development and raise farmers' living standards, since it may effectively reduce land abandonment, encourage agricultural scale operations, and boost farmers' revenue [6–8]. Land transfer has drawn a great deal of attention from academics both domestically and internationally due to the rapid expansion of the social economy, which has caused a huge number of farmers in developing nations to move to cities and a corresponding increase in the act of land transfer [9,10]. Because in many other nations outside China land is typically exchanged directly on the land market and is privately held, research on land transfer by foreign academics has tended to concentrate on land transactions, land rent, price, and the land market system [11,12]. For instance, Wineman et al. [9] contend that various effects on land allocation may result from different land market transactions. According to Weldesilassie Alebel B and colleagues, effective land management is a crucial component of rapid urbanization. Kibrom et al. [13] examined how land markets responded to changes in land scarcity in terms of re-rental market participation rates, pricing, and contractual structures, using nationally representative household survey data from Ethiopia, Malawi, and Tanzania. In China, ownership, contractual rights, and management rights are segregated into separate categories, under the notion of "separation of the three rights" [14]. Land transfers in China started to happen in the 1980s. The three main models are the lease model, which is exemplified by the Xiaogang area in Anhui [15], the exchange model exemplified by the Jiangjin area in Chongqing [16] and Shawan County in Xinjiang [17], and the transfer of contractual land rights through subcontracting and transferring to other farmers within a set time frame. Although academics have conducted several studies in this field, most of these have focused on a particular land transfer model [18–20], and very few have compared the variations among them.

Farmers are the primary beneficiaries of land transfers. These transfers will directly affect farmers' livelihoods, and studies on land transfers must take this into account. The land, assets, capabilities, and household income of farmers are collectively referred to as livelihood capital, within the sustainable livelihoods framework proposed by the UK Department for International Development (DFID) [21], and are further divided into natural capital, financial capital, social capital, and human capital [22]. Natural capital is the land that farmers own; financial capital is the money they have or can access; social capital refers to the social resources to which they have access; physical capital includes the tools, materials, equipment, and facilities they use for production and living; and human capital is the knowledge, education, and health status they rely on to make a living. Land transfer alters the amount of land that farmers own, by transferring land management rights. Some farmers may obtain more concentrated land, which may lower their production costs [23,24]. Other farmers may transfer their land to other work and have access to more social resources, which will diversify the sources of their income.

According to the available research, land transfer alters farmers' capital which affects their means of subsistence. Although there are several types of land transfer, few researchers have looked at variations in how various modalities affect farmers' capital for livelihood [25]. Most studies, particularly in arid and semi-arid regions, have paid less attention to the difficulties faced by farmers who sustain their livelihoods in less developed areas. Their economic growth is sluggish and resource-poor. There are significant disparities between dry and developed regions in the current state of farmers' livelihood capital [26,27]. However, the degree of agricultural growth in dry regions is low, and issues with dispersed farmers and fragmented land are significant [28]. The current study findings are intractable. Therefore, it is important to research how farmers in arid and semi-arid areas make a living. The leading agricultural production and animal husbandry area in western China is in the region of Xinjiang [29], which is a typical arid and semi-arid region. According to the third land survey, there are now 70.767 million hectares of cultivated land in Xinjiang. Within Xinjiang, Manas County is situated in the economic region of the Tianshan Mountains' northern side. The county has a strong base for agricultural growth and is predominantly agricultural [30,31]. In Manas County, a sizable number of land transfer methods have evolved as a result of the expansion of agricultural and rural regions [32]. The revenue of farmers has increased to some extent due to the variety of transfer channels. The productivity of most land in the area is still low, and farmers' livelihoods are precarious. Farmers that take part in land transfers may only manage to secure a temporary source of income, and be unable to establish a sustainable source of income [33,34]. At present, it is important to investigate how land transfers in Manas County affect farmers' livelihood capital, and to determine the best way to transfer land.

Therefore, the study region for this work was Manas County in Xinjiang, and the research subjects were 600 farmers who were chosen at random from eight villages and four towns in Manas County. First, the livelihood capital evaluation system was constructed to calculate the sampled farmers' livelihood capital. Second, the land management method was assessed to determine how Manas County organizes its land transfer. Next, analysis of the land transfer included various changes and differences to farmers' livelihood capital under various land transfer mechanisms, and finally further assessed the most appropriate land transfer mode in Manas County. The research concept, index system, and research findings of this study can serve as a reference for other arid and semi-arid regions, to improve the efficiency of rural land transfer and the livelihood of farmers in those regions. Although this study investigated only the Xinjiang region of China, the study area is representative of the typical arid and semi-arid regions to which it belongs.

2. Materials and Methods

2.1. Study Area Overview

The westernmost county in the Changji Hui Autonomous Prefecture is Manas County, which is part of the Xinjiang Uygur Autonomous Region and is situated in the Manas River Basin. Its location is between 43°21′21″ and 45°20′ N, and 85°40′ to 86°31′32″ east. See Figure 1 for details. Manas County's overall in 2021 was 1.102 million hectares, including 163,000 hectares of irrigated arable land, 13 townships, 81 administrative villages, 24,311 farmers, and 43,586 rural employees, while 34,669 rural jobs can be found in the countryside (28,718 agricultural workers). The principal industry in Manas County accounted for 475.202 million yuan of the county's 1534.769 million yuan GDP in 2021 [35]. Situated on the Tianshan Mountains' northern side, Manas County is a significant agricultural production area. By the end of 2020, Manas County has passed various types of transfer. The current rural land transfer area of Manas County exceeds 25,000 hectares, and the number of households participating in land transfer is 6827, with a transfer rate of 56%, showing great agricultural development potential and research value [36].

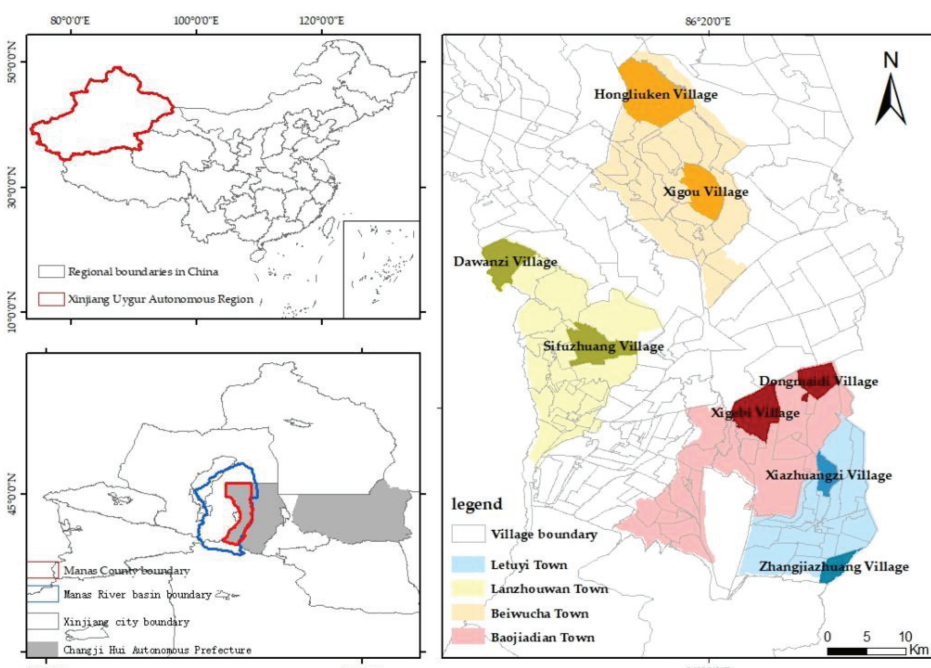

Figure 1. Location and overview map of the study area.

2.2. Data Source and Sample Characteristics

Socioeconomic statistics and survey data comprise the majority of this study's data. The questionnaire data originated from the visiting survey that the research group undertook in Manas County between June and September 2021. The social and economic statistics data were taken from the "Xinjiang Statistical Yearbook" and the "Manas County Statistical Yearbook data" (Table 1). This study selected Xiazhuangzi Village, Zhangjiazhuang Village, Dawanzi Village, Sifuzhuang Village, Hongliukeng Village, Xigou Village, Dongmaidi Village, and Xibibibi Village in Letuyi Town, Lanzhouwan Town, Beiwucha Town, and Baojiadian Town, with consideration given to the difficulty of data acquisition and data integrity. A total of 600 households were chosen at random, including 200 families in nearby villages that were not involved in land transfers and 400 homes in the transfer-affected township itself. A participatory farmer assessment approach [37] was employed to allow in-depth discussions with farm households, focusing mostly on the fundamental circumstances of families, such as income, savings, and educational attainment of family members. In all, 571 valid questionnaires were collected covering the two topics involved in the transfer: form of land transfer and transfer area. The 95.2% effective return rate satisfied the study's data criteria. Through surveys and interviews, the characteristics of the sample farmers were compiled (Table 2).

Table 1. Distribution of questionnaires in the study area.

Town Name	Village Name	Number of Questionnaires Distributed	Number of Questionnaires Returned	Questionnaire Return Rate
Letuyi Town	Xiazhuangzi Village	50	49	98.0%
	Zhangjiazhuang Village	50	47	94.0%
Baojiadian Town	Dawanzi Village	50	50	100.0%
	Sifuzhuang Village	50	46	92.0%
Beiwucha Town	Hongliukeng Village	50	50	100.0%
	Xigou Village	50	48	96.0%
Lanzhouwan Town	Dongmaidi Village	50	48	96.0%
	West Next Door Village	50	47	94.0%
Surrounding non-transferred villages		200	186	93.0%

Table 2. Descriptive statistics of sample farmers in the Study Area.

Type	Feature Description	Statistics	
		Quantity	Percentage
	Farmers' characteristics		
Age	Under 30 years old	65	11.4%
	30–40 years old	167	29.2%
	40–50 years old	233	40.8%
	Over 60 years old	106	18.6%
Education level	Elementary school and below	117	20.5%
	Junior high school	305	53.4%
	High school	106	18.6%
	College and above	43	7.5%
Social identity	General public	521	91.2%
	Public officials	50	8.8%
	Agricultural Resource Endowment		
Number of agricultural laborers	1 person	105	18.4%
	2–3 people	296	51.8%
	More than 3 people	170	29.8%
Existing arable land area	Less than 2 hm^2	97	17.0%
	2–10 hm^2	237	41.5%
	More than 10 hm^2	237	41.5%
Productive agricultural tools	There are	272	47.6%
	None	299	52.4%

2.3. Research Methodology

2.3.1. Division of Farmers and Land Transfer Mode

The farmers in the study area were divided into four groups based on the ratio of their non-agricultural income to total income: agricultural farmers, agricultural part-time farmers, non-agricultural farmers, and non-agricultural part-time farmers. The percentages of their non-agricultural income are shown in Table 3 as less than 10%, 10%–50%, 50%–90%, and more than 90%.

Table 3. Classification of farmers by type and criteria.

Farmers Type	Classification Criteria		Quantity	Percentage of
	Is There Any Non-Agricultural Occupation	Share of Non-Farm Income		
Purely agricultural farmers	No	$\leq$10 percent	145	23.5%
Agricultural part-time farmers	Yes	10% < x $\leq$ 50%	163	23.1%
Non-agricultural part-time farmers	Yes	50% < x $\leq$ 90%	187	24.5%
Non-agricultural farmers	Yes	>90%	128	28.9%

Based on the existing studies, four typical townships in Manas County were chosen as representatives, and two villages in each township were chosen to suggest the four most prevalent land transfer modes in the county: the farmers' spontaneous mode, the centralized continuous mode, the joint-stock cooperative model, and the leaseback and re-contracting mode. The land transfer modes were classified according to the differences in the operating agents after the land transfers. Different land transfer strategies were categorized according to how the land was managed. The farmers' spontaneous mode was categorized as individual operation, the centralized continuous mode as family operation, and the joint-stock cooperative model and leaseback and re-contracting mode were defined as collective operation. To compare variations in the changes in farmers' livelihood capital under various land transfer models, the meanings, transfer modalities, and characteristics of the various models were compiled and studied, as shown in Table 4.

2.3.2. Quantitative Model of Livelihood Capital

In their research evaluating farmers' livelihoods, local and foreign academics have in recent years proposed a range of assessment index systems [41]. This present study adopted the sustainable livelihood framework (SLF), currently the most popular framework, proposed by the United Kingdom International Development Agency (DFID), taking into account a combination of economic, social, and ecological positions. This study integrated the research findings of Zhang et al. and further separates physical capital into productive capital and living capital, in order to more fully depict the influence of land on farmers' livelihoods [42]. As a result, six different types of capital were considered in this study: natural capital, financial capital, human capital, social capital, production capital, and living capital. In this article, 18 evaluation elements from six categories were chosen in accordance with the framework and survey data from cities and villages in the Manas River Basin. Table 5 details the material and assignment requirements:

Table 4. Division of dominant modes of land transfer in Manas County.

Township Name	Village Name	Land Transfer Model	Mode of Operation	Meaning	Features
Letuyi Town	Xiazhuangzi Village	Leaseback and re-contracting	Collective operation	The village collectives or leading plantation companies lease land from farmers, plan the land use in a unified manner, and build farming infrastructure before contracting the land to farmers for cultivation [38].	Unified land management and re-planning; land scaling; improved land use efficiency.
	Zhangjiazhuang Village				
Lanzhouwan Township	Dongmaidi Village	Joint-stock cooperative		Farmers voluntarily join together and use their contracted land rights as shares. They give up their land in whole or in part, to be managed and controlled by a collective or professional land operator. At the end of the year the cooperative society divides the profits gained from the operation according to the shares.	Increases the source of farmers' income; achieves resource integration and prioritizes the more efficient use of resources.
	Xigebi Village				
Baojiadian Township	Dawanzi Village	Centralized and continuous	Family operation	Farmers with planting experience, mastering planting technology, take advantage of their own land. Some farmers are contracted in a group to achieve large-scale operation. [39]	To a certain extent, realizes large-scale operation and mechanized farming to improve farming efficiency and reduce agricultural input costs.
	Sifuzhuang Village				
North Wuchang Town	Hongliukeng Village	Farmers' spontaneous mode	Individual operation	Small-scale land transfer between friends, relatives, neighbors, or farmers who know each other within the village [40].	The transfer is more flexible, and the inflow party can choose the scale of land transfer. After the transfer, the operation is still fragmented and the land benefits are not significant.
	Xigou Village				

Table 5. Farmers' livelihood capital indicator system.

Livelihood Capital	Livelihood Indicators	Indicator Meaning and Assignment	Weights
Natural capital	Contracted land area	Area of all contracted land per farming household in survey villages (ha.)	0.077
	Quality of contracted land	Very good = 1, good = 0.8, average = 0.6, poor = 0.4, very poor = 0.2	0.069
	Annual production of land	Annual yield of cotton on contracted land of farmers in surveyed villages (kg/ha.)	0.072
Financial capital	Annual household income	Amount of net household income per farm household in surveyed villages (10,000 yuan)	un RMB0.087
	Family savings	Amount of household savings per farm household in surveyed villages (10,000 yuan)	0.044
	Government subsidies	Yes = 1, No = 0	0.043
Living capital	Housing conditions	Translated into RMB according to the current year's housing price and existing housing area (Yuan)	0.052
	Livestock, aquaculture	Yes = 1, No = 0	0.032
	Transportation owned	Minivan/commercial vehicle = 1, small car = 0.8, electric car = 0.5, bicycle = 0.2, none = 0	0.045
Produced capital	Number of productive tools	Number of mechanized tools used for agricultural production in the homes of farmers in surveyed villages (units)	0.056
	The degree of improvement of rural infrastructure	Very good = 1, good = 0.8, average = 0.6, poor = 0.4, very poor = 0.2	0.044
	Water irrigation facilities	Very good = 1, good = 0.8, average = 0.6, poor = 0.4, very poor = 0.2	0.041
Social capital	Social Security level	Very good = 1, good = 0.8, average = 0.6, poor = 0.4, very poor = 0.2	0.04
	Availability of official positions	Yes = 1, No = 0	0.058
	Level of policy understanding	Very good = 1, good = 0.8, average = 0.6, poor = 0.4, very poor = 0.2	0.06
Human capital	Number of laborers	Number of existing labor force in farm households in surveyed villages	0.082
	Educational level of family members	College and above = 1, high school = 0.8, middle school = 0.6, elementary school = 0.4, illiterate = 0.2	0.042
	Workforce health status	Very good = 1, good = 0.8, average = 0.6, poor = 0.4, very poor = 0.2	0.056

The methods of determining the indicator weights were primarily hierarchical analysis, expert scoring, and the entropy method [43]. In order to eliminate subjectivity in the assignment and the repetitiveness of the indicator attributes, this study used the entropy method to determine the weights. The specific calculation process was as follows.

First, the indicator data were invariantly steeled [44]. This selection used the extreme difference standardization method to standardize the replicated data to eliminate the effect of different data magnitudes; the formula is as follows:

$$M_{ij} = \left(X_{ij} - minX_j\right) / \left(maxX_j - minX_j\right) \tag{1}$$

where M_{ij} is the standardized value of item i under the jth indicator, X_{ij} is the value of livelihood capital assigned to the i-th farmer under the jth indicator, $minX_j$ and $maxX_j$ are the maximum and minimum values of the jth livelihood capital assigned, respectively.

The M_{ij} was normalized by the formula:

$$I_{ij} = M_{ij} / \sum_{i=1}^{m} M_{ij} + 0.001 \tag{2}$$

where I_{ij} is the normalized value, m is the farmer's value, and 0.001 is the overall shift to the right to prevent the presence of a 0 value and to facilitate subsequent calculations.

Next, the entropy values and entropy weights e_j, W_j, of each indicator were calculated with the following equations:

$$e_j = -1/\ln m \sum_{i=1}^{m} I_{ij} \ln I_{ij} \tag{3}$$

$$W_j = 1 - e_j / \sum_{j=1}^{n} \left(1 - e_j\right) \tag{4}$$

where, e_j ($0 \leq e_j \leq 1$) is the entropy value of the jth indicator, $-1/\text{Inm}$ is the information entropy coefficient, W_j is the entropy weight of the jth indicator, and n is the number of livelihood capital indicators.

Finally, the value of the livelihood capital indicator of farm households was calculated, with the magnitude of the value reflecting the level of livelihood capital. The formula is:

$$B_{ij} = \sum_{i=1}^{n} I_{ij} W_j \tag{5}$$

where B_{ij} is the value of each livelihood capital indicator of the ith farmer, I_{ij} is the normalized value of each livelihood capital indicator of the farmer, and W_j is the weight of each livelihood capital indicator.

2.3.3. Difference-in-Differences Model

The difference-in-differences model [45] involves comparing the effect of a research subject before and after the intervention of a specific factor, and the difference between the two is the net effect of that factor on the research subject [34]. The basic idea is to divide the survey sample into two groups: one group of subjects affected by the specific factor, namely the "experimental group", and one group of subjects not affected by the specific factor, namely the "control group". The specific model is expressed as follows:

$$Y_{ij} = \beta_0 + \beta_1 Treat_{ij} + \beta_2 Period_{ij} + \beta_3 DID_{ij} + \varepsilon_{ij} \tag{6}$$

$$DID_{ij} = Treat_{ij} * Period_{ij} \tag{7}$$

where $i = 1$ represents the pre-intervention period, $i = 2$ represents the post-intervention period, j represents the subject, Y_{ij} represents the value to be measured for the jth subject in period I, $Period_{ij}$ is a time dummy variable, $Period_{1j} = 0$ represents pre-intervention, $Period_{2j} = 1$ represents post-intervention, $Treat_{ij}$ is a group dummy variable, $Treat_{ij} = 0$ is the control group, $Treat_{ij} = 1$ is the experimental group, DID is the cross term of $Treat_{ij}$ and $Period_{ij}$, the ε_{ij} is the unobserved other variables affecting Y_{ij} controlled not to change.

Depending on the characteristics, it is possible to write separate models of changes in the variables to be measured in the control and treatment test subjects, before and after the factor intervention.

The control group $Treat_{ij}$ = 0 was modeled as $Y_{ij} = \beta_0 + \beta_2 Period_{ij} + \varepsilon_{ij}$. Therefore, the values to be measured for the control group in the periods before and after the factor intervention were:

$$Y_{ij} = \begin{cases} \beta_0 + \varepsilon_{ij}, & i = 1 \\ \beta_0 + \beta_2 + \varepsilon_{ij}, & i = 2 \end{cases} \tag{8}$$

The changes in the values to be measured in the control group before and after the factor-specific intervention were:

$$diff_1 = (\beta_0 + \beta_2 + \varepsilon_{ij}) - (\beta_0 + \varepsilon_{ij}) = \beta_2 \tag{9}$$

The experimental group *Treatij* = 1 was modeled as $Y_{ij} = \beta_0 + \beta_1 + \beta_2 Period_{ij} + \beta_3 Period_{ij} + \varepsilon_{ij}$. Therefore, the values to be measured for the control group in the two periods before and after the factor intervention were:

$$Y_{ij} = \begin{cases} \beta_0 + \beta_1 + \varepsilon_{ij}, & i = 1 \\ \beta_0 + \beta_1 + \beta_2 + \beta_3 + \varepsilon_{ij}, & i = 2 \end{cases} \tag{10}$$

The changes in livelihood capital in the experimental group before and after the ad hoc factor intervention were:

$$diff_2 = (\beta_0 + \beta_1 + \beta_2 + \beta_3 + \varepsilon_{ij}) - (\beta_0 + \beta_1 + \varepsilon_{ij}) = \beta_2 + \beta_3 \tag{11}$$

Thus, the net effect of a given factor on the observations of the subject to be measured is:

$$diff = (\beta_2 + \beta_3) - \beta_2 = \beta_3 \tag{12}$$

The final value β_3 is the final double difference value to be obtained. When $\beta_3 > 0$, it indicates that the specific factor had a positive effect on the study subject; when $\beta_3 < 0$, it indicates that the specific factor's effect was negative effect. The larger the absolute value of β_3, the greater the degree of influence of the specific factor on the study subject.

3. Results and Analysis

3.1. Analysis of Changes in Livelihood Capital of Different Types of Farmers

3.1.1. Description of Differences in Livelihood Capital of Different Types of Farmers

As shown in Table 6, the livelihood capital of non-agricultural and non-agricultural part-time farmers before land transfer was higher, with values of 2.553 and 2.309, respectively, while that of purely agricultural and agricultural part-time farmers was lower, with respective values of 2.039 and 2.241. This indicates that part-time farming has a positive effect on the livelihood capital of farmers.

Specifically, natural capital was highest for purely agricultural farmers, followed by agricultural part-time farmers and non-agricultural part-time farmers, while non-agricultural farmers had the lowest natural capital index values; the values were 0.459, 0.401, 0.374, and 0.358, respectively. The natural capital of these farmers was lower because they were engaged in non-agricultural activities, as non-agricultural farmers are mainly engaged in non-agricultural activities to maintain their livelihoods.

Financial capital was highest for non-agricultural farmers, followed by non-agricultural part-time farmers and agricultural part-time farmers, and the lowest values were for purely agricultural farmers, with indicator values of 0.573, 0.392, 0.376, and 0.297, respectively. Differences in financial capital of farmers were found in terms of annual household income, and farmers engaged in non-agricultural activities had a wider range of livelihood sources. Most of them go out to work, so their income is more stable than farming and is not limited by land quality and natural conditions.

Table 6. Values of livelihood capital indicators before and after land transfer for different types of farmers.

Pure Agricultural Farmers	Natural Capital	Financial Capital	Living Capital	Produced Capital	Social Capital	Human Capital	Livelihood Capital
Before transfer	0.459	0.297	0.304	0.335	0.271	0.373	2.039
After transfer	0.475	0.325	0.319	0.39	0.283	0.385	2.177
diff	0.016	0.028	0.015	0.055	0.012	0.012	0.138
Agricultural Part-Time Farmers	**Natural Capital**	**Financial Capital**	**Living Capital**	**Produced Capital**	**Social Capital**	**Human Capital**	**Livelihood Capital**
Before transfer	0.401	0.376	0.342	0.324	0.311	0.487	2.241
After transfer	0.395	0.41	0.355	0.339	0.338	0.509	2.346
diff	−0.006	0.034	0.013	0.015	0.027	0.022	0.105
Non-Agricultural Part-Time Farmers	**Natural Capital**	**Financial Capital**	**Living Capital**	**Produced Capital**	**Social Capital**	**Human Capital**	**Livelihood Capital**
Before transfer	0.374	0.392	0.361	0.331	0.357	0.494	2.309
After transfer	0.354	0.43	0.38	0.305	0.399	0.522	2.39
diff	−0.02	0.038	0.019	−0.026	0.042	0.028	0.081
Non-Agricultural Farmers	**Natural Capital**	**Financial Capital**	**Living Capital**	**Produced Capital**	**Social Capital**	**Human Capital**	**Livelihood Capital**
Before transfer	0.358	0.573	0.372	0.277	0.427	0.546	2.553
After transfer	0.343	0.587	0.385	0.268	0.438	0.557	2.578
diff	−0.015	0.014	0.013	−0.009	0.011	0.011	0.025

Livelihood capital was highest for non-agricultural farmers, followed by non-agricultural part-time farmers and agricultural part-time farmers, and the lowest livelihood capital was for purely agricultural farmers, with livelihood capital values of 0.372, 0.361, 0.342, and 0.304, respectively. Differences in livelihood capital were primarily found in the two indicators of housing quality and availability of transportation, with non-agricultural and part-time farmers not simply dependent on the land for their livelihood, but having a wider variety of livelihood sources and higher living capital.

Purely agricultural and agricultural part-time farmers had greater levels of productive capital than non-agricultural part-time farmers, who had the lowest levels. Production capital returned the following values: 0.335, 0.324, 0.331, and 0.277, correspondingly. The differences in productive capital were primarily due to differences in the number of productive tools, with farmers who were primarily dependent on land as a source of income generally acquiring more productive tools. Additionally, local government is strengthening the construction of farmland water conservation to increase production.

Human capital was highest for non-agricultural farmers, followed by part-time farmers, and was lowest for purely agricultural farmers, with indicator values of 0.546, 0.494, 0.487, and 0.373, respectively. Differences in human capital were mainly manifested in the educational level and health status of the labor force. Non-agricultural farmers had relatively higher education levels and filled a wider range of occupations.

Social capital was highest for non-agricultural farmers, followed by part-time farmers, and lowest for purely agricultural farmers, with indicator values of 0.427, 0.357, 0.311, and 0.271, respectively. As farmers increase their part-time employment, their understanding of national policies increases, and the social security they can enjoy also increases. In the process of engaging in more part-time employment, farmers' social interactions increase and their social capital increases.

3.1.2. Analysis of the Direction of Change in Livelihood Capital of Different Types of Farmers

Combining Table 6 with Figure 2 above, it can be calculated that the capital worth of pure farmers' livelihoods after land transfer was 2.177, which was 0.138 more than before the land transfer. Agricultural part-time farmers' livelihood capital value was 2.346, which was 0.105 higher than before circulation. Non-agricultural part-time farmers' livelihood capital value was 2.390, which was 0.081 higher than before circulation. Non-agricultural farmers' livelihood capital value was 2.578, which was 0.025 higher than before circulation. When compared to other capital, pure farmers' productive capital expanded greatly, while natural and financial capital increased only somewhat. Pure farmers tended to participate in land transfer by moving out plots of land that are far away or of poor quality, keeping plots of land that are of superior quality, and moving onto existing land near to their land to increase their operational scale. To boost the productivity of the remaining land, better instruments were obtained for it the same time.

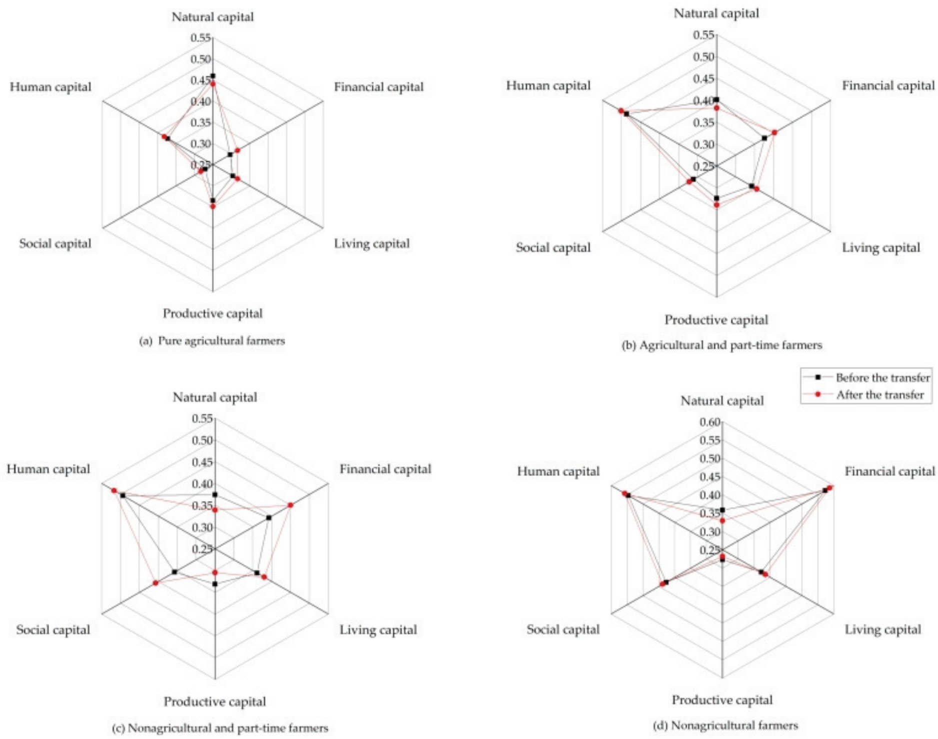

Figure 2. Direction of change in livelihood capital of different types of farmers.

In contrast to pure farmers, agricultural and non-agricultural part-time farmers' natural capital declined while their social capital rose dramatically. The other components of their capital were virtually unaffected. Compared to non-agricultural part-time farmers, who continued to focus primarily on land management, they experienced less loss of natural capital. However, these farmers work part-time jobs that will improve their social interactions, diversify their sources of income, and raise their incomes, so building their social and financial capital.

Natural and productive capital in non-agricultural farmers declined, whereas livelihood capital increased. Human, financial, and social capital all changed less, and livelihood capital did not change considerably. Because non-agricultural farmers have forgone agricultural activities and have an income that is entirely unrelated to agriculture, the process of land transfer essentially has no impact on these farmers' ability to support themselves. As a result, the change in their livelihood capital was insignificant.

3.2. Analysis of Changes in Farmers' Livelihood Capital under Different Land Transfer Modes

3.2.1. Descriptive Analysis of the Impact of Different Land Transfer Modes on Farmers' Livelihood Capital

There are variations in the final land management impacts and the advantages that farmers receive from land transfers, as a result of the various methods of trading land management rights in different models and the various operators after the land transfer. Table 7 shows the before-and-after mean differences in farmers' capital for sustaining their livelihood under various land transfer strategies. The findings reveal that the double difference estimates of the total value of farmers' livelihood capital before and after land transfer in the four modes were 0.058, 0.071, 0.111, and 0.122, respectively. Based on these findings, it can be said that all four land transfers have a positive impact on farmers' livelihood capital, at least in part, or that they encourage the expansion of that capital.

Table 7. Within- and between-group differences in farmers' livelihood capital before and after land transfer in different modes.

The Farmers' Spontaneous Mode	Farmers Not Participating in Land Transfer	Farmers Participating in Land Transfer	Diff
Before transfer	2.198	2.236	0.038
After transfer	2.206	2.302	0.096
diff	0.008	0.066	0.058
Centralized and Continuous Mode	**Farmers Not Participating in Land Transfer**	**Farmers Participating in Land Transfer**	**Diff**
Before transfer	2.211	2.25	0.039
After transfer	2.217	2.327	0.11
diff	0.006	0.077	0.071
Joint-Stock Cooperative Model	**Farmers Not Participating in Land Transfer**	**Farmers Participating in Land Transfer**	**Diff**
Before transfer	2.217	2.251	0.034
After transfer	2.216	2.361	0.145
diff	−0.001	0.11	0.111
Leaseback and Re-Contracting Mode	**Farmers Not Participating in Land Transfer**	**Farmers Participating in Land Transfer**	**Diff**
Before transfer	2.225	2.262	0.037
After transfer	2.219	2.378	0.159
diff	−0.006	0.116	0.122

3.2.2. Econometric Analysis of the Impact of Different Transfer Modes on the Livelihood Capital of Farmers

This study conducted econometric analysis by various methods on the effect of land transfer on farmers' livelihood capital, in order to confirm the aforementioned conclusion. Farmers that did not participate in land transfer around the community were considered the control group in this study, whereas farmers in villages that used one of four land transfer modalities were considered the experimental group. The net benefit of each mode on farmers' livelihood capital was calculated using Equations (6)–(12) and STATA 22.0, specifically with reference to Table 8. The outcomes can be seen in Table 9, which shows positive and significant DID values for individual, family, and collective land transfers on farmers' livelihood capital, with coefficients of 0.17, 0.183, and 0.2491, respectively. Among the models, the leaseback and re-contract mode and the land stock cooperative mode had higher DID values and a greater impact on farmers' capital for livelihood.

Table 8. Details of the grouping of the control and experimental groups in the difference-in-differences model.

<table>
<tr><th colspan="4">Experimental Group</th><th colspan="3">Control Group</th></tr>
<tr><th>Group Name</th><th>Farmers</th><th>Mode</th><th>Business Method</th><th>Group Name</th><th>Farmers</th><th>Mode</th></tr>
<tr><td>A1</td><td>Hongliukeng Village, Xigou Village</td><td>The farmers' spontaneous mode</td><td>Individual business</td><td rowspan="4">B1</td><td rowspan="4">Farmers in surrounding non-transferred villages</td><td rowspan="4">Uncirculated</td></tr>
<tr><td>A2</td><td>Dawanzi Village, Sifuzhuang Village</td><td>Centralized and continuous mode</td><td>Family business</td></tr>
<tr><td rowspan="2">A3</td><td>Dongmaidi Village, West Next Door Village</td><td>Joint-stock cooperative model</td><td rowspan="2">Collective management</td></tr>
<tr><td>Xiazhuangzi Village, Zhangjiazhuang Village</td><td>Leaseback and re-contracting mode</td></tr>
</table>

Table 9. Regression results of different modes of land transfer on farmers' livelihood capital.

	(1) Individual Operation	(2) Family Operation	(3) Collective Operation
VARIABLES	**Total**	**Total**	**Total**
DID	0.170 ***	0.183 ***	0.249 ***
	(0.0162)	(0.0137)	(0.0104)
Post	0.0614 ***	0.0673 ***	0.0508 ***
	(0.0133)	(0.00916)	(0.00839)
Constant	2.263 ***	2.268 ***	2.303 ***
	(0.00381)	(0.00377)	(0.00250)
Observations	852	852	1710
R-squared	0.399	0.443	0.499
Number of id	142	142	286

Robust standard errors in parentheses: *** $p < 0.01$.

This study evaluated the variations in impact on farmers' livelihood capital of the two land transfer mechanisms involving collective management, to further investigate the most suitable land transfer mode in the study region. Farmers who used the land shareholding cooperative method are referred to as control group D, whereas those who used the land-leaseback contracting style were considered experimental group C. The intra-group and component differences in the values of the two models' livelihood capital indices are shown in Table 10. The DID estimate value for experimental groups C and D was 0.048, as seen in Table 10, which is favorable and significant. This demonstrates that when land was transferred through the land leaseback contractual model, the improvement in farmers' livelihood capital, notably in financial capital and social capital, was more evident. This is mostly due to the fact that under the leaseback contracting mode, the "village collective + planting leadership firm" is primarily responsible for operating the property. They receive the land rented from the original farmers, design it uniformly, construct agricultural infrastructure, split the property after replanning, and lease it to farmers. This procedure may involve the whole agricultural supply chain, including the production and storage of agricultural goods as well as their distribution and sale. A high level of expertise and organization is required, which may support farmers' development while the process is being realized. As a result, farmers can gain more from this manner of land transfer since the operational scale is higher after the transfer. The DID value of human capital is negative, which means that the impact of the joint-stock cooperative model is slightly greater than that of the leaseback contracting model on the human capital of farmers. This may be because the land-leaseback contracting model includes a higher degree of modern agricultural technology and a lower participation of ordinary labor in the land transfer. This finding is also supported by the regression results.

Table 10. Regression results of land transfer on farmers' livelihood capital for the joint-stock cooperative mode and the land leaseback and recontracting mode.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Variables	**Total**	**Natural Capital**	**Financial Capital**	**Living Capital**	**Produced Capital**	**Social Capital**	**Human Capital**
DID	0.0480 ***	0.00121	0.0166 *	0.0110 ***	0.00637 **	0.0150 ***	−0.00223
	(0.0132)	(0.00160)	(0.00991)	(0.00367)	(0.00311)	(0.00480)	(0.00515)
Post	0.254 ***	0.0480 ***	0.0285 ***	0.0423 ***	0.0490 ***	0.0374 ***	0.0484 ***
	(0.00837)	(0.00119)	(0.00656)	(0.00249)	(0.00232)	(0.00325)	(0.00348)
Constant	2.272 ***	0.372 ***	0.453 ***	0.338 ***	0.300 ***	0.371 ***	0.438 ***
	(0.00329)	(0.000401)	(0.00247)	(0.000916)	(0.000779)	(0.00120)	(0.00129)
R-squared	0.530	0.647	0.057	0.396	0.427	0.272	0.242

Robust standard errors in parentheses: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

3.2.3. Robustness Test

The endogeneity issue in policy evaluation can be better addressed by the twofold difference method, but it must be founded on a number of key presumptions, requiring parallel trend tests and placebo testing [46,47]. In this regard, experiments pertaining to the identification hypothesis from various aspects were conducted in this study.

Parallel Trend Test

The 95 percent confidence interval before land transfer (pre 2, pre 1 in the Figure 3) contained 0, demonstrating that the trend of the change in farmers' livelihood capital was similar between the experimental and control groups before t. Parallel trend tests were conducted on the aforementioned four groups of experiments, respectively, to confirm the viability of the double difference method and the identifiability of the regression results.

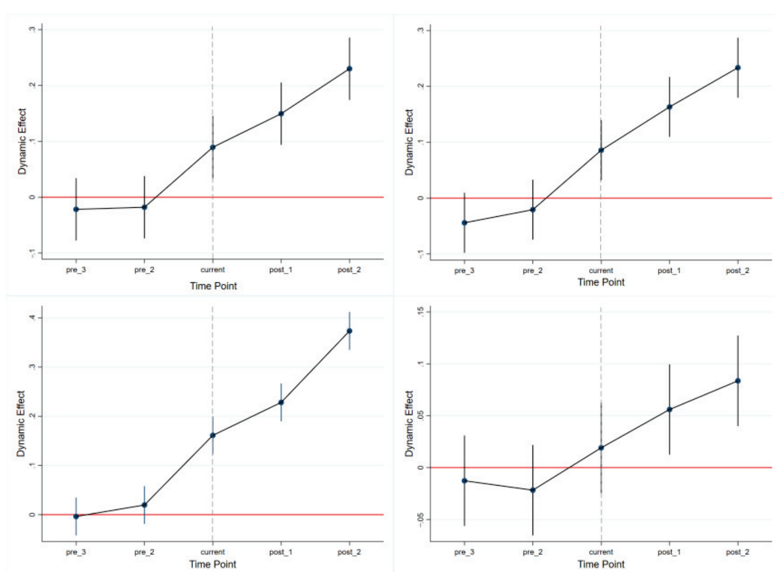

Figure 3. Results of parallel trend testing for DID.

Non-Observed Factor Effects

Although other variables that may affect farmers' livelihood capital were controlled for, there remain unobserved variables such as farmers' individual decisions that can have a potential impact on the difference between the experimental and control groups of farmers before land transfer, thus affecting the robustness of the regression results. Therefore, this study took the approach of creating random variables to test whether there was an effect of omitted variables. STATA 16 software was used to calculate and generate random shocks of land transfer on the livelihood capital of specific farmers, and repeated 500 times. Under such a premise, the mean value of DID was estimated, and the results are shown in Figure 4, indicating the distribution of the 500 estimated DIDs. The values of the DIDs in the random process were concentrated around 0 and were significantly far from the estimated values of the real experiment, by which it can be induced that the other farm household characteristics observed for the regression results had almost no effect on the regression results, thus proving that the previous estimation results were robust.

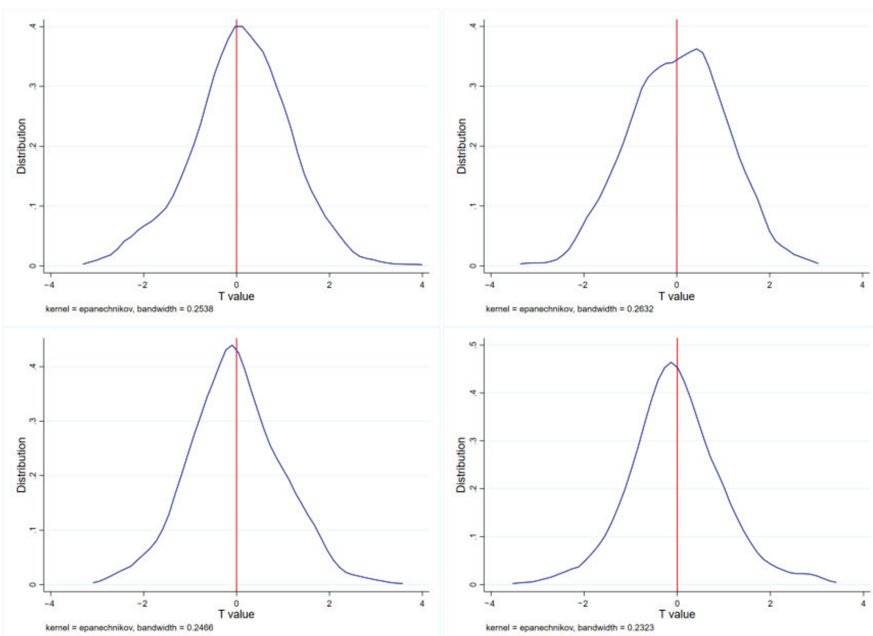

Figure 4. Placebo test results.

4. Discussion

Land transfers give land to farmers who are better able to farm it, which on the one hand increases the productivity of arable land and the efficiency of land use, and on the other expands the career options of farmers, increases their income, and is an efficient way to support local agricultural and economic development. The market-oriented land transfer policy has had a positive impact on improving urban land use efficiency, according to Jiang et al. [48]. Peng et al. [3] discovered that the scale of land transfers had a U-shaped effect on food crops, and suggested that the Chinese government should promote land transfers to ensure food self-sufficiency. Farmers, who are land operators, should be encouraged to transfer their land. Similar to the conclusions of this paper, Wu et al. [49] and Ren et al. [50] found that land tenure adjustment would improve farmers' livelihood capital and significantly reduce farmers' livelihood vulnerability, based on the livelihood sustainability framework. A difference is that this paper refers to Zhang Shichao's study [42], considering the existence of transfer outliers. In an area complementary to this study, Yang et al. [34] investigated the characteristics of livelihood capital and land transfer within farmers' livelihood strategies, and considered the influence of livelihood capital on land transfer. Together, their findings demonstrated a mutual relationship between land transfer and farmers' livelihood capital, further demonstrating that the two topics cannot be studied independently.

Different land transfer models have been implemented due to variations in types of land, economic conditions, and human cultures found in different regions. Each region selects the land transfer model based on the conditions found there, which is advantageous for the success of land transfer and makes it easier to raise standards of living for farmers.

Ref. [51], Zhang [52], Wang [53], and others have studied differences in the impact of the new business model and the government-led model on farmers' livelihood capital. Similar to existing studies, this paper has compared the two collective operation models again in order to confirm which is most appropriate for Manas County. The results show that the model with the village collective or a leading plantation company as the main operating agent is more effective in raising the standard of living for farm households. The land leaseback and re-contracting model, with village collectives or major plantation companies as the main operators, had the greatest impact on the livelihood capital of farmers in Manas County according to this paper's comparison of the two collective management models to confirm the most appropriate land transfer model for the area. The study's findings can serve as a guide for encouraging land transfer in Manas County. In future land transfers, farmers should be encouraged to pool land with scattered plots and lower yields, and they should be asked to promote this model in entire villages, because village collectives and top plantation companies have greater strengths in terms of land cultivation experience, national policies, and economic resources.

In conclusion, even though this study has included new ideas and enhanced previous research, there remain areas that merit further investigation. Since this study did not take into account livelihood strategies, the relationship of mutual influence between land transfer, livelihood strategy, and livelihood capital should be further delineated in the future. The existence of transfer-in and transfer-out behaviors within the process of land transfer indicates differences in farmers' choices for livelihood strategies.

5. Conclusions

The following findings can be drawn through field surveys, in-depth interviews, and the data analysis in this paper:

(1) Land transfer had a favorable and clear effect on farmers' capital for livelihood. The effect of land transfer on farmers' ability to maintain their way of life was higher when more agricultural operations are engaged. Following land transfers, all types of farmers, from big to small, experienced a transition in their capital of livelihood; purely agricultural farmers > agricultural part-time farmers > non-agricultural part-time farmers > non-agricultural farmers.

(2) Distinct categories of farmers experienced different changes in their means of subsistence as a result of land transfers. Production capital and natural capital of purely agricultural farmers rose greatly, whereas social capital and natural capital of part-time farmers fell or increased significantly. Non-agricultural farmers' capital of all types did not change greatly.

(3) The capital that supports farmers' livelihoods was found to be affected differently by various land transfer methods. Following land transfer, communal management is more effective than family management, and individual management is more effective than small-scale farming. When comparing the land stock cooperation mode with rural cooperatives as the main body, against the land leaseback and re-contract mode with "village collective + planting leading firm" as the primary management body, the improvement of farmers' livelihood capital was more evident. As a result, the modes

of land leaseback and re-contract were found to enhance effectively the method of land transfer for farmers' livelihood capital.

According to the survey of Manas County, the area now has sporadic land transfers, single employment of farmers who have been relocated, and ineffective land transfer security measures. On the basis of the findings of this investigation, the following recommendations are made:

(1) It is advised that the government strengthen the framework for securing land transfers, and increase farmers' job opportunities. Making it possible for farmers to receive greater advantages from land transfer would encourage more farmers to participate in land transfer. In order to boost farmers' farming ability, we should provide the transferred farmers with suitable subsidies, strengthen rural infrastructure, and undertake unified land management training. Meanwhile, for farmers who have been relocated, we should improve social security, offer assistance and job possibilities, and promote the migration of labor to secondary and tertiary industries.
(2) The government should actively encourage land scale transfer and management while nurturing new commercial entities. We should actively promote the circulation of the entire village, encourage collective management, maximize the allocation of collective land resources, cultivate the development of rural cooperatives, position large farmers, establish leading businesses, form other teams, increase scientific and technological training, establish an industry chain for the production, processing, and sale of agricultural products, and actively advance the construction of "village colliders".

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Article

Research on the Impact of Farmland Transfer on Rural Household Consumption: Evidence from Yunnan Province, China

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Abstract: By constructing the analytical framework of "farmland transfer—farmland function—income structure—rural household consumption", based on the sample data of 537 rural households in 50 villages in Yunnan Province of China, this paper uses the OLS model to explore the impact of farmland transfer on rural household consumption and uses an intermediary effect model to further explore its internal transmission mechanism. The research finds that: (1) Farmland transfer (farmland transfer-out or farmland transfer-in) can stimulate rural household consumption. (2) The coefficient of farmland transfer-out to non-food consumption is 0.118, which is greater than its coefficient of food consumption of 0.016; the rural households of farmland transfer-out are more willing to increase non-food consumption expenditure, which is conducive to the optimization of their consumption structure. (3) The coefficient of farmland transfer-in to food consumption is 0.028, which is greater than its coefficient to non-food consumption of 0.009; the rural households of farmland transfer-in are more willing to increase food consumption expenditure, which is not conducive to the optimization of their consumption structure. (4) Rural household consumption expenditure will show a downward trend with the increase in the age of the head of the rural household, and the consumption structure will also show a deterioration. (5) The more family assets rural households have, the stronger their consumption expenditure capacity, which is conducive to optimizing their consumption structure. (6) The results of the intermediary effect model show that farmland transfer affects rural households' consumption and consumption structure by affecting rural households' income under different livelihood modes. Accordingly, the paper puts forward some suggestions on establishing the benefit coordination mechanism of farmland transfer, improving the non-agricultural employment mechanism of the rural surplus labor force, raising the expected return on farmland investment, increasing the proportion of household income saved appropriately and strengthening the social security mechanism in order to further promote the orderly transfer of farmland, improve the consumption capacity and consumption level of rural households, expand rural domestic demand and promote rural consumption upgrading.

Keywords: farmland transfer; farmland function; income structure; rural household consumption; consumption structure; Yunnan Province

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1. Introduction

At present, the intensification of Sino-US trade contradictions has directly led to the increase of instability and uncertainty in China's foreign trade environment. In addition, the continuous impact of COVID-19 and the downward pressure of economic structural transformation have hindered the high-quality development of China's economy [1,2]. In response to this, on 10 April 2020, General Secretary Xi Jinping proposed at the seventh meeting of the Central Finance and Economics Commission to "build a new development pattern with a large domestic cycle as the mainstay and dual domestic and international cycles to promote each other" and take advantage of China's mega market and domestic demand potential. In December 2021, the Central Economic Work Conference stressed that "we should deepen the structural reform on the supply side, focusing on unblocking the domestic circulation, breaking through the supply constraint blockage and opening up the links of production, distribution, circulation and consumption". It can be seen that there is still a huge potential space for consumption to drive China's economic development. However, studies by relevant scholars show that China's final consumption accounts for 54.3% of GDP in 2020, which is far below the global average share of 78.1% [3]. To achieve high-quality development, China's economy must seek to tap the potential of domestic demand, which is mainly derived from insufficient consumption [4,5], especially in the context of rural revitalization, the rural consumption market is promising [6]. To this end, the No. 1 document of the Central Government of China in 2021 emphasized that "we should comprehensively promote rural consumption, promote effective linkage between urban and rural production and consumption, and meet the needs of rural residents for consumption upgrading". Meanwhile, China's 14th Five-Year Plan specifies that in the next five years we should "improve the urban-rural integration consumption network, expand the coverage of e-commerce in rural areas, improve the consumption environment in counties and promote the upgrading of rural consumption ladder". However, data from the China National Bureau of Statistics show that the per capita consumption expenditure of rural residents in China in 2021 is 15,916 RMB yuan, while the consumption expenditure of urban residents in the same period is 30,307 RMB yuan, and the urban-rural expenditure ratio is 1.904[1], so the rural consumption market has endless potential [7,8]. Therefore, it is easy to see that the rural market will be the main town to tap the consumption space in China both now and in the future.

In July 2013, General Secretary Xi Jinping pointed out during his visit to the Wuhan Comprehensive Rural Property Rights Exchange that the ownership, contract right and management right of farmland (unless otherwise specified, farmland in this paper is equivalent to contracted land of rural households) should be separated. In November of the same year, the Third Plenary Session of the 18th CPC Central Committee resolved to establish a model of "separation of three rights" in China's agricultural management system [9–12], breaking the shackle that the management right of farmland could not be freely transferred. Since then, under the mandatory arrangement of a series of formal institutions, China's farmland transfer market has gradually developed and begun to take shape [13–16]. By the end of 2017, the area of contracted land of rural households transfer in China reached 512 million mu[2], accounting for 37% of the total area of family-operated arable land [17]. It is noteworthy that from 2013 to 2018, the per capita consumption expenditure of Chinese rural residents rose from 7485 RMB yuan to 12,124 RMB yuan, with an average annual growth rate of 10.12%. Coincidentally, in the year (2014) following the formal implementation of the "separation of three rights" model for farmland, the growth rate of per capita consumption expenditure of rural residents in China was as high as 12% (see Figure 1). Based on this, we can draw a general guess that there may be a certain correlation between the transfer of farmland and the consumption of rural households. In fact, relevant scholars have already paid attention to the possible impact of farmland transfer on rural household consumption. Based on the perspectives of farmland transfer-out, Xing and Chen [18], Chen et al. [19] and Shi and Zhu [20] pointed out that farmland transfer-out significantly increased the consumption level of rural households. A study by Yang et al. [21] based on the perspective of social capital showed that farmland transfer could influence the key natural capital changes and livelihood strategy adjustment of rural households, which positively and significantly promoted the consumption level of rural households, and rural households who participated in farmland transfer had higher consumption enthusiasm compared with those who did not engage in farmland transfer. Hu and Ding [22] used the regression analysis results of OLS and Quantile models with 7000 rural households in CFPS 2012, which showed that farmland transfer had heterogeneous effects on the consumption level of rural households with different characteristics, and only the complementary effects of farmland transfer and social security could effectively promote rural household consumption.

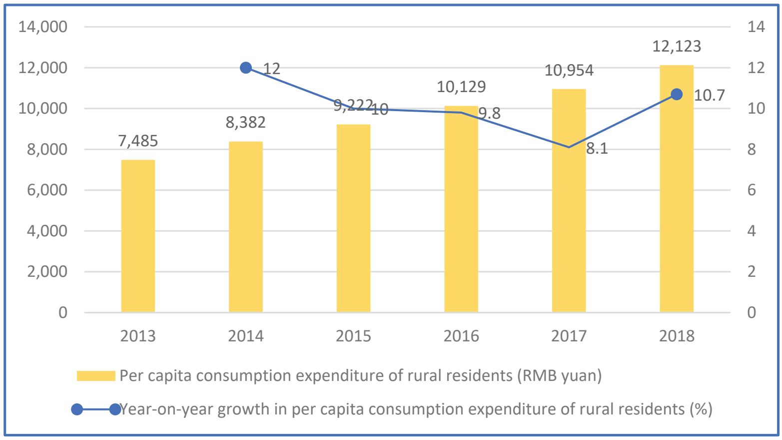


Figure 1. Trend of per capita consumption expenditure of rural residents in China[3].

Farmland transfer has received extensive academic attention because of the fundamental importance of agriculture, and a large number of studies have focused on the effects of farmland transfer on rural household income [23,24], rural poverty reduction [25,26], willingness to citizenship [27], food cultivation structure [28], willingness to livelihood transition [29] and have gradually transitioned to the effects on arable land quality protection [30,31], agricultural production efficiency [32], rural household entrepreneurial decisions [33] and other areas. There is a consensus in the academic community that enhancing the consumption capacity and consumption level of rural households is the finishing touch to expanding China's rural domestic demand [1]. Although scholars have conducted empirical studies on the impact of farmland transfer on rural household consumption, the relevant literature is still relatively scarce. In addition, in the relatively scarce papers, first, there is almost no systematic theoretical analysis framework to specifically elaborate the theoretical mechanism relationship between farmland transfer and rural household consumption; second, there is almost no use of a persuasive indicator like the Engel coefficient that can reflect the consumption structure of rural households to study the impact of farmland transfer on rural household consumption structure. In view of these, the impact of farmland transfer on rural households' consumption deserves further study. Therefore, the aims of the study are: First, we will construct a theoretical framework of "farmland transfer—farmland function—income structure—rural household consumption" to systematically explain the theoretical mechanism relationship between farmland transfer and rural household consumption. Second, by using first-hand research data of 537 rural households in 50 villages in Yunnan Province of China, we use the OLS model to explore the impact of farmland transfer on rural household consumption[4] and use the intermediary effect model to further explore its internal transmission mechanism. Third, because the Engel coefficient can reflect the characteristics of consumption structure, so we dichotomize the total consumption expenditure of rural households into two types of expenditure, food consumption and non-food consumption to further investigate how farmland transfer affects the consumption structure of rural households.

2. Theoretical Analysis and Research Hypotheses

Theoretically, the income level of rural households and the level of social security entitlement are the two fundamental factors that influence rural households' consumption [1]. Farmland, as the largest livelihood, influences the general social structural characteristics of most rural households in China [21]. Since the reform and opening up, with the rapid progress of urbanization, industrialization and agricultural modernization, farmers have broken free from the shackles of farmland to gradually enter the cities and towns for non-agricultural employment. The small-scale, loose and fragmented farmland management model is no longer able to meet the needs of rural economic development [34]. For this reason, the Chinese government has been making efforts in top-level design, formulating and issuing a series of relevant policy documents to strengthen rural households' residual claims to farmland, relax the management rights of farmland and guarantee the realization of farmland transfer benefits for rural households. Undoubtedly, the transfer of farmland can promote the optimal allocation of land resources and moderate scale operation of agriculture, allow the rational and adequate allocation of rural factors of production such as land, labor, technology and capital, effectively promote the development of the rural economy and the improvement of the income level of rural households and completely activate the productive and property functions of farmland [9–12]. However, it must be acknowledged that the social security system in China's rural areas is not yet sound, and the transfer of farmland can indeed change the fate of the rural households concerned to a certain extent. In addition, farmland is increasingly becoming a basic survival guarantee for vulnerable groups of rural households who lack the ability to move to urban areas [35–37]. Of course, the security function of farmland is the most important and basic function of farmland for rural households. Whether it is the "further" property function of farmland or the "step back" productive function of farmland, when rural households realize the functional differentiation of farmland, not only does the security function of farmland not become lost [1] but also it increasingly strengthens the property and productive functions of farmland [38,39].

At present, the transfer of farmland is gradually becoming a new way for rural households to accumulate original capital. Based on the perspective of rural household livelihood of farmland transfer-out, the income effect of farmland property function can be divided into direct effect and indirect effect [40]. Among them, the direct effect is the rental income brought by the lease or transfer of farmland management rights to rural households of farmland transfer-out, and the income from the direct effect is agricultural income. However, at this time, the dependence of rural households on the agricultural income brought by farmland transfer-out is weak. While the indirect effect refers to the wage income obtained by farmland transfer-out to promote the transfer of surplus rural labor to the non-agricultural sector for employment. The rental income of farmland is an important part of transfer income, which has the characteristics of temporary income and rural households will be more casual in spending [3]. Wage income has a permanent character, and rural households prefer to use this income as a recurrent consumption expenditure [1]. It is obvious that the income structure of rural households is enriched and diversified by the property function of farmland. In addition, the theory of "psychological accounts" suggests that rural households can allocate different incomes to different accounts, which cannot be filled by each other, and that rural households have different consumption tendencies for different sources of income [41]. The enrichment of rural households' income structure is essentially the division of their holistic income into numerous units, which will greatly strengthen the perception of subjective wealth increase [1]. Therefore, the change in income structure brought about by the transfer-out of farmland can stimulate the consumption of rural households with both rental income and wage income [42]. At the same time, as a component reflecting the hierarchy of rural households' needs and the order of their satisfaction, food consumption is a demand dominated by rural households' physiological requirements, while non-food consumption is a pursuit of rural households' convenience and performance needs and personal enjoyment and development needs [43]. As the transfer-out of farmland gives rural households a richer income structure and brings them a higher level of subjective income, they will gradually reduce food consumption to satisfy their physiological needs and increase non-food consumption of goods and services for convenience and performance needs as well as personal enjoyment and development needs [44]. Thus, the transfer-out of farmland can lead to an increase in the non-food consumption capacity of rural households, which in turn helps to optimize the consumption structure of rural households.

The perspective of the rural household livelihood strategy is based on farmland transfer-in, rural households mainly focus on agricultural production, and farmland has become one of the most important means of production for them. At this time, the dependence of rural households on agricultural income is very strong, and they will do everything possible to expand the scale of farmland to increase agricultural productive income. Therefore, farmland transfer promotes the rational and optimal allocation of land resources, allowing ordinary rural households to acquire relatively concentrated farmland, which is beneficial to a certain extent to the development of the agricultural production of rural households of farmland transfer-in in the direction of moderate scale, intensification, specialization or marketization and rural households realize income growth in the realization of productive functions of farmland and continuously improve their consumption capacity [40]. However, along with the basic completion of China's farmland titling and certification work, on the one hand, farmland titling has properly solved the problems of inaccurate area of contracted land of rural households parcels and unclear four directions, and the "public domain" of farmland property rights has been priced into the market, and rural households of farmland transfer-in have lost the organizational space to earn the "public domain" of property rights [9–12]. On the other hand, the stable property rights of farmland encourage the impersonalization and high rent of farmland transfer among acquaintances [45], which enhances the bargaining position and bargaining power of farmland transfer-out transactions of rural households. As a result, farmland transfer-in of rural households based on the productive use of farmland is faced with the dilemma of increasing production expenditure due to the expansion of production scale, while the income from single-structure agricultural production increases. The theory of "loss aversion" suggests that rural households feel more strongly when weighing losses than gains [1]. In addition, farming is a tough occupation, and rural households value hard-earned income [3]. In view of this, rural households are reluctant to increase their non-food consumption of goods and services for convenience and performance needs as well as personal enjoyment and development needs [44], resulting in a slowdown or even a decrease in the growth rate of non-food consumption expenditure [46]. Instead, rural households tend to increase their spending on food consumption to satisfy physiological needs [44], which is not conducive to optimizing the consumption structure of rural households.

Based on the above theoretical analysis, this paper constructs an analytical framework for the impact of farmland transfer on rural households' consumption (see Figure 2). Meanwhile, the following research hypothesis 1, hypothesis 2 and hypothesis 3 are proposed.

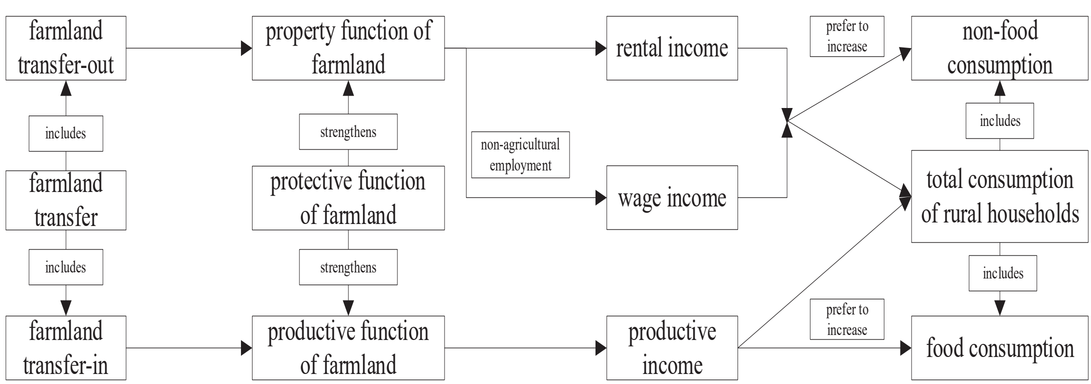


Figure 2. Analytical framework of the impact of farmland transfer on rural household consumption.

H1: *The transfer-out of farmland from rural households stimulates their consumption and makes them more willing to increase their non-food consumption expenditures, and then contributes to the optimization of their consumption structure.*

H2: *The transfer-in of farmland from rural households stimulates their consumption and makes them more willing to increase their food consumption expenditure, and then does not contribute to the optimization of their consumption structure.*

H3: *The transfer of farmland (farmland transfer-out or farmland transfer-in) from rural households affects their income under different livelihoods, and then affects their consumption and consumption structure.*

3. Research Design

3.1. Description of Selected Research Site and Data Sources

3.1.1. Description of Selected Research Site

Yunnan Province, located in southwest China, is an important part of the Yunnan-Kweichow Plateau and a relatively underdeveloped area in China. Compared with Guizhou Province, where 62% of the land area is karst landform, Yunnan Province has its comparative advantage in landform, which makes the farmland in Yunnan Province more valuable for circulation. In addition, although Yunnan Province is not the main grain-producing area in China, it is of great practical significance to study the impact of farmland transfer behavior on rural household consumption in plateau mountainous and underdeveloped areas. Based on the above explanations, we selected Yunnan Province as the final research point of this paper.

3.1.2. Data Sources

To explore the impact of farmland transfer on rural households' consumption, in November 2021, teachers, doctoral students and master's students of related majors from the School of Economics of Guizhou University and the School of Economics of Yunnan University, formed a relevant subject group to conduct rural household surveys in 16 prefecture-level cities or autonomous prefectures in Yunnan Province. In order to reduce sampling bias, the research team used a stratified random sampling method, stratified according to the administrative vertical relationship of the city (state)—county (city, district)—township (town)—village in turn. One county (city or district) was randomly selected in each prefecture-level city or autonomous prefecture, two townships or towns were randomly selected in each county (city or district), one to two villages were randomly selected in each township or town, and 10 to 15 questionnaires were randomly distributed to rural households in each village under investigation. In addition, this paper takes 2020 as a unit time cycle and a key time node of this survey, so as to facilitate the interview of relevant issues and data collection and collation by the members of the research group. Finally, in this survey, 650 questionnaires were distributed in 50 villages, and 600 questionnaires were recovered with a recovery rate of 92.31%. In addition, out of the 600 questionnaires collected, the questionnaires with obvious errors, repeated relevant content and inconsistent with the research theme of this paper were discarded. Finally, 537 valid questionnaires were obtained, involving 50 villages, with an effective rate of 82.62%.

3.2. Variable Settings

3.2.1. Explained Variables

The China National Bureau of Statistics categorizes the consumption of rural residents in China into eight major types, including food, clothing, housing, household equipment and supplies, transportation and communication, education and entertainment, health care and other consumption. Besides this, rural household and family are both organizational concepts. Unless otherwise specified, the number of rural households and family members in this paper is consistent. We use the 2020 per capita household consumption expenditure (logarithmicized) to represent the total consumption expenditure of rural households according to China's national statistical caliber and drawing on the research practices of Geng et al. [1], Chen et al. [19] and Yang et al. [21]. However, unlike Cai et al. [47] who covered per capita household consumption expenditure divided into three types of expenditure: subsistence consumption, developmental consumption and productive consumption to measure the consumption expenditure and consumption structure of rural households, this paper uses this feature of the Engel coefficient to reflect changes in consumption structure to dichotomize per capita household consumption expenditure in 2020 into two types of expenditure: per capita rural household food consumption and per capita rural household non-food consumption. As we all know, the Engel coefficient refers to the proportion of food consumption expenditure in the total consumption expenditure of the family. It was put forward by Engel, a German statistician in the 19th century, on the change of consumption structure based on empirical statistical data. Generally speaking, the smaller the Engel coefficient, the better the consumption structure of the family. In other words, the more the family spends on non-food consumption, the better the consumption structure of the family will be.

3.2.2. Explanatory Variables

The modes of farmland transfer are more complex, including lease, exchange, transfer, equity and etc. Drawing on the research results of Chen et al. [19] and Yang et al. [21], this paper uses farmland transfer-out and farmland transfer-in to measure farmland transfer: (1) Farmland transfer-out, the question in the research questionnaire is "In 2020, did your family transfer-out contracted land to others?". The relevant values are: 1 = yes and 0 = no. (2) Farmland transfer-in, means "In 2020, did your family transfer in contracted land from other people or collectives, excluding your own contracted land?". If the answer is "yes", the value is 1, and if not, the value is 0.

3.2.3. Mediating Variable

In order to test whether farmland transfer (farmland transfer-out or farmland transfer-in) affects the income of rural households under different livelihoods, and then affects the consumption structure of rural households. In the questionnaire, we set the question "What is the annual income of your family in 2020 by choosing the corresponding livelihood mode through the transfer of farmland (farmland transfer-out or farmland transfer-in)?" to identify this. In addition, the logarithm of per capita household income in 2020 was used to indicate the income of rural households under different livelihood options.

3.2.4. Control Variables

To mitigate the omission of variables that lead to biased estimation results, this paper also includes variables at the level of household head characteristics [1], family characteristics [19] and village characteristics [21] that affect rural household consumption as control variables. Among them, household head characteristics include the gender of the household head, age of the household head and marriage of the household head; family characteristics include the number of family members, age per capita of the family and assets per capita of the family (logarithmicized); and village characteristics include whether there is non-agricultural economy in the village, the availability of public transportation in the village, the topographical condition of the village, and the distance from the village to the county. In addition, the unit of consumption and asset-related variables is RMB yuan, and there is no unit in the value assignment of variables after logarithmic processing. The specific relevant variable settings and statistical descriptions are shown in Table 1.

Table 1. Variable definitions and descriptive statistics.

Dimension	Variable Name	Variable Assignment	Mean	Standard Deviation
Explained variables	Total consumption of rural households	ln (1 + per capita household consumption expenditure)	9.487	0.746
	Food consumption	1n (1 + per capita household consumption expenditure on food)	8.445	0.807
	Non-food consumption	1n (1 + household per capita non-food consumption expenditure)	8.871	1.008
Explanatory variables	Farmland transfer-out	1 = yes, 0 = no	0.340	0.474
	Farmland transfer-in	1 = yes, 0 = no	0.375	0.485
Mediating variable	rural household income	ln (1 + household income per capita)	9.809	1.381
Control variables	Gender of household head	1 = male, 0 = female	0.677	0.480
	Age of household head	age	49.907	9.969
	Marriage of household head	1 = married, 0 = unmarried	0.981	0.172
	Number of family members	person	3.752	1.378
	Family age per capita	age	39.802	12.000
	Family assets per capita	ln (1 + family assets per capita)	11.356	1.042
	Whether there is non-agricultural economy in the village	1 = with non-agricultural economy, 0 = without non-agricultural economy	0.601	0.494
	Availability of public transportation in the village	1 = with public transportation, 0 = without public transportation	0.662	0.473
	Topographical conditions of the village	1 = flat land, 2 = sloping land	1.483	0.511
	Distance from the village to the county	km	27.645	20.256

3.3. Model Selection

Because this paper mainly explores the impact of farmland transfer on rural household consumption, it is appropriate to use an OLS model for estimation. To this end, a relevant benchmark model is constructed by drawing on the research practices of Dong and Huang [48] and Hu and Ding [22], which has the following basic form:

$$CS_i = \beta_0 + \beta_1 X_i + \beta_2 D_i + \varepsilon_{i1} \tag{1}$$

In Equation (1), CS_i denotes the total consumption of rural households, food consumption and non-food consumption. X_i denotes farmland transfer-out and farmland transfer-in. D_i denotes a matrix of control variables, including household head characteristics, family characteristics and village characteristics. β_0 is a constant term, β_1 and β_2 are coefficients to be estimated and ε_{i1} denotes an error term and is assumed to satisfy a standard normal distribution.

To test whether farmland transfer (farmland transfer-out or farmland transfer-in) acts on rural households' consumption and consumption structure through the path of influencing rural households' income under different livelihoods. Then, this paper draws on the study of Wen and Ye [49] and further constructs an intermediary effect model based on model (1) with rural households' income under different livelihoods as the mediating variable as follows:

$$FI_i = \delta_0 + \delta_1 X_i + \delta_2 D_i + \varepsilon_{i2} \tag{2}$$

$$CS_i = \phi_0 + \phi_1 X_i + \phi_2 FI_i + \phi_3 D_i + \varepsilon_{i3} \tag{3}$$

In the above model, FI_i is the mediating variable, representing rural households' income under different livelihoods; δ_0 and ϕ_0 are constant terms, δ_1, δ_2, ϕ_1, ϕ_2 and ϕ_3 are coefficients to be estimated, ε_{i2} and ε_{i3} denote error terms and are assumed to satisfy standard normal distribution; other variables and coefficients are defined in the same way as Equation (1).

4. Results and Analysis

4.1. Multicollinearity Test

Since the introduction of more variables at the level of household head characteristics, family characteristics and village characteristics in this paper may pose the problem of multicollinearity, variance inflation factor (VIF) is used for multicollinearity diagnosis. In Table 2, the results show that the variance inflation factor (VIF) values are all less than 10, and we can judge that there is no more serious multicollinearity problem basically.

Table 2. Multicollinearity test.

Variable Name	Total Consumption of Rural Households		Food Consumption		Non-Food Consumption	
	VIF	VIF	VIF	VIF	VIF	VIF
Farmland transfer-out	1.401		1.412		1.461	
Farmland transfer-in		1.343		1.329		1.394
Rural household income	1.261	1.216	1.217	1.319	1.378	1.301
Gender of household head	1.231	1.097	1.283	1.271	1.269	1.265
Age of household head	1.116	1.112	1.328	1.374	1.325	1.451
Marriage of household head	1.383	1.262	1.391	1.471	1.271	1.308
Number of family members	1.365	1.341	1.413	1.296	1.523	1.357
Family age per capita	1.219	1.258	1.258	1.365	1.579	1.426
Family assets per capita	1.187	1.096	1.143	1.429	1.421	1.329
Whether there is non-agricultural economy in the village	1.236	1.163	1.274	1.385	1.438	1.075
Availability of public transportation in the village	1.291	1.061	1.381	1.279	1.219	1.091
Topographical conditions of the village	1.363	1.247	1.227	1.394	1.105	1.208
Distance from the village to the county	1.348	1.119	1.421	1.283	1.194	1.364

4.2. Benchmark Regression Results

4.2.1. Analysis of the Impact of Farmland Transfer-Out on Rural Household Consumption

In Table 3, the coefficients of the farmland transfer-out variable are significantly positive, and the coefficient of non-food consumption is 0.118, which is larger than the coefficient of food consumption is 0.016, which verifies hypothesis 1 of this paper, that is, farmland transfer-out can stimulate the consumption of rural households, and rural households are more willing to increase their non-food consumption expenditure, which is beneficial to the optimization of rural consumption structure. The "psychological accounts" theory states that people categorize their income into different accounts according to the way they receive it, which are mutually exclusive and not complementary, and that different income patterns result in different consumption tendencies [1]. The income structure will become richer as rural households generally receive farmland rental income and wage income after their farmland is transferred out, which will continuously strengthen the subjective wealth effect of rural households and induce them to consume. In addition, after rural households transfer out of farmland, they will generally move away from the countryside to engage in non-agricultural production activities in the city. Affected by the new consumption habits of the surrounding people, rural households who transfer-out farmland will gradually change their original consumption habits that prefer to increase food consumption expenditure to those that are more willing to increase non-food consumption expenditure. Therefore, when rural households satisfy the surplus of food consumption expenditure, they are more willing to increase the expenditure on non-food consumption, and their consumption structure will be optimized accordingly.

Table 3. Impact of farmland transfer on rural household consumption: Results of benchmark regression.

Variable Name	Total Consumption of Rural Households		Food Consumption		Non-Food Consumption	
Farmland transfer-out	0.083 **		0.016 **		0.118 **	
	(2.454)		(2.323)		(2.367)	
Farmland transfer-in		0.017 **		0.028 **		0.009 **
		(2.445)		(2.312)		(2.327)
Gender of household head	0.020	−0.065	−0.072	0.001	−0.010	−0.021
	(0.237)	(−0.961)	(−1.068)	(0.015)	(−0.167)	(−0.362)
Age of household head	−0.023 ***	−0.021 ***	−0.010 ***	−0.016 ***	−0.017 ***	−0.018 ***
	(−5.467)	(−3.040)	(−2.899)	(−5.166)	(−5.616)	(−5.367)
Marriage of household head	0.107	−0.129	−0.136	0.114	0.029	0.032
	(0.466)	(−0.691)	(−0.730)	(0.499)	(0.183)	(0.202)
Number of family members	−0.020	−0.063	−0.063	−0.024	−0.030	−0.033
	(−0.665)	(−0.154)	(−0.156)	(−0.801)	(−1.430)	(−1.537)
Family age per capita	−0.010	−0.007	−0.008	−0.004	−0.092	−0.004
	(−0.149)	(−1.364)	(−1.234)	(−1.071)	(−1.241)	(−0.086)
Family assets per capita	0.298 ***	0.209 ***	0.107 ***	0.184 ***	0.189 ***	0.192 ***
	(4.574)	(5.921)	(5.897)	(4.394)	(6.213)	(6.064)
Whether there is non-agricultural economy in the village	−0.041	−0.004	−0.005	−0.057	−0.034	−0.043
	(−0.493)	(−0.061)	(−0.067)	(−0.694)	(−0.583)	(−0.740)
Availability of public transportation in the village	−0.099	−0.047	−0.047	−0.081	−0.054	−0.045
	(−1.136)	(−0.660)	(−0.665)	(−0.936)	(−0.894)	(−0.736)
Topographical conditions of the village	−0.015	0.036	0.032	−0.013	−0.001	−0.001
	(−0.174)	(0.525)	(0.452)	(−0.155)	(−0.015)	(−0.009)
Distance from the village to the county	0.002	0.000	0.000	0.000	0.000	−0.001
	(0.913)	(0.200)	(0.204)	(0.218)	(0.188)	(−0.342)
-Cons	7.634 ***	8.821 ***	8.443 ***	7.387 ***	11.343 ***	7.936 ***
	(8.638)	(10.561)	(10.560)	(8.691)	(14.313)	(14.394)
N	537	537	537	537	537	537

Note: *** and ** refer to the statistics being significant at the 1% and 5% levels, respectively. Inside the regression parentheses are *t* values of coefficients.

4.2.2. Analysis of the Impact of Farmland Transfer-In on Rural Household Consumption

The coefficients of farmland transfer-in variables are significantly positive, and the coefficient of food consumption is 0.028, which is larger than the coefficient of non-food consumption is 0.009. Hypothesis 2 of this paper that farmland transfer can stimulate rural household consumption but rural households who transfer-in farmland are more willing to increase their expenditure on food consumption, which is not beneficial to the optimization of their consumption structure, is confirmed. Schultz's rational theory of small farmers shows that small farmers are poor and efficient, that is, farmers are people with entrepreneurial spirit and can use the right resources [22]. Rural households who transfer-in farmland may engage in moderate scale operation, take advantage of the scale of farmland to reduce the cost of agricultural production, give full play to the rational and effective allocation of resources such as labor and agricultural machinery for agricultural production to bring about an increase in production efficiency, improve the income of agricultural production of rural households and enhance the consumption capacity of rural households. As a matter of fact, agriculture is a very difficult occupation, and rural households cherish the income that is difficult to obtain. In addition, rural households tend to have a high propensity to save preventively for a single productive income from agriculture [47]. After rural households transfer-in farmland, they are still mainly engaged in agricultural production. The consumption habits of the surrounding people and themselves will not change much. Rural households who transfer-in farmland will still maintain their original consumption habits and are more willing to increase food consumption expenditure than non-food expenditure. Therefore, the increase in income obtained from the transfer-in of farmland to rural households will increase their consumption capacity to a certain extent, but they will save after satisfying the surplus of food consumption expenditure and are generally unwilling to spend too much on non-food consumption, which makes it difficult to optimize their consumption structure.

Furthermore, based on the communication with rural households in the field survey, we know that rural households are mainly engaged in agricultural production before the transfer of farmland. Although the total consumption expenditure of rural households will increase, rural households are more inclined to increase food consumption expenditure, which is not conducive to the optimization of rural households' consumption structure. After the transfer of farmland, the total consumption expenditure of rural households will continue to increase, but rural households who transfer-in farmland are more willing to increase food consumption expenditure, which is not conducive to the optimization of their consumption structure. The rural households that transfer-out farmland are more willing to increase non-food consumption expenditure, which is beneficial to the optimization of their consumption structure. Therefore, the farmland transfer has a heterogeneous impact on the consumption expenditure and consumption structure of rural households of the farmland transfer-out and rural households of the farmland transfer-in.

4.2.3. Analysis of the Impact of Control Variables on Rural Household Consumption

The coefficients of the household head's age variable are all significantly negative, and their coefficients on food consumption are larger than those on non-food consumption, that is, the consumption expenditure of rural households tends to decline as the household head gets older, and their consumption structure also shows a deterioration. The possible explanation is that in rural Chinese society, the head of the household is the mainstay of the family and his income is the most important source of income for the rural household. The coefficients of the family assets per capita variable are all significantly positive, and their coefficients on non-food consumption are larger than those on food consumption, indicating that the more family assets, rural households have the stronger consumption capacity and the more conducive to optimizing their consumption structure. The possible reason for this is that family assets have a certain "wealth effect" and "asset effect", which can bring a stable income stream to rural households, thus enhancing their consumption ability and improving their consumption structure [48].

4.3. Robustness Test and Endogeneity Discussion

4.3.1. Robustness Test I: Sub-Sample Test

In the field research, we found that a few rural households have two-way farmland transfer behaviors of both farmland transfer-out and farmland transfer-in. However, mixing rural households' two-way farmland transfer behaviors with one-way farmland transfer behavior for regression estimation may affect the authenticity of the results. For this reason, drawing on the study of Yang et al. [21], the data of a sample of 16 rural households with both farmland transfer-out and farmland transfer-in 2020 are excluded from the subsample test. The results in Table 4 show that the significance level of coefficients and the sign of coefficients of the farmland transfer-out and farmland transfer-in variables and the magnitude of coefficients between them on food consumption and on non-food consumption variables are consistent with the results of the benchmark regression, indicating that the benchmark regression results are robust.

Table 4. Robustness test I: Sub-sample test.

Variable Name	Total Consumption of Rural Households		Food Consumption		Non-Food Consumption	
Farmland transfer-out	0.081 **		0.018 **		0.119 **	
	(2.426)		(2.318)		(2.347)	
Farmland transfer-in		0.016 **		0.029 **		0.008 **
		(2.432)		(2.351)		(2.358)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
-Cons	7.595 ***	8.812 ***	8.424 ***	7.408 ***	11.348 ***	7.913 ***
	(8.701)	(10.596)	(10.243)	(8.638)	(14.254)	(14.313)
N	521	521	521	521	521	521

Note: *** and ** refer to the statistics being significant at the 1% and 5% levels, respectively. Inside of regression parentheses are *t* values of coefficients. Control variables are kept consistent with Table 3.

4.3.2. Robustness Test II: Replacing Core Explanatory Variables and Re-Estimating

To exclude the estimation bias caused by measurement bias, this paper uses the method of Hu and Ding [22] to conduct robustness tests using the average per mu income from farmland transfer-out and the average per mu expenditure from farmland transfer-in as proxies for farmland transfer-out and farmland transfer-in[5], respectively. The results in Table 5 show that the significance levels of the coefficients and the sign of the coefficients of the variables of the average per mu income from farmland transfer-out and the average per mu expenditure from farmland transfer-in and the magnitudes of the coefficients between the variables of food consumption and non-food consumption are consistent with the results of the benchmark regression, indicating that the results of the benchmark regression are robust.

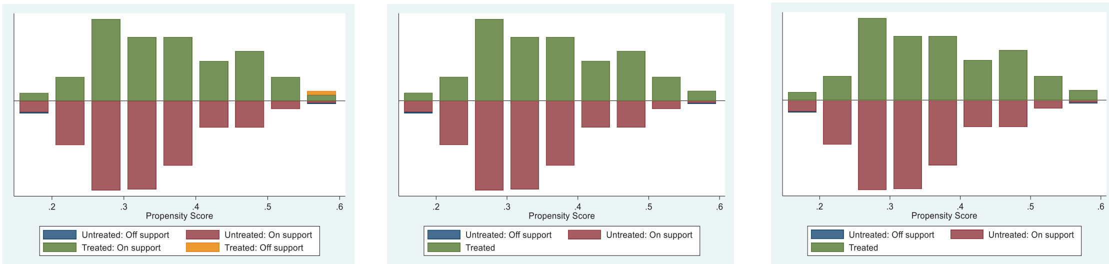
Table 5. Robustness test II: Replacement of core explanatory variables.

Variable Name	Total Consumption of Rural Households		Food Consumption		Non-Food Consumption	
The average per mu income from farmland transfer-out	0.016 **		0.009 **		0.019 **	
	((2.362))		((2.543))		((2.436))	
The average per mu expenditure from farmland transfer-in		0.007 **		0.009 **		0.005 **
		(2.392)		(2.385)		(2.521)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
-Cons	6.527 ***	7.697 ***	7.493 ***	6.467 ***	10.396 ***	6.921 ***
	(8.576)	(9.989)	(10.542)	(9.634)	(11.357)	(11.186)
N	537	537	537	537	537	537

Note: *** and ** refer to the statistics being significant at the 1% and 5% levels, respectively. Inside of regression parentheses are *t* values of coefficients. Control variables are kept consistent with Table 3.

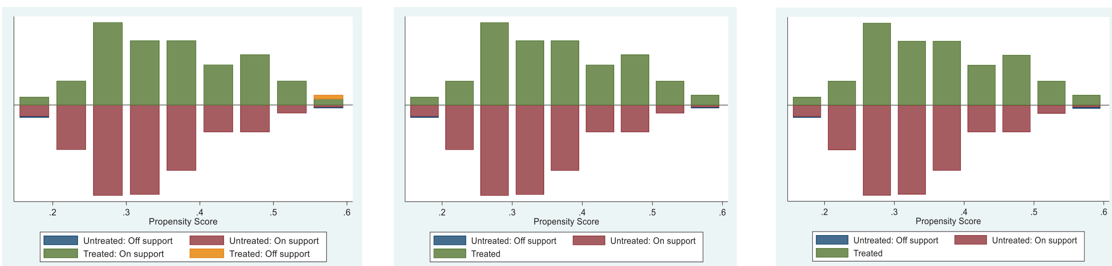
4.3.3. Robustness Test III: Re-Estimation Using Propensity Matching Score Method

To eliminate the endogeneity problem caused by the possible selectivity bias of the sample, this paper uses the propensity matching score method (PSM) for robustness testing [50]. Based on Table 3 control variables matching control and experimental groups, rural households of farmland transfer-out and farmland transfer-in are set as the experimental group, and rural households of farmland non-transfer-out and farmland non-transfer-in are set as the control group. The average treatment effects (ATT) of farmland transfer-out and farmland transfer-in are estimated using nearest neighbor matching, radius matching and kernel matching, respectively. The results of the common support condition test of Figure 3 show that most of the observations are within the common range of values when matching using the three matching methods of nearest neighbor matching (k = 4), radius matching (caliper = 4) and kernel matching (bwidth = 0.06), and thus the matching quality is reliable.



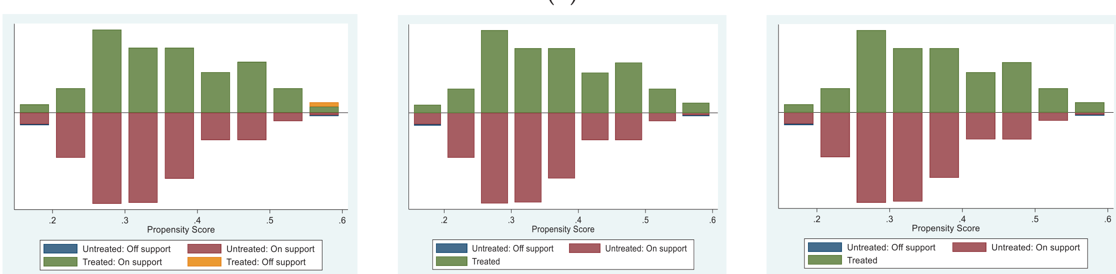
nearest neighbor matching radius matching kernel matching

(**a**)



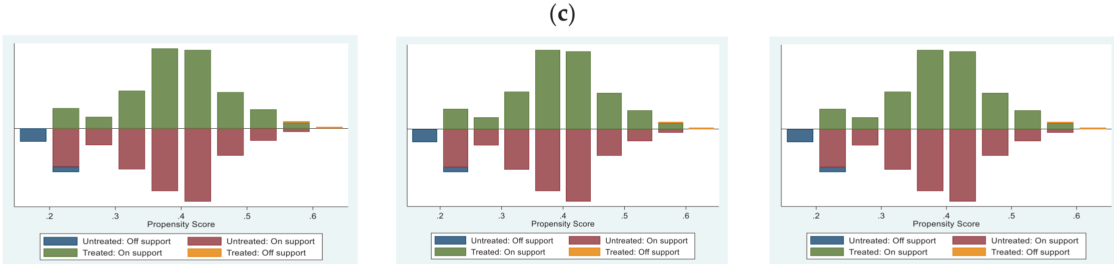
nearest neighbor matching radius matching kernel matching

(**b**)



nearest neighbor matching radius matching kernel matching

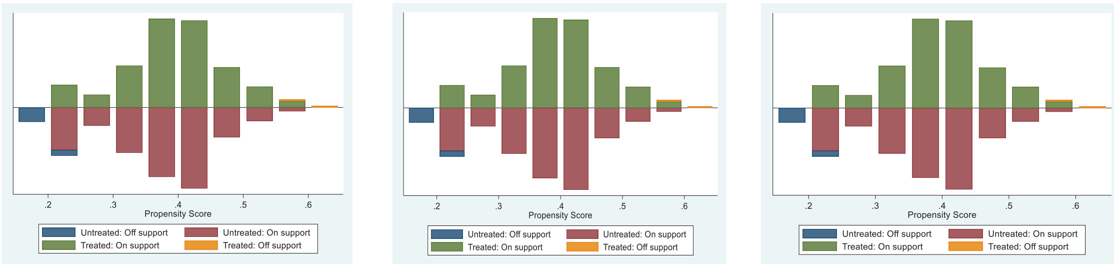
(**c**)



nearest neighbor matching radius matching kernel matching

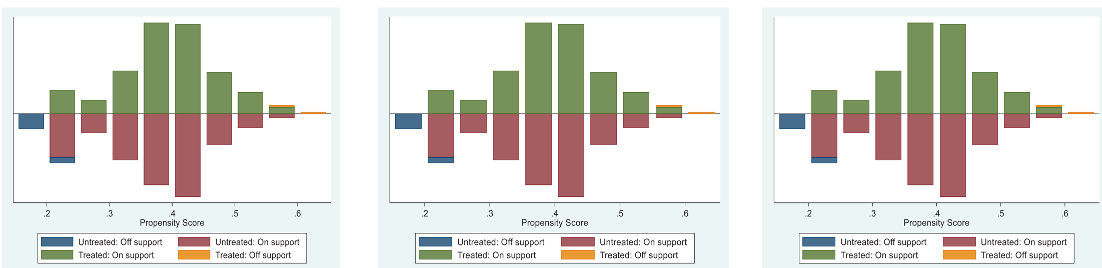
(**d**)

Figure 3. *Cont.*



nearest neighbor matching radius matching kernel matching

(**e**)



nearest neighbor matching radius matching kernel matching

(**f**)

Figure 3. Propensity score distribution and the common support for propensity score estimation. (**a**) farmland transfer-out and farmland not transfer-out, *CS* = total consumption of rural households. (**b**) farmland transfer-out and farmland not transfer-out, *CS* = food consumption. (**c**) farmland transfer-out and farmland not transfer-out, *CS* = non-food consumption. (**d**) farmland transfer-in and farmland not transfer-in, *CS* = total consumption of rural households. (**e**) farmland transfer-in and farmland not transfer-in, *CS* = food consumption. (**f**) farmland transfer-in and farmland not transfer-in, *CS* = non-food consumption.

The results in Table 6 show that the average treatment effects obtained by the nearest neighbor matching, radius matching and kernel matching methods provide further evidence that either farmland transfer-out or farmland transfer-in significantly enhances the consumption capacity of rural households. In addition, taking the nearest neighbor matching method as an example, after excluding other factors, the per capita non-food consumption expenditure of rural households transferred out farmland will increase by 4.081% (exp (0.040) − 1), which is larger than the per capita food consumption expenditure by 0.602% (exp (0.006) − 1), and the per capita food consumption expenditure of rural households transferred in farmland will increase by 1.207% (exp (0.012) − 1), which is larger than the per capita non-food consumption expenditure by 0.401% (exp (0.004) − 1). Therefore, the re-estimation results based on the propensity matching score method (PSM) show that the benchmark regression results are robust.

Table 6. Robustness test III: Re-estimation using PSM.

Variable Name	Matching Methods	ATT(Farmland Transfer-out)	*t*-Value	ATT(Farmland Transfer-In)	*t*-Value
Total consumption of rural households	nearest neighbor matching	0.030 ***	3.224	0.007 ***	3.278
	radius matching	0.029 ***	3.486	0.006 ***	3.316
	kernel matching	0.029 ***	3.218	0.006 ***	3.265
Food consumption	nearest neighbor matching	0.006 ***	3.212	0.012 ***	3.223
	radius matching	0.006 ***	3.317	0.011 ***	3.468
	kernel matching	0.005 ***	3.236	0.010 ***	3.384
Non-food consumption	nearest neighbor matching	0.040 ***	3.238	0.004 ***	3.341
	radius matching	0.039 ***	3.311	0.004 ***	3.408
	kernel matching	0.038 ***	3.289	0.003 ***	3.227

Note: *** refers to the statistics being significant at the 1% level. Control variables are kept consistent with Table 3.

4.3.4. Robustness Test IV: Re-Estimation Using Instrumental Variable Method

When examining the impact of farmland transfer on rural household consumption, there may be endogeneity problems caused by reverse causality and omitted variables, and then the direct use of the OLS estimation method is likely to cause bias in model estimation. For this reason, this paper attempts to construct an instrumental variable model to eliminate the endogeneity problem caused by reverse causality and omitted variables. Drawing on the research results of Yang et al. [21] and Hu and Ding [22], the two-stage least squares (2SLS) estimation is conducted using "village farmland transfer-out rate" and "village farmland transfer-in rate" as the instrumental variables for farmland transfer-out and farmland transfer-in. As we all know, a qualified instrumental variable must satisfy two conditions, namely, the instrumental variable is highly correlated with the endogenous explanatory variables (correlation) and the instrumental variable is uncorrelated with the disturbance term (exogeneity). In this paper, the "village farmland transfer-out rate" and "village farmland transfer-in rate" are calculated based on the level of farmland transfer-out and the level of farmland transfer-in in the surveyed villages, which satisfy the requirements of correlation and exogeneity of the instrumental variable. The results in Table 7 show that the one-stage F values are all much greater than 10, indicating that the model does not have the problem of weak instrumental variables. The DWH values reject the original hypothesis that farmland transfer-out and farmland transfer-in are exogenous variables at the 1% level, indicating that the model has endogeneity problems. However, after correcting for the endogeneity problem induced by reverse causality and omitted variables, the significance level of coefficients and the sign of coefficients of farmland transfer-out and farmland transfer-in variables and the magnitude of coefficients between them on food consumption and on non-food consumption variables are consistent with the results of the benchmark regression, which verifies the credibility of the benchmark regression results.

Table 7. Robustness test IV: Re-estimation using instrumental variables method.

Variable Name	Total Consumption of Rural Households		Food Consumption		Non-Food Consumption	
Farmland transfer-out	0.064 **		0.011 **		0.116 **	
	(2.468)		(2.357)		(2.349)	
Farmland transfer-in		0.016 **		0.023 **		0.007 **
		(2.412)		(2.316)		(2.363)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Adj R^2	0.341	0.295	0.234	0.213	0.263	0.245
The one-stage F-value	100.781	99.867	96.483	96.538	95.892	97.346
DWH-Chi^2	10.212 ***	10.028 ***	9.863 ***	9.816 ***	9.647 ***	9.829 ***
N	537	537	537	537	537	537

Note: *** and ** refer to the statistics being significant at the 1% and 5% levels, respectively. Inside the regression parentheses are *t* values of coefficients. Control variables are kept consistent with Table 3.

4.4. Endogeneity Discussion

The endogeneity problem is mainly caused by measurement error, selectivity bias, omitted variables and reverse causality [51]. For the measurement error problem, this paper solves it by replacing the core explanatory variables. For the selectivity bias problem, this paper mitigates it by using the propensity matching score method (PSM), which enables the observations to effectively avoid the estimation bias caused by sample self-selection through matching and resampling [52], thus improving the accuracy of the estimation results. For the omitted variables and reverse causality problems, this paper eliminates them by using the instrumental variables method, while adding as many control variables as possible to exclude the influence of omitted observables on the estimation results of this paper. In addition, the sub-sample of 16 households with both farmland transfer-out and farmland transfer-in is excluded for re-estimation to exclude the influence of different samples with different sensitivity to the obtained results. In summary, strictly speaking, there is no particularly serious endogeneity problem in this paper.

4.5. Mechanism of Action: Intermediary Effect Test

The results of the benchmark regressions and robustness tests indicate that farmland transfer (farmland transfer-out or farmland transfer-in) can stimulate rural household consumption, but there is heterogeneity in its effect on the consumption structure of rural households of farmland transfer-out and rural households of farmland transfer-in. Here, we further use the intermediary effect model to test its internal transmission mechanism. However, whether farmland is transferred out or transferred in actually represents the choice of livelihood modes of different rural households. As a result, the income of rural households who transfer-out farmland mainly includes rental income and wage income, and the income of rural households who transfer-in farmland mainly includes productive income. Therefore, this paper is not to test the intermediary effect of rent income, wage income and productive income on rural household consumption in the transfer of farmland, but to test the intermediary effect of income from the farmland transfer-out of rural households (the sum of rent income and wage income) on rural households' consumption and productive income from the farmland transfer-in of rural households on rural households' consumption. The results in Table 8 show that there is a significant positive effect of farmland transfer on the income of rural households under different livelihoods, indicating that rural households after farmland transfer can bring in stable income based on different livelihood strategies. In addition, the fitted regression results show that rural household income under different livelihoods positively affects total consumption of rural households, food consumption and non-food consumption at the 1% level of significance, which indicates that the intermediary effect of rural household income under different livelihoods exists and is significant. Besides this, the optimized consumption structure of rural households of farmland transfer-out and the deteriorated consumption structure of rural households of farmland transfer-in remain consistent with the benchmark regression results. That is, the impact path of "farmland transfer—rural households' income under different livelihoods—rural household consumption" holds. Through calculation, it is found that the intermediary effects of farmland transfer-out on the total consumption of rural households, food consumption and non-food consumption by affecting the income of rural households of farmland transfer-out are 39.014% (39.014% is obtained by multiplying the coefficient 0.257 of the farmland transfer-out variable to the rural household income variable in Table 8 by the coefficient 0.126 of the direct effect of the rural household income variable to the total consumption of rural households variable, and then dividing it by the coefficient 0.083 of the farmland transfer-out variable to the total consumption of rural households variable in Table 3, and then multiplying it by 100%. The rest of the intermediary effect proportion data can be obtained according to this calculation method), 30.519% and 44.648%, respectively; the intermediary effects of farmland transfer-in on the total consumption of rural households, food consumption and non-food consumption by affecting the income of rural households of farmland transfer-in are 38.912%, 40.250%

and 35.389%, respectively, which show that the intermediary effect accounts for a large proportion in the total utility of affecting the total consumption of rural households, food consumption and non-food consumption. The income of rural households based on different livelihood modes is a transmission mechanism that can not be ignored in the impact of farmland transfer on the rural household consumption, respectively. In addition, under different livelihood strategies, rural households' dependence on agricultural income is different, which may also be an important potential reason for the optimization of rural households who transfer-out farmland consumption structure and the deterioration of rural households who transfer-in farmland consumption structure. The intermediary effect of this paper is a partial intermediary effect.

Table 8. Intermediary effect test.

Variable Name	Rural Household Income		Total Consumption of Rural Households		Food Consumption		Non-Food Consumption	
Farmland transfer-out	0.257 ***		0.051 **		0.011 **		0.065 **	
	(3.518)		(2.337)		(2.362)		(2.464)	
Farmland transfer-in		0.245 ***		0.010 **		0.017 **		0.006 **
		(3.459)		(2.351)		(2.348)		(2.336)
Rural household income			0.126 ***	0.027 ***	0.019 ***	0.046 ***	0.205 ***	0.013 ***
			(3.351)	(3.421)	(3.462)	(3.475)	(3.373)	(3.648)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
-Cons	7.621 ***	8.232 ***	6.476 ***	8.342 ***	8.411 ***	7.253 ***	9.243 ***	7.814 ***
	(6.232)	(6.838)	(8.325)	(9.187)	(9.904)	(8.362)	(13.473)	(13.857)
N	537	537	537	537	537	537	537	537

Note: *** and ** refer to the statistics being significant at the 1% and 5% levels, respectively. Inside the regression parentheses are *t* values of coefficients. Control variables are kept consistent with Table 3.

At the same time, a non-parametric percentile bootstrap sampling method with bias correction is used to conduct 5000 sampling tests to examine the intermediary effect of rural households' income under different livelihoods. In Table 9, the value of $\delta_1 \times \phi_2$ does not contain 0 at a 95% confidence interval, and the coefficients of δ_1, ϕ_1 and ϕ_2 pass the 5% significance level test, and $\delta_1 \times \phi_2$ has the same sign as ϕ_1, which indicate that the income of rural households under different livelihoods plays a part in the intermediary effect of farmland transfer on rural households' consumption and consumption structure, thus the results of the intermediary effect model test in this paper are valid and robust.

Table 9. Robustness test of intermediary effect.

Coefficient	Farmland Transfer-Out			Farmland Transfer-In		
	Total Consumption of Rural Households	Food Consumption	Non-Food Consumption	Total Consumption of Rural Households	Food Consumption	Non-Food Consumption
β_1	0.083 ** (2.454)	0.016 ** (2.323)	0.118 ** (2.367)	0.017 ** (2.445)	0.028 ** (2.312)	0.009 ** (2.327)
δ_1		0.248 *** (3.186)			0.235 *** (3.672)	
ϕ_2	0.137 *** (3.867)	0.021 *** (3.652)	0.211 *** (3.034)	0.031 *** (3.651)	0.049 *** (3.439)	0.017 *** (3.758)
$\delta_1 \times \phi_2$	0.034	0.005	0.052	0.007	0.012	0.004
$\delta_1 \times \phi_2$ (95% Boot CI)	0.0013~0.0126	0.0002~0.026	0.0113~0.2212	0.0021~0.0301	0.0036~0.0512	0.0016~0.0213
Φ_1	0.049 ** (2.353)	0.011 ** (2.325)	0.066 ** (2.375)	0.010 ** (2.363)	0.016 ** (2.298)	0.005 ** (2.362)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
-Cons	8.634 *** (7.654)	8.975 *** (8.134)	7.908 *** (9.079)	8.768 *** (9.908)	9.031 *** (12.136)	8.902 *** (11.784)
Test conclusion	Partial intermediary effect	Partial intermediary effect	Partial intermediary effect	Partial intermediary effect	Partial intermediary effect	Partial intermediary effect

Note: *** and ** refer to the statistics being significant at the 1% and 5% levels, respectively. Inside the regression parentheses are *t* values of coefficients. Control variables are kept consistent with Table 3.

5. Discussion

In this section, we discuss the potential contributions and limitations of this research.

The first discussion concerns the major contributions to the existing literature. This paper contributes to the current studies in four ways. (1) We use the survey data of 537 rural households in 50 villages in Yunnan Province, which is relatively underdeveloped in Southwest China and is located in the Yunnan-Kweichow Plateau, mainly in plateau and mountain terrain, to study the impact of farmland transfer on rural household consumption, which has unique regional characteristics and greater practical significance. (2) By constructing an analytical framework of "farmland transfer—farmland function—income structure—rural household consumption", we comprehensively analyzed the theoretical mechanism relationship between farmland transfer and rural household consumption. (3) Although there is a small amount of literature on the impact of farmland transfer on rural household consumption, this paper more systematically studies the impact of farmland transfer on rural household consumption through benchmark regression, robustness test and intermediary effect test. At the same time, we have achieved more fruitful study results. (4) Based on the empirical study of 537 rural households in 50 villages in Yunnan Province, we have obtained some new findings. For example, rural household consumption expenditure will show a downward trend with the increase in the age of the head of rural household, and the consumption structure will also show a deterioration. Another example is that the more family assets, rural households have the stronger consumption expenditure capacity, which is conducive to optimizing their consumption structure.

The second discussion is about the limitations of this study. (1) The results of this study are based on the corresponding empirical analysis of 537 rural households survey data in 50 villages in Yunnan Province. There are certain regional limitations, and whether it is applicable to other regions remains to be discussed, but the significance of the results of this study is not to be underestimated. (2) Based on the cross-sectional data of 537 households in 50 villages in Yunnan Province in 2020, the research conclusion is that the static impact of farmland transfer on rural household consumption and consumption structure cannot reflect the trend of time dynamic impact of farmland transfer on rural household consumption and consumption structure. This requires our team to conduct a continuous follow-up survey on these rural households and use panel data to overcome the limitation of this study.

6. Conclusions and Policy Implications

6.1. Conclusions

Based on the first-hand survey data of 537 rural households in 50 villages in Yunnan Province, this paper constructs an analytical framework of "farmland transfer—farmland function—income structure—rural household consumption", uses the OLS model to deeply explore the impact of farmland transfer on rural household consumption, and further uses the intermediary effect model to explore its internal transmission mechanism. The following conclusions are drawn: First, farmland transfer (farmland transfer-out or farmland transfer-in) can stimulate rural household consumption. Second, the coefficient of farmland transfer-out to non-food consumption is 0.118, which is larger than the coefficient of farmland transfer-out to food consumption is 0.016; rural households who transfer-out farmland are more willing to increase non-food consumption expenditure, which is beneficial to the optimization of their consumption structure. Third, the coefficient of farmland transfer-in to food consumption is 0.028, which is larger than its coefficient of non-food consumption is 0.009; rural households who transfer-in farmland are more willing to increase food consumption expenditure, which is not conducive to the optimization of their consumption structure. The above research results are still robust after excluding possible endogenous problems through four robustness tests, namely, sub-sample test, replacement core explanatory variables test, propensity matching score (PSM) test and instrumental variable test, which shows that the conclusions obtained from benchmark regression are true and reliable to a large extent. Fourth, rural household consumption expenditure will show a downward trend with the increase in the age of the head of the rural household, and the consumption structure will also show a deterioration. Fifth, the more family assets, rural households have the stronger consumption expenditure capacity, which is conducive to optimizing their consumption structure. Sixth, the results of the intermediary effect model show that the transfer of farmland affects rural households' consumption and consumption structure by affecting rural households' income under different livelihood modes. At the same time, using the non-parametric percentile bootstrap sampling method of deviation correction, the results of 5000 sampling tests show that the effect of the intermediary effect model is effective and robust.

6.2. Policy Implications

Improving the consumption capacity and consumption level of rural households is not only a strong response to the major strategic deployment of "accelerating the construction of a new development pattern with domestic big cycle as the main body and domestic and international double cycles promoting each other" put forward in China's 14th Five-Year Plan, but also conducive to the orderly advancement of China National New Urbanization Plan and China Rural Revitalization Strategy. Therefore, in order to further release the consumption capacity of rural households and improve their consumption level, this paper draws the following enlightenment: first, it is necessary to establish the interest coordination mechanism of farmland transfer, constantly reduce the transaction cost of farmland transfer and guide rural households to carry out farmland transfer in an orderly manner, so as to realize the optimal allocation of farmland resources. Second, improve the non-agricultural employment mechanism of rural surplus labor force, reasonably arrange rural households of farmland transfer-out and strengthen their skills training, so as to ensure the stability of their non-agricultural employment and obtain higher income. Third, improve the stability of farmland property rights, promote rural households of farmland transfer-in for moderate scale operation and constantly encourage them to improve the expected return on investment in farmland, so as to ensure the sustained and stable growth of their agricultural production. Fourth, social security shoulders the major responsibility of ensuring people's livelihood, promoting social equity and meeting the needs of the people for a better life. In the new era, rural areas should build a multi-level social security system in an all-around way, so as to lay a foundation for promoting the improvement of rural households' consumption ability and the optimization of consumption structure. Fifth, rural households should save an appropriate amount of their income and appropriately increase their family assets.

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Notes

[1] Data source: http://www.stats.gov.cn/tjsj/sjjd/202201/t20220118_1826529.html (accessed on 12 October 2022).

[2] 1 mu = 1/15 hectare.

[3] Data source: «China Statistical Yearbook» (2014–2019).

[4] In this paper, rural household consumption of rural households, food consumption and non-food consumption; among them, total consumption expenditure of rural households is the sum of food consumption expenditure and non-food consumption expenditure.

[5] ln (1 + the average per mu income from farmland transfer-out) and ln (1 + the average per mu expenditure from farmland transfer-in) are used to define the average per mu income from farmland transfer-out and the average per mu expenditure from farmland transfer-in, respectively.

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Article

Coordinated Development of Farmland Transfer and Labor Migration in China: Spatio-Temporal Evolution and Driving Factors

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Abstract: The coordinated development of farmland transfer (FT) and labor migration (LM) is of great efficiency significance to facilitate the development of rural economy and implement the rural revitalization strategy. The study used socioeconomic data from 30 provinces/autonomous regions/municipalities (hereafter referred to as provinces) in China to measure the coupling coordination degree (CCD) of FT and LM. It adopted the coupling coordination degree model (CCDM), exploratory spatial data analysis method (ESDA), and gray relational analysis model (GARM) to investigate the spatial differences in the CCD and its influencing factors. The results indicate the following: (1) Regional differences are evident despite the fact that the comprehensive evaluation level of FT and LM in the various provinces is relatively low and displaying a rising trend. (2) The CCD of FT and LM exhibits a fluctuating upward trend and is at the primary coupling coordination stage, with a significant difference in coupling coordination levels between regions, and a spatial distribution pattern of central region > eastern region > northeast region > western region. (3) The CCD shows a strong global spatial positive correlation with clear fluctuations, demonstrating the agglomeration dispersion development tendency over time; the local spatial agglomeration state emerges and stabilizes. According to the distribution pattern, the Western region exhibits weak agglomeration type, whereas the eastern and central regions exhibit strong agglomeration type. (4) There are significant variations between provinces in terms of the intensity of the CCD of FT and LM, as well as the level of concurrent employment business, the level of non-agricultural industry development, the level of urbanization, the level of agricultural equipment, and the land approval.

Keywords: farmland transfer; labor migration; coupling coordination degree; spatio-temporal evolution; driving factor; China

1. Introduction

As the key elements of agricultural production, the movement and reorganization of labor and land are not only significance to address problems affecting farmers, rural areas, and agriculture in China, but also beneficial for consolidate progress toward poverty alleviation and achieve common prosperity. However, in light of fundamental national conditions in China, which include a large population and limited land, as well as the institutional arrangement of a household contract responsibility system with output-linked compensation, the problems of the small scale of agricultural operations, the relatively low agricultural labor productivity, and the continuous increase of agricultural surplus labor become extremely prominent. In order to solve the above problems, farmers select different forms of farmland transfer (FT) and labor migration (LM) to optimize the allocation of land and labor factors from production sectors with relatively low marginal productivity to production sectors with relatively higher marginal productivity, so as to continuously improve the income of farmers and achieve the goal of rational allocation of land resources and labor resources [1–3]. In fact, influenced by resource endowment [4,5], welfare guarantee function of rural land [6], farmers' risk awareness [7], land transfer cost [8], family labor allocation [9], the high level of labor migration, and a high level of farmland transfer has not occurred concurrently, and the farmland transfer has a deviation from labor migration in the development process. Such incoordination directly affects the orderly economic and social development, as well as agricultural and rural modernization construction. The issue of coupling and coordinated development of FT and LM has become one of the key concerns of rural economic research in the context of rural revitalization strategy. Therefore, this study intended to focus on the above questions and provide a reference for decision making to advance the mutual promotion of FT and LM in China and establish a positive interaction with organic coupling and coordination between them.

At present, the academic community has accumulated abundant research results related to FT and LM; there are two general categories of existing literature. On the one hand, it explored the mutual influence of FT and LM. The majority of the literature held the view that FT and LM had an inverted "U" relationship [10–12]. Concerning the effect that the FT has on LM, the current fragmentation of land prevents the rural labor migration and is not good for agricultural mechanization [13], while farmland transfer and land consolidation may solve this problem by reducing agricultural labor intensity, realizing labor resource reallocation, improving the use efficiency of rural labor force [14–16], improving the level of labor migration [17], increasing the income of farmers [18,19], and reducing the urban–rural disparity [20]. The decision-making behavior of farm households to transfer in or out farmland is correlated to the number of non-agricultural labor forces and agricultural labor productivity [21], whereas changes in land use are brought about by large-scale land transactions, while large-scale land transactions lead to changes in land use, both of which have a direct effect on household labor distribution and gender division of labor [22]. In addition, the absence of farmland transfer right [23], household income increases after labor migration [24], a well-functioning land market [25], and the instability of the duration of farmland contractual rights [26] can also significantly affect the level of LM. Due to the fixed time and maturity of crops, labor demand is mainly distributed throughout the growing season [27]; this means that the rural labor force has the possibility of moving out for employment. In terms of the impact of LM on FT, current studies concluded that LM could influence FT [28–31], specifically, the level of non-agricultural income and the proportion of non-agricultural employment positively affect the farmland transfer [32]: the larger the household labor force, the greatest probability that the peasant household is to transfer to the farmland, and the larger the proportion of non-agricultural labor force in the household labor force, the greater the possibility to transfer out of the farmland [33]; most current literature emphasizes that LM was beneficial to promoting land reallocation and reuse [34] with a phased impact [35]. Meanwhile, the expansion of urban non-agricultural population size has also become the main driving force of FT as the rural labor forces move to cities and towns [36,37].

On the other hand, the relationship between LM and the FT has been the subject of discussion. Existing studies have found an interaction relationship between LM and the FT; with the continuous rise of non-agricultural wages and a large number of rural labor force transferred to cities, the phenomenon of farmland abandonment is increasingly serious [38–41]; to solve this problem and improve the allocation efficiency of land resources, farmland should be transferred from farmers not willing to manage agriculture or with relatively lower agricultural productivity to those willing to manage agriculture or with higher agricultural productivity [42]. However, for some parts of the transferred labor force, the social pension function of farmland increases the opportunity cost of labor force transfer, thus hindering the transfer of farmland [43]. Some studies suggest that the development of LM and the FT are affected by the same factors, such as farmland certification [44–47]. In addition, a few existing studies have revealed the coupling and coordinated relation between FT and LM from the theoretical and practical levels. In the coupling theory analysis study, research scholars studied the internal mechanism of FT and LM based on different theoretical perspectives. For example, Wang et al. measured the CCD of FT and LM in Xinjiang, the study found that the CCD of FT and LM in Xinjiang was at the stage of high coupling and primary coordination, and there were large differences between regions [48].

To sum up, the existing literature is not comprehensive in the explanation of the relation between farmland and labor force. In reality, most existing studies have focused on the interaction between FT and LM and lack research on the spatial distribution characteristics and driving factors of the coupling coordination degree (CCD) between the farmland transfer and labor migration. The research units placed emphasis on a province in China, lacking meso-scale provincial comparative analysis. Therefore, it is necessary to conduct detailed and in-depth research on the CCD of FT and LM in China to obtain reliable conclusions, and the research conclusions of this study offer an effective supplement to the current research on resource allocation and the agricultural economy.

The questions that this paper hopes to answer are as follows: What is the coupling coordination degree between the two systems of FT and LM in provinces of China? What are the changes of the coupling and coordination relations between them in different space and time? What are the driving factors affecting the changes in the level of coupling and coordination between them? This study had three main research objectives: (1) Using the data of the panel statistics from 2015 to 2019, applying the linear weighting method to measured farmland transfer and labor migration evaluation index and comprehensive evaluation index in China, and constructing a coupling coordination degree model (CCDM) to measure the CCD of FT and LM in 30 provinces/autonomous regions/municipalities (hereafter referred to as provinces) in China. (2) Applying the exploratory spatial data analysis method (ESDA) investigate the spatial differences in the CCD. (3) Using gray relational analysis model (GARM) to determine the driving factors behind CCD of FT and LM.

This study contribution of this paper is as follows: Reliable evidence regarding the coordinated development of farmland transfer and labor migration was obtained by constructing CCDM. This study also adds evidence to the research framework on the coordinated development of farmland transfer and labor migration and provides guidance to implement the rural revitalization strategy for other regions and provinces.

The rest part of this paper is structured as follows: The second part introduces the data sources, study area and research methods, and the third part presents the econometric analysis results of the coupling coordination, spatio-temporal evolution, and driving factors of FT and LM. The fourth part analyzes and discusses the empirical results, and the fifth part draws the conclusions of this paper.

2. Materials and Methods

2.1. Data Sources

The data of FT and LM used in this paper came from China Rural Management Statistical Annual Report. The social and economic statistics data were taken from the China Statistical Yearbook and the China Rural Statistical Yearbook. The relative indexes are calculated according to the corresponding original data, and the individual data with missing or abnormal data are corrected by the mean replacement method. Moreover, due to the lack of some statistical data in Hong Kong, Macao, Taiwan, and Tibet, this study identified 30 provinces in China as the research units.

2.2. Study Area

Since the reform and opening up, the industrialization and urbanization level has continued to improve in 30 provinces in China, and rural areas have undergone many changes in the rural land system and household registration management system, which have significantly promoted the farmland transfer and labor migration. As recorded by China Rural Management Statistical Annual Report, there is a total of area of 3.70 million hectares of farmland transfer, with a total of 254 million people of labor migration in 2019 in China, and the level of farmland transfer or labor migration had a large increase compared with 2018. However, the improvement of farmland transfer level and labor migration level brings about changes in the extent of farmland use, and problems such as the contradiction between rural labor and farmland are gradually highlighted. At the same time, as China's farmland transfer and labor migration expand, the level of them varies significantly between provinces. Specifically, only a few provinces such as Inner Mongolia and Liaoning in China have reached the equilibrium state of farmland transfer level and labor migration level. Other provinces have failed to achieve the trend of balanced development, which means that the two have not reached coupled and coordinated development. For details, see Figure 1. Therefore, the evaluation of the CCD of FT and LM is not only significant to improve of the use efficiency of land resource elements and labor resource elements, but also beneficial for the development of agriculture, rural areas, and farmers in China.

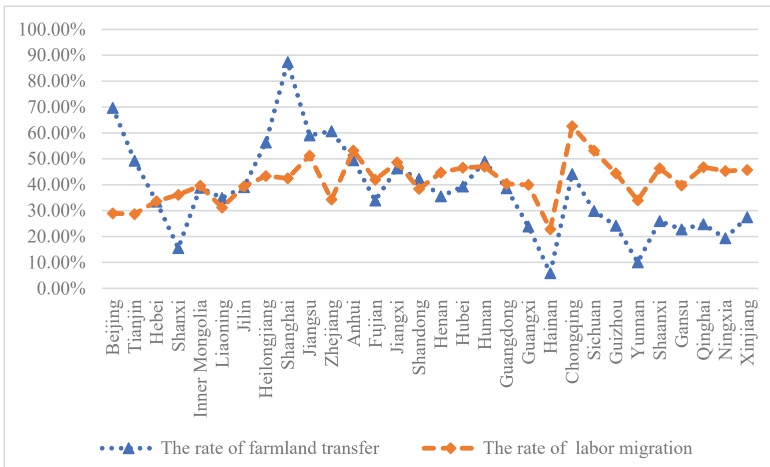

Figure 1. The rate of farmland transfer (FT) and labor migration (LM) in 2019 in China.

2.3. Methods

2.3.1. The Evaluation Index System

The study referred to previous studies [48] and the index system was built according to scientificalness, integrity, and operability to measure the development levels of FT and LM. In this study, we selected 14 indexes from three aspects to represent the degree of FT development, and 13 indexes from three aspects to represent the degree of LM development (Table 1).

Table 1. Evaluation index system and weight of farmland transfer (FT) and labor migration (LM) in China.

Target layer	Standard Layer	Index Layer	Description	Weight
Farmland Transfer (FT)	Farmland conditions and business conditions	Farmers engaged in agricultural operation situation	The annual rate of increase in the number of farmers working in agriculture	0.0572
		Agricultural planting structure situation	The percentage of food crops planted	0.0952
		The average arable land area	The ratio of the total area of household contracted arable land to the total number of rural households	0.0946
		The level of agricultural scale management	The percentage of total households comprised of large-scale peasant households	0.0988
		The level of land approval	The percentage of all granted land management rights	0.0727

Table 1. *Cont.*

Target layer	Standard Layer	Index Layer	Description	Weight
	The intensity of farmland transfer	The rate of FT	The proportion of the area of farmland transfer in the area of farmland contracted by households	0.0553
		The development level of farmland transfer	FT area's annual growth rate	0.0523
		The participation degree of new business entities	The percentage of the area transferred by the new business entities in the total circulation area	0.0434
		The participation degree of farmers	The percentage of households that have been relocated compared to the total number of households	0.0732
	External conditions	The development level of new business entities	The rate of increase in the number of brand-new agricultural business entities over time	0.0635
		The level of agricultural equipment	Number of mechanical power forces per mu of land	0.0830
		Rural labor productivity	The ratio of agricultural output value and rural labor force	0.0743
		Growth in farmers' disposable income	The rate of increase in farmers' disposable income over time	0.0672
		The development level of planting industry	The output value of planting industry accounts for the output value of agriculture, forestry, animal husbandry and fishery	0.0693
	Rural labor force conditions	The percentage of agricultural labor force	Agricultural labor force accounts for the percentage of rural labor force	0.0942
		Average number of labor force per household	The ratio of the total number of rural labor force to the total number of rural households	0.0775
Labor Migration (LM)	The intensity of labor migration	The rate of LM	The proportion of labor migration in the rural labor force	0.0833
		The development level of labor migration	The annual rate of labor migration growth	0.0553
		The level of seasonal labor force transfer	The percentage of seasonal migration in the rural labor force	0.0566
		The level of perennial labor force transfer	The percentage of perennial migration in the rural labor force	0.0895
		The level of part-time job	The percentage of part-time farmers in the total number of rural households	0.0698
		The labor migration breadth	The number of migrations from outside the county accounted for the percentage of the rural labor force	0.0938
	External conditions	Income ratio between residents of urban and rural	The ratio of the disposable income of urban residents to that of rural residents	0.0821
		The ratio of family burden	The ratio of non-working-age population to working-age population	0.0801
		Growth in wage income	Wage income growth rate over time	0.0521
		The development level of non-agricultural industry	Non-agricultural industries' added value made up a portion of the regional GDP	0.0812
		The rate of urbanization	The proportion of the urban population in the total population	0.0845

Before calculating the CCD of FT and LM, the study determined each index's weight used the mean variance decision method. The specific steps are as follows: Firstly, to find a solution to the issue of significant differences in evaluation indicators, the extreme method is used to standardize the original indexes in the evaluation index system of FT and LM. The formula can be described by Equations (1) and (2):

$$\text{Benefit Indicator}: X'_{ij} = \frac{X_{ij} - X_{\min}}{X_{\max} - X_{\min}} \tag{1}$$

$$\text{Coat Indicator}: X'_{ij} = \frac{X_{\max} - X_{ij}}{X_{\max} - X_{\min}} \tag{2}$$

The X_{ij}, X'_{ij} represent the original and standardized values of the index, and the j index's maximum and minimum values are respectively represented by X_{max} and $X_{min.}$

The determination of the index weight has an important influence on the accuracy and objectivity of the evaluation results. We select the mean variance decision method in the objective empowerment method to determine the index weight and obtain the weight of each criterion layer and each index. The formula can be described by Equations (3)–(6):

$$E(s) = \frac{1}{n}\sum_{i=1}^{n} Z_{ij} \tag{3}$$

$$\sigma(S_i) = \sqrt{\sum_{i=1}^{n} Z_{ij} - E({S_i}^2)} \tag{4}$$

$$w_i = \sigma(S_i) / \sum_{j=1}^{m} \sigma(S_j) \tag{5}$$

$$D_i(w) = \sum_{j=1}^{m} Z_{ij} w_i \tag{6}$$

In the formula, $E(s)$ is the mean of a random variable, $\sigma(S_i)$ is the mean variance of S_i, w_i is the weight factor of S_i, and D_i (w) is the multi-indicator decision and ranking.

2.3.2. Linear Weighting Method

Based on the standardized weight and value of each index, drawing on the relevant research results [49], the evaluation index of FT and LM is calculated by linear weighting method. The formula can be described by Equations (7) and (8):

$$f(x) = \sum_{\mathrm{i}=1}^{m} w_i x_{ij} \tag{7}$$

$$g(x) = \sum_{j=1}^{n} w_j x_{ij} \tag{8}$$

The $f(x)$ and $g(x)$ indicate the evaluation index of FT and LM, w_i and w_j represent the index weights of FT and LM, respectively, and the index value following standardization is x_{ij}.

2.3.3. CCDM

In order to study the level of CCD between FT and LM, the study referred to relevant research [50], and constructed the coupling coordination degree model (CCDM). The formula can be described by Equations (9)–(11):

$$C = \left\{ \frac{f(x) \times g(x)}{\left[\frac{f(x)+g(x)}{2}\right]^2} \right\}^{\frac{1}{2}} \tag{9}$$

$$D = \sqrt{C \times T} \tag{10}$$

$$T = \alpha f(x) + \beta g(x) \tag{11}$$

where C is the coupling degree (CD) of FT and LM, D is the CCD of FT and LM, and T is the comprehensive evaluation index of them. α and β are the pending coefficients of FT and LM, respectively. The study accepts that the two subsystems of FT and LM are similarly significant, so the pending coefficient is $\alpha = \beta = 0.5$.

Referring to the correlation study [51], the CCD between FT and LM was divided into 10 grades by using the uniform function distribution method (Table 2).

Table 2. Classification standards for coupling and coordination degree.

CCD	Type	CCD	Type
0.00–0.09	Extreme coupling disorders	0.50–0.59	Barely coupling coordination
0.10–0.19	Severe coupling disorders	0.60–0.69	Primary coupling coordination
0.20–0.29	Moderate coupling disorders	0.70–0.79	Middle coupling coordination
0.30–0.39	Mild coupling disorders	0.80–0.89	Good coupling coordination
0.40–0.49	Near coupling disorders	0.90–1.00	Quality coupling coordination

2.3.4. ESDA Method

When carrying out the overall research on the provinces in China, we ought to follow a mix of overall and local development, propose a top-level design based on the strategic height, and formulate the coordinated development strategy of spatial linkage. Therefore, spatial analysis should also be introduced when analyzing the relevant problems of the provinces in China. According to the relevant literature [52,53], the study used the ESDA method to analyze the CCD, and studied the spatial agglomeration, dispersion, and interaction mechanism by describing and visualizing their spatial layout, which is typically divided into global and local spatial autocorrelations. A global *Moran's I* was used to calculate global spatial autocorrelation in order to show how the CCD of FT and LM were distributed across the entire space. The formula is as follows:

$$\mathrm{I} = \frac{\mathrm{M}}{\mathrm{S}_0} \times \frac{\sum_{i=1}^{M}\sum_{j=1}^{M} w_{ij}\left(\mathrm{X_i} - \overline{\mathrm{X}}\right)\left(\mathrm{X_j} - \overline{\mathrm{X}}\right)}{\sum_{\mathrm{j}=1}^{M}\left(\mathrm{X_i} - \overline{\mathrm{X}}\right)^2} \tag{12}$$

where M is the number of the study regions, and X_i and $\overline{X}$ represent the observed value and average value, respectively. The study regions i and j are weighted spatially as w_{ij}, and the space adjacent is 1 and space non-adjacent is 0. the range of the *Moran's I* values is $[-1,1]$, where a value larger than 0 indicates a positive correlation and a value lower than 0 indicates a negative correlation.

To determine the degree of spatial correlation and difference between the CCD of FT and LM in neighboring provinces, the local spatial autocorrelation test was calculated using local *Moran's I.* The formula is as follows:

$$I_i = Z_i \sum_{i=1}^{M} W_{ij} Z_j \tag{13}$$

where W_{ij} are the spatial weights, while Z_i and Z_j are the normalized values of the observed values in the study regions i and j, respectively.

2.3.5. GRA Model

The driving factors of CCD of FT and LM were examined using the GRA model in 30 provinces in China [54]. The following is the workflow: Find out the feature sequence and the factor sequence. The characteristic sequence, which is denoted by *Y0(m,t)*, is the CCD of FT and LM. Each driver was selected as the factor sequence and represented by *Xi(m,t)*. Next, the grey correlation coefficients were determined. The formula can be described by Equation (14):

$$r_i(m,t) = \frac{\min_{i,m,t}\left|Y'_0(m,t) - X'_i(m,t)\right| + \rho \times \max_{i,m,t}\left|Y'_0(m,t) - X'_i(m,t)\right|}{\left|Y'_0(m,t) - X'_i(m,t)\right| + \rho \times \max_{i,m,t}\left|Y'_0(m,t) - X'_i(m,t)\right|} \quad (14)$$

Among them, *Y′0(m,t)* and *X′i(m,t)* represent the feature and factor sequences after standardized treatment, respectively, and the coefficient of resolution is ρ (ρ = 0.5).

Finally, we calculated the grey correlation degree of the panel data by Equation (15):

$$r_i = \frac{1}{M \times T}\sum_{m=1}^{M}\sum_{t=1}^{N} r_i(m,t) \quad (15)$$

In the formula, *ri* represents the gray correlation degree, where the larger the *ri* value, the stronger the correlation between the feature sequence and the factor sequence and the weaker the correlation.

3. Results

3.1. The Integrated Level of FT and LM Has Changed over Time in a Time Series

The level of China's LM evaluation index was relatively high from 2015 to 2019, with an overall slight upward trend but obvious fluctuations, soaring to 0.5082 in 2019, up from 0.4958 in 2015, representing an average annual growth rate of 0.50%. While the index level showed a small decline from 2016 to 2017 and started to rise after reaching a minimum value in 2017. The evaluation index of FT fluctuated from 0.3798 in 2015 to 0.4009 in 2019, with an annual growth rate of 1.11% on average, and showed a good upward trend in all years except for a short decline in 2016. It benefited from the improvement of the level of FT and LM, the comprehensive evaluation index of them in China increased from 0.4378 in 2015 to 0.4546 in 2019, with an annual growth rate of 0.76% on average, and the comprehensive evaluation index during the study period showed a stable upward trend without obvious differences in the rate of change. For details, see Figure 2.

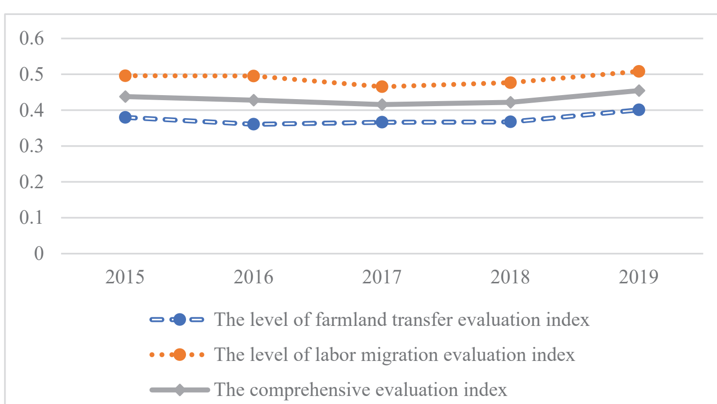

Figure 2. Farmland transfer (FT) and labor migration (LM) evaluation index and comprehensive evaluation index in China (2015–2019).

There are great differences in provincial FT, LM, and comprehensive evaluation index levels in China. The national average values of FT and LM evaluation indexes were only 0.3750 and 0.4882, respectively, from 2015 to 2019, whereas the comprehensive evaluation index only had an average value of 0.4316 (Figure 3). Among them, 21 provinces had the evaluation indexes of FT higher than the national average value, showing the spatial distribution characteristics of northeast region > central region > eastern region > western region. In total, 11 provinces had the evaluation indexes of LM higher than the national average value, showing the spatial distribution characteristics of central region > eastern region > western region > northeast region. Under the interaction of FT index and LM index in 30 provinces, there were 16 provinces with comprehensive evaluation index higher than the national average value, forming the spatial distribution characteristics of central region > eastern region > northeast region > western region.

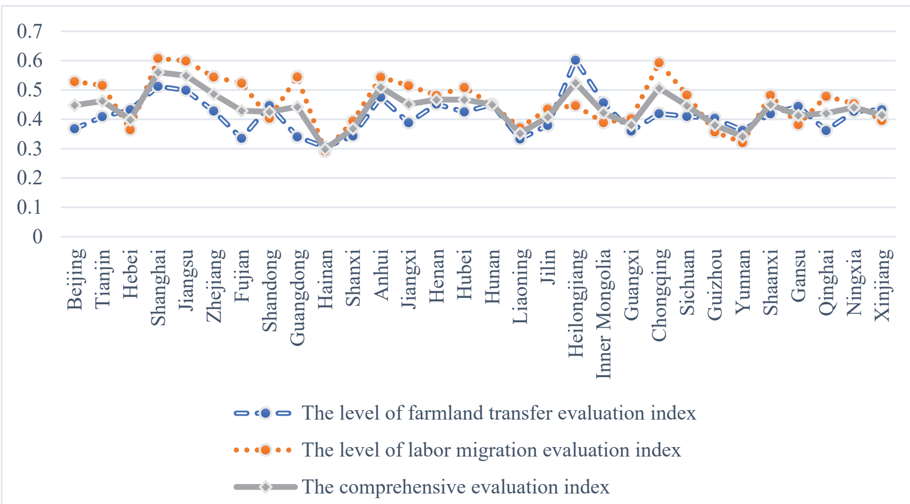

Figure 3. Average evaluation index of farmland transfer (FT) and labor migration (LM) and comprehensive evaluation index in China (2015–2019).

3.2. Spatio-Temporal Evolution of the CCD between FT and LM

The CDs of FT and LM in China from 2015 to 2019 were all higher than 0.970, indicating that the CD of FT and LM reached a high level of coupling and tends to be stable. While the CCD between FT and LM in China showed a tendency of upward and fluctuate, from 2015 to 2019, the CCD increased from 0.6558 to 0.6695, reaching the overall primary coupling coordination; however, the average annual growth rate was only 0.42%, which was relatively slow. The CCD of FT and LM had a large difference among regions, showing a distribution pattern of central region > eastern region > northeast region > western region. Among them, the central region had the highest level of coupling coordination between FT and LM, with an excellent upward trend, and the CCD fluctuated between 0.6692 and 0.6917, with an annual growth rate of 0.67% on average, which was at the middle and late stage of primary coupling coordination. Followed by the eastern region, the CCD decreased from 0.6654 to 0.6599, with an annual growth rate of −0.17% on average, and the CCD showed a slight downward trend. The northeast region ranked the third, with the CCD rising from 0.6420 to 0.6427, with an average annual growth rate of 0.02% and a relatively slow upward trend. The western region had the lowest coupling coordination level, rising from 0.6292 to 0.6346, with an annual growth rate of only 0.17% on average. For details, see Figure 4.

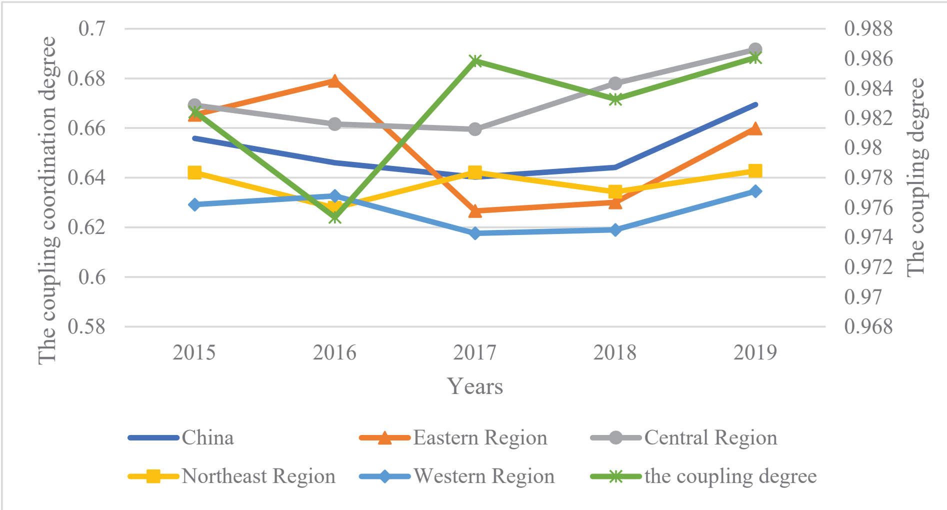

Figure 4. The development trend of coupling and coordination of farmland transfer (FT) and labor migration (LM) in China (2015–2019).

The CD of FT and LM of provinces in China from 2015 to 2019 was consistent with the overall national coupling degree and reached a high level of coupling. Except for Guangdong (0.942), the coupling degrees of FT and LM in all other provinces were above 0.950. In contrast, the CCDs of FT and LM in provinces of China were not high. The national average value was 0.6542, while most provinces had CCDs between 0.60 and 0.70, which was at a primary coupling coordination level (Table 3). Particularly, there were 15 provinces with CCD of FT and LM higher than the national average value, accounting for 50.00%, among which five provinces, including Shanghai (0.7450), Jiangsu (0.7361), Heilongjiang (0.7155), Anhui (0.7107), and Chongqing (0.7003) had the highest level of coupling coordination, with the average value higher than 0.70, which was at the early stage of the middle coupling coordination, accounting for 16.67% over the country. The CCDs of 10 provinces, including Zhejiang, Henan, and Hubei, were between 0.6578 and 0.6916, which were at the middle and late stage of primary coupling coordination, accounting for 33.33% of the country. There were 15 provinces with the CCD of FT and LM lower than the national average, accounting for 50.00% nationwide, among which 12 provinces, including Shandong, Inner Mongolia, and Guangdong, had the CCD between 0.6047 and 0.6502, and were at the middle and early stage of primary coupling coordination, accounting for 40.00% nationwide. Three provinces including Liaoning, Yunnan, and Hainan, had the CCD between 0.5411 and 0.5913 and were at the level of barely coupling coordination, accounting for 10.00% nationwide. Therefore, at this stage, there are still obvious regional differences in the CCD between FT and LM in 30 provinces in China. Although all of them have reached the coupling coordination, the coordination levels of most provinces are relatively low, and there is still large room for growth.

Table 3. The mean degree of the coupling and coupled coordination of farmland transfer (FT) and labor migration (LM) in China (2015–2019).

Province	CD	CCD	Type	Province	CD	CCD	CD
Beijing	0.9664	0.6578	Primary coupling coordination	Liaoning	0.9945	0.5913	Barely coupling coordination
Tianjin	0.9814	0.6738	Primary coupling coordination	Jilin	0.9922	0.6357	Primary coupling coordination
Hebei	0.9880	0.6271	Primary coupling coordination	Heilongjiang	0.9778	0.7155	Middle coupling coordination
Shanghai	0.9914	0.7450	Middle coupling coordination	Inner Mongolia	0.9920	0.6473	Primary coupling coordination
Jiangsu	0.9876	0.7361	Middle coupling coordination	Guangxi	0.9857	0.6124	Primary coupling coordination
Zhejiang	0.9844	0.6916	Primary coupling coordination	Chongqing	0.9693	0.7003	Middle coupling coordination
Fujian	0.9510	0.6389	Primary coupling coordination	Sichuan	0.9890	0.6644	Primary coupling coordination
Shandong	0.9942	0.6502	Primary coupling coordination	Guizhou	0.9840	0.6112	Primary coupling coordination
Guangdong	0.9420	0.6455	Primary coupling coordination	Yunnan	0.9832	0.5793	Barely coupling coordination
Hainan	0.9839	0.5411	Barely coupling coordination	Shaanxi	0.9910	0.6680	Primary coupling coordination
Shanxi	0.9944	0.6047	Primary coupling coordination	Gansu	0.9908	0.6391	Primary coupling coordination
Anhui	0.9913	0.7107	Middle coupling coordination	Qinghai	0.9784	0.6413	Primary coupling coordination
Jiangxi	0.9753	0.6633	Primary coupling coordination	Ningxia	0.9967	0.6623	Primary coupling coordination
Henan	0.9974	0.6819	Primary coupling coordination	Xinjiang	0.9948	0.6419	Primary coupling coordination
Hubei	0.9894	0.6795	Primary coupling coordination	Mean	0.9844	0.6542	Primary coupling coordination
Hunan	0.9956	0.6693	Primary coupling coordination				

3.3. Spatial Autocorrelation of the CCD between FT and LM

The global *Moran's I* index estimates of the CCD of FT and LM in China from 2015 to 2019 were all positive, demonstrating an overall positive spatial correlation. The significance test was passed by all *Moran's I* indexes during the study period, and a highly significant correlation was observed between 2015 and 2019 in *Moran's I* indexes. Some years' low global *Moran's I* indexes suggested that there was little clustering and no obvious spatial autocorrelation feature. Among them, the maximum value of 0.3678 was reached in 2015, followed by a cyclic development trend of decreasing firstly and then increasing and decreasing, which reached the minimum value of 0.1773 in 2019. Therefore, the CCD of FT and LM in China shows a development trend of agglomeration–dispersion over time (Figure 5).

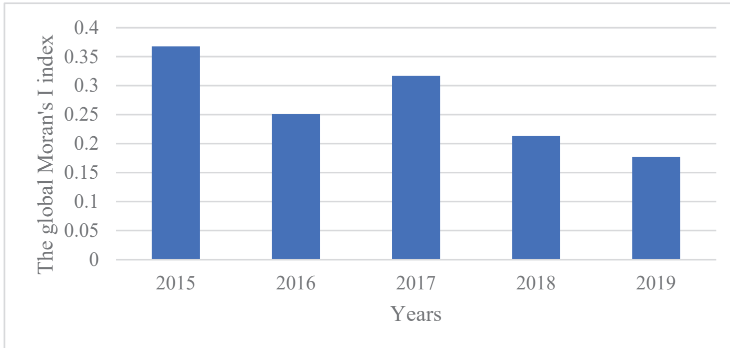

Figure 5. The Global *Moran's I* of the coupling and coordination degree (CCD) of farmland transfer (FT) and labor migration (LM) in China.

Most provinces are located in H-H and L-L agglomeration areas, indicating that both provinces with higher coupling coordination of FT and LM and those with lower coupling coordination have emerged as agglomeration effects and showed a tablet distribution in space. Specifically, from 2015 to 2019, the number of H-H agglomeration areas increased from 8 to 11, and the proportion increased from 26.67% to 36.67%, with this type of area with the greatest proportion. The increase in the number of H-H agglomeration areas indicates that the development level of both FT and LM in China has entered a high level, and it has basically formed a benign coordination situation with mutual promotion (Table 4). In terms of spatial distribution, it gradually expands in scope, with the development trend from relatively scattered to concentrated, and the distribution range is concentrated in the central-eastern region. In general, the strong–strong clustering type is primarily distributed in the east-central region, and the weak–weak clustering type is primarily distributed in the western region. The spatial coordination of FT and LM in China has significant clustering characteristics and tends to be stable. The distribution and number of clustering types change slightly with time, but generally remain stable.

Table 4. Spatial correlation changes of the coupling and coordination degree (CCD) of farmland transfer (FT) and labor migration (LM) in China from 2015 to 2019.

Years	H-H		L-H		L-L		H-L	
	Province	%	Province	%	Province	%	Province	%
2015	Shanghai, Jiangsu, Zhejiang, Anhui, Henan, Hubei, Gansu, Ningxia (8)	26.67	Beijing, Fujian, Shandong, Jilin, Shanxi, Jiangxi, Inner Mongolia, Shaanxi, Qinghai (9)	30.00	Guangdong, Hainan, Liaoning, Guangxi, Sichuan, Guizhou, Yunnan (7)	23.33	Tianjin, Hebei, Heilongjiang, Hunan, Chongqing, Xinjiang (6)	20.00
2016	Shanghai, Jiangsu, Zhejiang, Anhui, Hubei, Beijing, Chongqing, Qinghai (8)	26.67	Gansu, Fujian, Jiangxi, Shandong (4)	13.33	Guangdong, Hainan, Guangxi, Guizhou, Yunnan, Hebei, Shanxi, Inner Mongolia, Liaoning (9)	30.00	Tianjin, Jilin, Heilongjiang, Henan, Hunan, Sichuan, Shaanxi, Ningxia, Xinjiang (9)	30.00

Table 4. *Cont.*

Years	H-H		L-H		L-L		H-L	
	Province	%	Province	%	Province	%	Province	%
2017	Shanghai, Jiangsu, Zhejiang, Anhui, Jiangxi, Henan, Hubei, Hunan, Chongqing, Shaanxi (10)	33.33	Fujian, Shandong (2)	6.67	Hebei, Shanxi, Hainan, Inner Mongolia, Liaoning, Jilin, Guangxi, Guizhou, Yunnan, Gansu, Qinghai, Xinjiang (12)	40.00	Beijing, Tianjin, Heilongjiang, Guangdong, Sichuan, Ningxia (6)	20.00
2018	Shanghai, Jiangsu, Zhejiang, Anhui, Jiangxi, Shandong, Henan, Hubei, Hunan, Chongqing, Shaanxi (11)	36.67	Tianjin, Shanxi, Fujian, Guangdong, Ningxia (5)	16.66	Hebei, Inner Mongolia, Liaoning, Jilin, Guangxi, Hainan, Guizhou, Yunnan, Gansu, Qinghai, Xinjiang (11)	36.67	Beijing, Heilongjiang, Sichuan (3)	10.00
2019	Shanghai, Jiangsu, Zhejiang, Anhui, Jiangxi, Henan, Hubei, Hunan, Chongqing, Shaanxi, Ningxia (11)	36.67	Shanxi, Jilin, Fujian, Shandong (4)	13.33	Beijing, Hebei, Liaoning, Guangxi, Sichuan, Guizhou, Hainan, Yunnan, Gansu, Qinghai, Xinjiang (11)	36.67	Tianjin, Inner Mongolia, Heilongjiang, Guangdong (4)	13.33

3.4. Driving Factors of CCD between FT and LM

FT and LM have formed a complex coupled resource–population–economy system through interaction, and the coupled and coordinated development between them is the result of multiple factors. This study identified the factors of land approval (X_1), the level of agricultural equipment (X_2), the level of concurrent employment business(X_3), the level of non-agricultural industry development (X_4), and the level of urbanization (X_5) as the main driving factors and carried out research. As shown in Table 5, the drivers that significantly affect FT and LM are, in descending order, the level of concurrent employment business (0.6979) > the level of non-agricultural industry development (0.6501) > the level of urbanization (0.6312) > the level of agricultural equipment (0.6207) > the land approval (0.6187).

Table 5. Correlation degree between coupled and coordinated driving factors of farmland transfer (FT) and labor migration (LM) in China.

Region		X_1	X_2	X_3	X_4	X_5
Eastern Region	Beijing	0.5144	0.6170	0.6538	0.6073	0.5907
	Tianjin	0.6013	0.6784	0.5796	0.5673	0.5135
	Hebei	0.5968	0.6967	0.6501	0.6218	0.6206
	Shanghai	0.6118	0.6057	0.8550	0.7067	0.6402
	Jiangsu	0.6713	0.7415	0.7686	0.5890	0.7343
	Zhejiang	0.6250	0.6826	0.7505	0.6898	0.6026
	Fujian	0.5677	0.5968	0.5827	0.7672	0.7442
	Shandong	0.6085	0.6590	0.8735	0.6172	0.6458
	Guangdong	0.6752	0.6933	0.3535	0.5003	0.5618
	Hainan	0.7769	0.6553	0.6307	0.5264	0.5659

Table 5. *Cont.*

Region		X_1	X_2	X_3	X_4	X_5
Central Region	Shanxi	0.7456	0.6310	0.7595	0.5814	0.5668
	Anhui	0.5761	0.5128	0.6339	0.6674	0.6446
	Jiangxi	0.5778	0.5165	0.6935	0.7108	0.6567
	Henan	0.7803	0.7008	0.6621	0.7407	0.6542
	Hubei	0.5729	0.6176	0.7895	0.6285	0.5943
	Hunan	0.7397	0.5904	0.7959	0.7347	0.7498
Northeast Region	Liaoning	0.5410	0.5097	0.8450	0.6697	0.6295
	Jilin	0.5785	0.6047	0.7419	0.7486	0.6563
	Heilongjiang	0.7614	0.4789	0.8138	0.7290	0.6821
Western Region	Inner Mongolia	0.6271	0.5436	0.5151	0.6620	0.8374
	Guangxi	0.7180	0.7248	0.7115	0.5512	0.4367
	Chongqing	0.4136	0.6414	0.7915	0.7824	0.6212
	Sichuan	0.3836	0.6116	0.7000	0.5862	0.5901
	Guizhou	0.5761	0.5406	0.6478	0.7028	0.6149
	Yunnan	0.6486	0.4886	0.7278	0.6636	0.6905
	Shaanxi	0.7615	0.5318	0.7759	0.8155	0.6522
	Gansu	0.6209	0.7269	0.7072	0.5898	0.5965
	Qinghai	0.5715	0.6653	0.5939	0.6713	0.6428
	Ningxia	0.5651	0.7501	0.6508	0.5070	0.5835
	Xinjiang	0.5521	0.6091	0.6834	0.5677	0.6163
Mean		0.6187	0.6207	0.6979	0.6501	0.6312

4. Discussion

4.1. Temporal Evolution Analysis of Integrated Level

From a temporal perspective, the evolution trend of FT and LM in China from 2015 to 2019 is not obvious due to the influence of agricultural production conditions, the development of non-agricultural industries, and new urbanization, and its evolution trend is relatively stable. From the spatial perspective, in order to clarify rural land contracting relationships, clarify rural land property rights, solve the problems of inaccurate arable land area and the unclear four boundaries operated by peasant households under contract, guide the orderly transfer of rights to manage rural land, and realize large-scale agricultural operations, China has carried out the registration and certification of land contracting rights and the rural land system reform of "separating rural land ownership rights, contract rights, and management rights", which has increased the enthusiasm of rural labor forces to participate in the transfer of farmland, guided them to complete the transfer of farmland in an orderly manner, concentrated the land in individuals or organizations such as large planters and new agricultural business entities, promoted the moderate scale operation of agriculture and the rational allocation of land resources, and significantly improved the level of FT. The provinces with relatively high LM evaluation index are concentrated in the eastern region, which is due to the higher level of new urbanization and development of non-agricultural industries in the eastern region, which has a certain radiation and driving effect, and is conducive to improving the absorption capacity of cities and towns for rural labor forces and providing sufficient jobs for them. At the same time, the transfer of farmland can promote occupational differentiation within society and division of labor within families, promote the transfer of rural labor forces to cities and non-agricultural industries, realize the flow and reorganization of labor factors, and improve the level of LM. The difference between the overall evaluation levels of FT and LM in provinces is significant, which is due to the unbalanced development levels of the two subsystems in most provinces, and the lower level of FT in areas with a higher level of LM and vice versa, which directly affects the overall evaluation index level of the whole system.

4.2. Spatio-Temporal Evolution Analysis of Coupling Coordination

At the regional level, as a region with a higher economic levels and social development and better agricultural production conditions in China, the eastern region ought to have a higher CCD of FT and LM than other regions; however, it has a lower coupling coordination level that in the central region, which is due to the expansion of demand for land from new urbanization and non-agricultural industry development, so that it has caused some farmland in the eastern region to be converted to non-agricultural use, which directly affects farmland transfer and leads to a small decline in its coupling coordination level. The rate of LM in the central region has increased significantly, and the conditions of agricultural production and operation have improved. The geographical environment conditions are better, which makes the level of FT and LM increase significantly, thus making its coupling coordination level higher than other regions. As the main grain producing area in China, the northeast region has superior land resource endowment conditions, high level of agricultural mechanization and large-scale operation, and should have a higher level of FT, but the level of FT varies significantly within the region. Agriculture still occupies an important position in the region, and the level of LM is relatively lagging behind, so that the CCD of FT and LM in the northeast region is lower than that in the central and eastern regions. Compared with other regions, the western region has relatively backward agricultural production conditions, urbanization level, and non-agricultural industry development level, and the level of FT and LM are not dominant, so its coupling coordination level is lower than other regions. From the perspective of provinces, the provinces with relatively high level of coupling coordination between FT and LM are mainly located in the east and central regions. The reason is that the level of FT and LM in these provinces is at a higher level, which directly affects the other subsystem and enables it to enjoy certain advantages in the coupling coordination development of FT and LM, so it shows a higher degree of coupling coordination. For Shanghai and Jiangsu, the rapid development of economy and society, new urbanization, and non-agricultural industries can provide a large number of employment opportunities, absorb a large number of migrated labor forces, and fully meet the requirements of rural labor force for concurrent employment or non-agricultural employment. While Heilongjiang has comparative advantages in land resource endowment, excellent level of agricultural equipment, high efficiency of agricultural labor production, and better development of farmland transfer market. The level of FT is higher than that of other regions. The provinces with relatively low level of coupling coordination are mainly located in the western region, while the other three regions also involve a few provinces. This is due to the low development level of both subsystems in Hainan, Yunnan, and Liaoning provinces, which directly reduces the level of coupling coordination. The agricultural farming conditions in these provinces are relatively backward, and the rural labor force is more dependent on the land. The degree of fragmentation of farmland is high, such as the "land belonging to one production unit but enclosed in that of another" in Hainan Province. The imperfect development of the transfer market makes the level of FT relatively low. The large population and poor comprehensive quality of the rural labor force in the western region, the outstanding structural contradictions in transferring employment, and the level of development of local non-agricultural industries cannot meet the willingness to transfer locally, which seriously hinders the development of LM.

4.3. Spatial Autocorrelation Analysis

The CCD of FT and LM in China shows agglomeration effects with high and low values, respectively. On the one hand, because the level of urbanization and non-agricultural industry development in the eastern region is better than other regions, which can provide sufficient employment opportunities for LM, the higher level of LM will directly affect the development of FT, which is manifested by the higher CCD of these provinces; thus, the phenomenon of agglomeration in high-value areas has emerged. On the other hand, the agricultural production conditions, urbanization level, and development level of non-agricultural industries in western provinces are relatively backward, so the development level of FT and LM are both low and have not yet achieved coordinated development, resulting in a low degree of coupling coordination between them, thus showing a significant low-value area agglomeration phenomenon.

4.4. Analysis of Driving Factors

(1) The level of concurrent employment business has the greatest influence on the CCD of FT and LM, primarily because of the rise in agricultural production efficiency and the level of agricultural mechanization and because the demand for labor factors in agricultural production and operation activities continues to decrease, from which a significant amount of unneeded labor is released. Under the combined influence of various aspects, such as the heterogeneity of resource endowment of farm households, the comparative income gap between agriculture and non-farm industries, the nature of agricultural production's seasonality, and the traditional concept of farm households, a large number of concurrent employment farm households have emerged and gradually become the common production status of farm households. However, concurrent employment farmers still have a certain degree of attachment to the land, and the transfer of farmland does not always occur in this production state, which makes the efficiency of farmland transfer not optimal, and the LM under the concurrent employment operation has obvious "migratory bird" characteristics, which directly affects the coupling coordination development of FT and LM.

(2) The level of non-agricultural industry development has the second highest impact on coordination degree of FT and LM. This is due to the significant pull effect of non-agricultural industries on LM; the higher level may help the economic growth of the province and create more jobs for rural surplus labor. The more non-agricultural employment opportunities, the more likely rural laborers will break away from agricultural production to engage in non-agricultural employment. Meanwhile, as rational economic people, income level is the key factor for rural laborers to measure whether to transfer employment. When the level of non-farm income is higher than the income from agricultural operation, laborers will choose to shift to non-farm industries and generate the willingness to shift to self-contracted land management.

(3) The impact of the level of urbanization on coordination degree is in the third place. For rural laborers, the expansion of new urbanization offers numerous employment opportunities, which is conducive to increasing the transfer income of laborers, ensuring their long-term and stable transfer, and increasing the rate of transfer of rural laborers. Meanwhile, in order to meet the increasingly diversified demands of urban residents for agricultural products, the state has introduced corresponding "strong and favorable agricultural" policies to encourage the development of new agricultural business entities and orderly guide capital to the countryside, which has gradually strengthened the demand for land in order to realize large-scale, specialized, and scientific agricultural production and operation, and stimulated the farmland transfer market. It has accelerated the orderly transfer of farmland.

(4) The level of agricultural equipment affects the development of coupling coordination in fourth place. Agricultural machinery can replace some labor factors, reduce labor factor inputs in agricultural production and operation activities, improve agricultural production efficiency, release more surplus agricultural labor, promote occupational differentiation within rural society and division of labor within households, improve the transfer market's supply–demand relationship, realize stable and efficient farmland transfer, increase the willingness of rural labor to transfer employment, and improve the level of FT and LM.

(5) The influence of the land approval on coupling coordination development is in the fifth position. On the one hand, it is conducive to solving the problem of ambiguous property rights of farmland, urging farmers to participate actively in FT, improving the probability and level of FT, and releasing the bundle of fragmented farmland operation and inefficient agricultural production labor. On the other hand, land approval can enhance the strength of farmland property rights, enhance land rights and interest protection during

LM, reduce the cost of LM, make the migrated labor not worry about the risk of land loss, encourage the employment of LM, and improve the long-term and stability of transfer employment.

4.5. Limitations and Future Work

This paper investigated the coordination, spatio-temporal evolution, and driving factors of the coupling between FT and LM in China's provinces. The results of this study are significant for implementing the rural revitalization strategy, realizing the modernization of agriculture and rural areas, and promoting the development of urban–rural integration, but there is room for further in-depth research. On the one hand, this study took China's provinces as the geographical unit and conducted in-depth analysis on the coordination, spatio-temporal evolution characteristics and driving factors of the coordination degree of FT and LM. It will be of great practical guidance if long-term provincial panel data or county-level data are used to conduct the study. On the other hand, as farmers are the main decision makers of FT and LM, it is necessary to analyze the coordination degree of FT and LM by using the data of farmers' survey in the future to further clarify the influence of farmers' behavior and willingness on the coupling coordination between them.

5. Conclusions

This study measured the coordinated development between FT and LM in 30 provinces in China from 2015 to 2020 and used the ESDA method and GRA model to study the spatial difference characteristics of coordination degree and analyze the driving factors of coupling coordination development. The following are the main findings of the study: (1) From 2015 to 2019, the level of the evaluation index of LM in China was relatively high. The rising trend of the level of FT was more obvious, and their level of comprehensive evaluation continued to rise. The regional differences were obvious, with the central region being higher than the eastern and northeastern regions and the western region being the lowest. (2) From 2015 to 2019, the coordination degree of FT and LM in China showed a fluctuating upward trend and was at the primary coupling coordination stage, among which the difference in the coordination degree of FT and LM between regions was large, showing a distribution pattern of central region > eastern region > northeast region > western region. (3) The coordination degree of FT and LM in China has a significant global positive spatial correlation and exhibits a clear development trend of agglomeration dispersion over time with obvious fluctuations. Local spatial agglomeration appears and tends to be stable, and strong agglomeration types are concentrated in the eastern and central regions, while weak agglomeration types are concentrated in the western region. (4) The driving factors of the CCD of FT and LM are, in descending order, the level of concurrent employment business, the level of non-agricultural industry development, the level of urbanization, the level of agricultural equipment, and the land approval. There are significant differences in the main driving factors in different provinces.

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Article

Policy Impacts of High-Standard Farmland Construction on Agricultural Sustainability: Total Factor Productivity-Based Analysis

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Abstract: High-standard farmland construction is an important initiative in China that promotes sustainable agricultural development and ensures food security through land consolidation. This study measures the growth of agricultural total factor productivity (ATFP) in China, which is used to characterize the sustainable development of agriculture. Using provincial panel data from China and a continuous difference-in-difference (DID) model, the study examines the impact of high-standard farmland construction policy on ATFP growth. Results show that ATFP in China has an increasing trend with an average annual growth rate of 3.6%. The average enhancement effect of high-standard farmland construction policy on ATFP is 1.0%, which remains significant after various robustness tests. The positive effect of the policy on ATFP becomes apparent in the third year of implementation and shows a gradually increasing trend. The study also finds that the impact of high-standard farmland construction on ATFP is more pronounced in the central regions of China, the main grain-producing regions, and the regions with higher ATFP. High-standard farmland construction policy enhances ATFP by promoting agricultural technology change and technical efficiency. To promote the growth of ATFP and achieve sustainable agricultural development, China should continue to promote the construction of high-standard farmland and explore suitable construction models for different regions.

Keywords: rural–urban migration; rural development; land consolidation; income distribution

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1. Introduction

Promoting sustainable agriculture and meeting the global demand for food is a major challenge for humanity [1,2]. Increasing agricultural total factor productivity (ATFP) is crucial for promoting sustainable agricultural development [3]. Previous research has shown that a key factor in the sustained growth of Chinese agriculture is the increase in ATFP [4–6]. ATFP is the portion of agricultural output that is not explained by the inputs used for production [7]. As ATFP represents the ability of creation to grow under given input conditions, the level of ATFP is an important basis for assessing the sustainability of agriculture [8–10].

The Chinese government places great importance on improving ATFP. In recent years, China has been promoting a policy of building high-standard farmland. High-standard farmland construction is an agricultural land improvement project that aims to make farmland concentrated, flat, high-yielding, and ecologically improved by improving farmland infrastructure [11,12]. Theoretically, high-standard farmland construction can improve farmland quality, promote agricultural scale operation, and thus increase ATFP [13,14]. However, in reality, the impact of high-standard farmland construction policy on ATFP is not yet known due to the geographical differences among provinces and the quality of policy implementation. The objective of this paper is to assess the impact of high-standard farmland construction on ATFP using an econometric approach, with the aim of providing a new perspective for sustainable agricultural development.

The method for measuring ATFP is complex. There are two main methods for calculating ATFP: stochastic frontier analysis (SFA) and data envelopment analysis (DEA). SFA is a parametric estimation method that involves setting specific functional forms and probability distributions for random error terms [15,16]. DEA, on the other hand, is a nonparametric estimation method that calculates efficiency by enveloping the production frontier [17]. Many studies use a combination of DEA and the Malmquist index to measure ATFP [18,19]. As ATFP measurement methods have improved, scholars have started to focus on the determinants of ATFP. Improving farmers' human capital enables them to adopt more advanced technology, which significantly improves ATFP [20]. Infrastructure development can improve agricultural production conditions and increase the land strength of cultivated land, contributing to the advancement of ATFP [21,22]. Agricultural subsidies can help farmers alleviate financial constraints in agricultural production and invest more or adopt more advanced production technologies, thereby increasing ATFP [23,24]. Agricultural and institutional reforms, such as the household responsibility system, agricultural taxation reform, and land system reform in China, have also played a significant role in the growth of ATFP in China [25–28].

Previous research focused on the factors that influence ATFP growth, such as human capital, infrastructure development, government investment, and agricultural policy changes [29,30]. Among these, agricultural policy changes and infrastructure development are particularly important factors in influencing ATFP. In China, a high-standard farmland construction policy is a government policy aimed at improving agricultural infrastructure. The Chinese government invested heavily in the construction of high-standard farmland. Previous research focused on the impact of this policy on farmers' income and eco-efficiency [31,32] but neglected its impact on agricultural sustainability. This paper aims to address this gap by using ATFP to assess the impact, heterogeneity, and mechanisms of high-standard farmland construction policy on agricultural sustainability in China.

This study makes four contributions to the literature. First, we examine the causal relationship between land reclamation and ATFP based on the construction of high-standard farmland in China, offering a new perspective on sustainable agricultural development. Second, this paper investigates the heterogeneous effects of policy implementation on ATFP from multiple angles, providing empirical evidence for the promotion and improvement of high-standard farmland construction policies. Third, this study's continuous difference-in-difference-based research design effectively addresses the endogeneity problem of policy change, accurately identifying the causal relationship between high-standard farmland policy and ATFP. Fourth, this research provides empirical evidence for developing countries to promote the construction of high-standard farmland and sustainable agricultural development.

2. Policy Background

The construction of high-standard farmland is an important component of land consolidation in China, which aims to promote sustainable agricultural development and ensure food security. According to the document "Standard for Construction of High-Standard Basic Farmland", high-standard farmland is defined as "Basic farmland formed through rural land remediation that is concentrated and contiguous, with supporting facilities, high and stable yields, good ecology, strong disaster resistance, and compatible with modern agricultural production and operation methods." The construction of high-standard farmland in China can be divided into two phases: the exploration phase (1988–2010) and the standardized implementation phase (2011–present).

Before 2011, there were no professional documents specifying the measurement standards and construction requirements for high-standard farmland. During this phase, the main focus of comprehensive land development was on increasing the area of arable land. In 2011, the Chinese government launched the National Land Improvement Plan (2011–2015), which established the construction standards and requirements for high-standard farmland. Local governments also formulated their own guidelines for implementing high-standard farmland based on the national document, marking the start of a standardized period for high-standard farmland in China. In this paper, data from 2013 and 2017 were selected for visual analysis because they are the years of advancement of high standards of construction, and the results are shown in Figure 1.

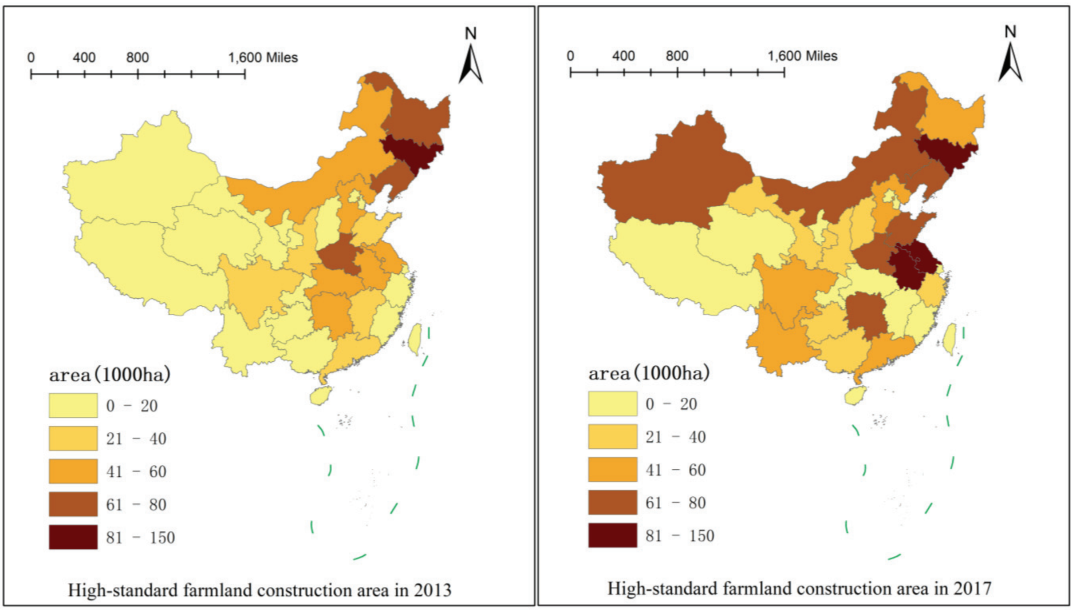

Figure 1. Change in the new area of high-standard farmland.

After 2013, high-standard farmland entered the stage of large-scale standardized construction, and the scope of construction gradually expanded to 31 provinces in China. In 2013, 99,000 hectares of high-standard farmland were constructed, with the top three provinces in terms of construction area being Jilin, Heilongjiang, and Henan, with 92,070 hectares, 71,470 hectares, and 69,470 hectares of high-standard farmland constructed, respectively, according to *China Financial Statistics Yearbook*. By 2017, China had accumulated a total of 46.67 million hectares of high-standard farmland construction, with Shandong, Henan, and Jiangsu accumulating over 3 million hectares of high-standard farmland construction each, according to *China Financial Statistics Yearbook*.

3. Model and Data

3.1. Model

3.1.1. Total Factor Productivity Measurement Model

In order to accurately measure ATFP in this paper, we adopt the DEA method and combine it with the Super Efficiency model and the global Malmquist index proposed by Pastor and Lovell [33] and Oh [34]. This hybrid approach, known as the EBM–SGM index and proposed by Tone and Tsutsui [35], is used to construct the production frontier. The EBM–SGM index considers both radial and non-radial slack variables and avoids the defects of linear programming non-solution and non-transmissibility. To calculate the EBM–SGM index, we use the following formula:

$$\begin{aligned} & r^* = \min\theta - \varphi \sum_{i=1}^{m} \frac{\omega_i s_i}{m_0} \\ & \text{s.t.}\{\theta m_0 - M\rho - s = 0; \rho N \geq n_0; \rho \geq 0, s \geq 0\} \end{aligned} \quad (1)$$

In Equation (1), r^* represents the production efficiency value, θ represents the radial efficiency value, and φ represents the parameter considering both radial and non-radial slack variables. w_i is the relative importance of the i factor of production and s_i is the slack variable of the i factor of production. ρ is the relative weight, and M and N represent the input and output vectors, respectively. m_0 and n_0 represent the input and output levels under the radial constraint, respectively.

In order to accurately measure ATFP in this study, the EBM Super-Global–Malmquist (EBM–SGM) index is used. This combination effectively avoids issues such as linear programming non-solution and non-transmissibility. The formula for the EBM–SGM index is shown below.

$$\begin{aligned} & \text{ATFP}^{t,t+1}\left(m^t, n^t; m^{t+1}, n^{t+1}\right) = \left[\frac{1+D^t\left(m^t,n^t\right)}{1+D^t\left(m^{t+1},n^{t+1}\right)} \times \frac{1+D^{t+1}\left(m^t,n^t\right)}{1+D^{t+1}\left(m^{t+1},n^{t+1}\right)}\right]^{\frac{1}{2}} \\ & = \frac{1+D^t\left(m^t,n^t\right)}{1+D^t\left(m^{t+1},n^{t+1}\right)} \times \left[\frac{1+D^{t+1}\left(m^t,n^t\right)}{1+D^t\left(m^t,n^t\right)} \times \frac{1+D^{t+1}\left(m^{t+1},n^{t+1}\right)}{1+D^t\left(m^{t+1},n^{t+1}\right)}\right]^{\frac{1}{2}} \\ & = \text{TE}\left(m^{t+1}, n^{t+1}; m^t, n^t\right) \times \text{TC}\left(m^{t+1}, n^{t+1}; m^t, n^t\right) \end{aligned} \quad (2)$$

In Equation (2), D_t and D_{t+1} denote the set of production technologies in periods t and t + 1, respectively. Referring to Färe et al. [36], ATFP can be decomposed into agricultural technical change (TC) and agricultural technical efficiency (TE).

3.1.2. Model of the Impact of High-Standard Farmland Construction Policy on ATFP

Referring to the existing literature [37], this paper uses a continuous DID model to estimate the effect of the high-standard farmland policy on ATFP. The following model is constructed in this paper based on this analysis.

$$\text{LNATFP}_{i,t} = \alpha_1 + \alpha_2 \text{treated}_i \times \text{time}_t + \beta X_{i,t} + \eta_t + \gamma_i + \mu_{i,t} \quad (3)$$

In Equation (3), i stands for region and t stands for year. ATFP stands for agricultural total factor productivity, treated stands for proportion of high-standard farmland. time_t stands for the dummy variable at the time of policy. When $t \geq 2011$, time is 1; otherwise, it is 0. X stands for control variable, γ_i and η_t stand for year effect and region effect, respectively. $\mu_{i,t}$ stands for classical random disturbance term. α and β stand for parameters to be estimated. In particular, it is important to note that α_2 is the core estimated parameter in this paper, representing the net effect of high-standard farmland construction policy on ATFP.

3.1.3. Parallel Trend Test

The parallel trend assumption is a crucial prerequisite for DID estimation. Based on previous research [38], the following model is constructed in this paper to test the parallel trend assumption.

$$\text{LNATFP}_{i,t} = \sum_{k=2008}^{2017} \beta_k \text{treated}_i \times d_t + \beta X_{i,t} + \eta_t + \gamma_i + \mu_{i,t} \quad (4)$$

Equation (4) shows this model, where time represents the year dummy variable, treated represents the area of high-standard farmland construction, and other variables and coefficients are set consistently with Equation (3). We can determine whether the parallel trend assumption holds by examining the statistical significance of the estimated parameters of the interaction term. If the estimated parameters of the interaction term are statistically insignificant before 2011, we can assume that the parallel trend assumption is valid.

3.1.4. Impact Mechanism Model

This paper will study the impact of high-standard farmland construction policies on total factor productivity (ATFP) by decomposing ATFP into technical change (TC) and technical efficiency (TE). This approach was used in previous studies [39,40]. The impacts on TC and TE will be analyzed separately to understand the mechanism behind the effects of these policies. Two models will be used for this analysis:

$$LNTC_{i,t} = \alpha_1 + \alpha_2 treated_i \times time_t + \beta X_{i,t} + \eta_t + \gamma_i + \mu_{i,t} \tag{5}$$

$$LNTE_{i,t} = \alpha_1 + \alpha_2 treated_i \times time_t + \beta X_{i,t} + \eta_t + \gamma_i + \mu_{i,t} \tag{6}$$

The estimated parameters of the $treated_i \times time_t$ variable in Equations (5) and (6) represent the effects of high-standard farmland construction policy on TC and TE, respectively.

3.2. Variables

3.2.1. Explained Variables

In this study, ATFP is the main explained variable. To calculate ATFP, we use the EBM–SGM method, which requires the selection of appropriate input and output variables. According to existing research [41–43], the input variables chosen in this study include: (1) the combined agricultural sown area and aquaculture area, (2) the number of people employed in the primary industry at the end of the year, (3) the total power of agricultural machinery, (4) the amount of fertilizer, and (5) the effective irrigation area in agriculture. These variables represent land, labor, machinery, fertilizer, and irrigation inputs in agricultural production. The total agricultural output value is used as the agricultural output indicator in this study.

3.2.2. Core explanatory Variable

The key explanatory variable in this paper is the policy variable $treated_i \times time_t$ (difference-in-differences) of high-standard farmland construction. This variable is created through the interaction of a time dummy variable, representing the implementation of the policy and the regional area of high-standard farmland treated. The size of its parameter indicates the impact of the high-standard farmland construction policy on ATFP.

3.2.3. Control Variables

According to existing research [44,45], the following variables are used as control variables in this study: (1) Infrastructure, represented by the number of road miles per unit area (ROAD); (2) Human capital, represented by the average number of years of education for the regional labor force (EDU); (3) Urbanization level, represented by the ratio of the urban population to the total population (UR); (4) Land quality, represented by the ratio of effective irrigated area to sown area (LAQA); (5) Disaster rate, represented by the ratio of the disaster area to total sown area (DR) to control for the impact of climate on ATFP; (6) Agricultural planting structure, represented by the ratio of sown area of food crops to the total sown area (AS); (7) Fiscal support to agriculture, represented by the ratio of fiscal support for agriculture expenditure to total fiscal expenditure (AF). These variables are included to account for their potential influence on ATFP and to ensure the accuracy of the results of this study.

3.3. Data

This paper uses data from 30 provinces in China for the study period of 2008–2017. Hong Kong, Macau, Taiwan, and Tibet are not included due to a lack of sufficient statistical data. The data used for calculating ATFP, including input and output variables, were obtained from the *China Statistical Yearbook* and *China Rural Statistical Yearbook*. Control variables were obtained from the *China Statistical Yearbook* and EPS database. Data on high-standard farmland construction was obtained from the *China Financial Yearbook*. Some abnormal data were removed, and missing data were completed using the interpolation method. The statistical description of the data used in this paper is shown in Table 1.

Table 1. Descriptive statistics of variables.

Variables	Abbreviation	Units	*N*	Mean	S.D.	Min	Max
Agricultural total factor productivity	ATFP	-	300	1.037	0.055	0.886	1.210
Agricultural technology change	TC	-	300	1.035	0.041	1.000	1.205
Agricultural technology efficiency	TE	-	300	1.003	0.052	0.862	1.210
$treated_i \times time_t$	DID	-	300	2.544	1.909	0.000	5.782
Total agricultural production value	Output	Billion Yuan	300	232.8	168.7	14.5	804.3
Land input	Input1	1000 km^2	300	5687.0	3808.0	123.9	15,205.0
Labor input	Input2	10,000 individuals	300	939.5	666.6	37.1	2847.0
Mechanical input	Input3	10,000 kW	300	3257.0	2923.0	95.3	13,353.0
Fertilizer input	Input4	10,000 tons	300	191.6	146.1	8.0	716.1
Irrigation inputs	Input5	1000 km^2	300	2096.0	1570.0	115.5	6031.0
Infrastructure	ROAD	Km	300	0.915	0.506	0.079	2.297
Human capital	EDU	Year	300	9.616	1.143	6.971	13.530
Urbanization level	UR	%	300	0.547	0.132	0.291	0.896
Land quality	LAQA	%	300	0.389	0.183	0.118	1.000
Disaster rate	DR	%	300	0.195	0.138	0.000	0.695
Agricultural planting structure	AS	%	300	0.654	0.130	0.353	0.958
Fiscal support to agriculture	AF	%	300	0.111	0.030	0.030	0.190

4. Empirical Results

4.1. The Results of ATFP Measurement

In this study, the Empirical Border Malmquist Super-Global index was used to measure the Total Factor Productivity (ATFP) growth in China from 2008 to 2017 (Table 2). The results show that China's ATFP experienced an upward trend with an average annual growth rate of approximately 3.6% during this period. Most provinces had positive ATFP growth, and the growth of ATFP was generally balanced across provinces. The results also show that the growth of ATFP in China was determined by a combination of technological change (TC) and technical efficiency (TE). The average annual growth rate of TC was 2.8%, while the average annual growth rate of TE was 0.7%. These findings are consistent with those of previous studies and by existing studies [39,46,47]. The Malmquist index was converted to a growth index with 2008 as the base period to understand the results better.

Table 2. ATFP Growth and Decomposition in China from 2008 to 2017.

Year	TFP	TC	TE
2008–2009	0.946	1.022	0.927
2009–2010	1.128	1.087	1.039
2010–2011	1.030	1.020	1.010
2011–2012	1.051	1.074	0.980
2012–2013	1.039	1.072	0.966
2013–2014	1.040	1.042	0.999
2014–2015	1.032	1.009	1.023
2015–2016	1.053	1.010	1.043
2016–2017	1.054	1.011	1.042
Mean	1.036	1.028	1.007

Note: The mean values in Table 2 are calculated from the geometric mean.

4.2. Baseline Regression Results

The effects of the high-standard farmland construction policy on ATFP were analyzed in this section, with the results shown in Table 3. Model 1 represents the results without controlling for any variables, while Model 2 shows the results after adding control variables. The results in Table 3 indicate that, when controlling for all variables, time-fixed effects and regional-fixed effects, the impact of the high-standard farmland construction policy on ATFP is significant at the 1% confidence level with an estimated coefficient of 0.010. This indicates that, on average, the policy has increased ATFP by 1.00%. The policy reform had a significant effect on ATFP. As a key land remediation project in China, the construction of high-standard farmland can significantly improve ATFP and promote sustainable agricultural development.

Table 3. Baseline regression results.

Variables	Model 1	Model 2
$treated_i \times time_t$	0.545 *** (0.003)	0.010 *** (0.004)
ROAD	—	0.274 *** (0.080)
EDU	—	0.516 *** (0.140)
UR	—	0.536 *** (0.110)
LAQA	—	0.261 *** (0.051)
AS	—	−0.043 (0.146)
AF	—	0.207 (0.356)
DR	—	−0.012 (0.039)
Time fixed effects	Yes	Yes
Regional fixed effects	Yes	Yes
_Cons	4.624 *** (0.009)	1.090 *** (0.412)
R^2	0.514	0.743
N	300	300

Note: *** is significant at the significance level of 1%.

According to the results, infrastructure development can significantly increase ATFP, which is consistent with the findings of Shamdasani et al. [22]. Human capital, represented by the average number of years of education for the regional labor force, can also promote ATFP growth, which is consistent with the study of Chen et al. [47]. Farmers with higher human capital are more capable of adopting new agricultural technologies and are more likely to be familiar with them. The level of urbanization can significantly increase ATFP, which is generally consistent with the results of Li et al. [42]. Land quality has a significant positive effect on ATFP growth, which is generally consistent with the findings of Song and Pijanowski [48]. In addition, the regression results of disaster rate, agricultural restructuring coefficient, and fiscal support to agriculture are statistically insignificant, and this paper has yet to find empirical evidence that disaster rate, agricultural restructuring, and fiscal support to agriculture will enhance ATFP.

4.3. Dynamic Effect of the Policy

To further understand the policy's impact, this paper explores the policy's dynamic effects on ATFP through an interaction regression of the policy variable and time dummy variables [37]. The regression results are shown in Table 4. Model 1 controls for time and area effects, while Model 2 adds control variables based on Model 1. The results in Table 4 suggest the following conclusions. First, the estimated parameters for the first two years of policy implementation are statistically insignificant, indicating that the policy's impact on ATFP growth has a lag period of two years. Second, the estimated parameters increase with increasing years, indicating that the policy's effect on ATFP growth is continuous and increasing. We believe that there are differences in the understanding of the policy of high-standard farmland construction in various regions and no standardized implementation, which leads to the lagging effect of the policy.

Table 4. Dynamic effects of the policy.

Variables	Model 1	Model 2
Policy × 2011	0.024 *** (0.005)	0.001 (0.005)
Policy × 2012	0.035 *** (0.005)	0.004 (0.005)
Policy × 2013	0.042 *** (0.004)	0.016 *** (0.005)
Policy × 2014	0.048 *** (0.004)	0.021 *** (0.005)
Policy × 2015	0.053 *** (0.004)	0.023 *** (0.005)
Policy × 2016	0.063 *** (0.004)	0.027 *** (0.005)
Policy × 2017	0.077 *** (0.004)	0.037 *** (0.006)
Control variables	No	Yes
Time fixed effects	Yes	Yes
Regional fixed effects	Yes	Yes
_Cons	4.634 *** (0.008)	2.560 *** (0.431)
R^2	0.659	0.784
N	300	300

Note: *** indicates significance at the significance level of 1%.

4.4. Heterogeneity Analysis

The impact of high-standard farmland construction policy on ATFP is influenced by resource endowment and policy bias. There is regional heterogeneity in the effects of ATFP. The results of heterogeneity can better optimize the policy. In this paper, heterogeneity is analyzed based on natural geographical location, agricultural functional areas, and productivity differences.

4.4.1. Heterogeneity of Natural Geographic Location

We consider that there will be significant heterogeneity in the impact of high-standard farmland construction policies on ATFP growth in different natural geographic locations. This study divides the study area into three regions in eastern, central, and western China and conducts grouped regressions based on Equation (3). The results, shown in Table 5, suggest that in the central region of China, the construction of high-standard farmland has the most significant effect on improving ATFP. However, the results for the samples from the eastern and western regions are not statistically significant.

Table 5. Results of heterogeneity of natural geographic location.

Variables	Model 1	Model 2	Model 3
$treated_i \times time_t$	−0.008 (0.010)	0.028 *** (0.007)	−0.005 (0.006)
Control variables	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes
Regional fixed effects	Yes	Yes	Yes
_Cons	−0.410 (0.751)	1.286 (0.797)	−0.623 (0.759)
R^2	0.834	0.835	0.816
N	90	90	120

Note: *** indicates significance at the significance level of 1%.

4.4.2. Productivity Heterogeneity

For provinces with different productivities, the effect of high-standard farmland construction on ATFP may vary. In this paper, the policy effects on different quartiles of ATFP are assessed with the help of panel unconditional quantile regressions, and the results are shown in Table 6. Compared with conditional quantile regression, unconditional quantile regression does not depend on the increase or decrease of control variables and is widely used for heterogeneity analysis of treatment effects [49]. Model 1, Model 2, Model 3, and Model 4 represents the regression results for quartiles 25, 50, 75, and 90, respectively. The estimated coefficients were 0.041 and 0.026 at quintiles 25 and 50, respectively, and were statistically significant. The estimated coefficients were not significant at the 75th and 90th quartiles. The study's results indicated that the effect of high-standard farmland construction on ATFP gradually diminished as the quantile increased. High-standard farmland as a land improvement policy can significantly reduce the differences in ATFP among provinces.

Table 6. Unconditional quantile regression results.

Variables	Model 1	Model 2	Model 3	Model 4
$treated_i \times time_t$	0.041 ***	0.026 **	−0.007	−0.020
	(0.011)	(0.012)	(0.014)	(0.013)
Control variables	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes
Regional fixed effects	Yes	Yes	Yes	Yes
_Cons	1.924 **	0.939	−1.066	0.210
	(0.775)	(0.889)	(1.491)	(2.361)
R^2	0.338	0.605	0.416	0.204
N	300	300	300	300

Note: *** and ** indicate significance at the significance level of 1% and 5%.

5. Discussion

During 2008–2017, China's ATFP showed an increasing trend, which is similar to the findings of Liu et al. [50] and Li and Lin [41]. The decomposition of the ATFP shows that China's ATFP growth is still largely dependent on technological change. This finding is generally consistent with that of Fan et al. [51]. Unlike these studies, the focus of our study is to explain the possible reasons for the changes in ATFP in China, which can help us to understand the sustainable growth of Chinese agriculture. This paper argues that the improvement of China's ATFP is mainly due to the following aspects: first, China has continued to make efforts to improve the quality of agricultural science and technology in recent years, breaking through several critical technological bottlenecks and applying several high-tech achievements, such as breeding and promoting important new varieties of super rice, water-saving and drought-resistant wheat, and transgenic insect-resistant cotton [52,53]. Secondly, China has invested more in agricultural infrastructure in recent years, improving agricultural production conditions and significantly contributing to ATFP growth [54].

Then, our research shows that a high-standard farmland construction policy can significantly improve ATFP and thus promote sustainable agricultural development. Existing studies started to discuss the impact of high-standard farmland construction on farmers' behavior and farm income [31,32] but lacked a discussion on sustainable agricultural development. We innovatively used ATFP to measure agricultural sustainability and studied the policy effects. Our study can provide lessons for sustainable agricultural development in developing countries. We think the main reasons why high-standard farmland construction can contribute to ATFP growth are as follows. First, the construction of high-standard farmland can enhance agricultural production conditions and increase the disaster resistance of agriculture, thus ensuring food security. In agricultural production, irrigation has always been the weak segment. Traditional agriculture often reduces grain yield due to untimely or insufficient irrigation [55–57]. The construction of high-standard farmland can effectively alleviate the problem of difficult irrigation and promote the improvement of agricultural ATFP. Secondly, high-standard farmland enhances agricultural scale, mechanization, and social services and supports agricultural transformation and upgrading. In China, the problem of land fragmentation is severe, which is not conducive to agricultural scale and mechanization. A study by Adamopoulos and Restuccia [58] showed that low agricultural productivity in developing countries mainly comes from small planting scale, low productive investment, and low agricultural mechanization. High-standard farmland can effectively compensate for these deficiencies and thus increase ATFP. In addition, our study shows that the policy effects of high-standard farmland are progressively growing, further suggesting that the construction of high-standard farmland can promote sustained agricultural productivity growth.

Moreover, our research indicates that the effects of high-standard farmland construction policy on ATFP are significantly heterogeneous under different conditions, which is also an important contribution to our paper. Through heterogeneity analysis, we can obtain the differences in policy effects in different regions or different groups. The results of heterogeneity can help us optimize the high-standard farmland construction policy in a more targeted way. First, the high-standard farmland construction policy significantly affects the central region rather than the east and west. This paper considers the possible reason for this is that central China is the main grain-producing region, and the construction of high-standard farmland is more standardized [59]. Second, the enhancement effect of the high-standard farmland construction policy is more obvious in the main grain-producing regions. The reason is that the construction of high-standard farmland in China mainly focuses on grain production [60]. Finally, the high-standard farmland construction policy is more pronounced in provinces with lower ATFP, which suggests that high-standard farmland construction is an important policy tool to reduce inter-regional productivity differences and may narrow the income gap between provinces. In addition, high-standard farmland construction policies can increase ATFP through technological change and technical efficiency improvements. The results suggest that high-standard farmland enhancement of agricultural ATFP is multi-dimensional. After the construction of high-standard farmland, farmers can introduce more advanced agricultural technologies into agricultural production, which will significantly promote agricultural technological change [61,62]. At the same time, the construction of high-standard farmland will reduce the degree of land fragmentation, which can improve the efficiency of agricultural technology [32].

Based on our findings, we recommend the following actions: firstly, continue promoting the construction of high-standard farmland. China's current proportion of high-standard farmland is still low and requires further efforts to strengthen construction efforts. To support this, the government should increase financial investment in the construction of high-standard farmland and consider implementing balanced matching funds from both the central and local governments. Additionally, the construction area of high-standard farmland should be carefully planned, and the overall area of high-standard farmland should be increased to support sustainable agricultural development. Then, improve the quality and standards of high-standard farmland construction. The government should prioritize quality management during project implementation, refine construction quality requirements, and ensure that construction units follow technical specifications closely. Additionally, the acceptance process for high-standard farmland projects should be thorough and rigorous. Finally, explore local solutions for high-standard farmland construction. Local governments should consider developing differentiated policies for constructing high-standard farmland based on the heterogeneity of policy implementation in different regions. For example, in the eastern region, agricultural science and technology research, development, and promotion should be prioritized. In the central region, water-saving irrigation technology should be promoted to improve water resource utilization efficiency. In the western hilly areas, the promotion of local practical technologies should be emphasized.

6. Conclusions and Prospects

6.1. Conclusions

In this study, we employed China's high-standard farmland construction policy as a "quasi-natural experiment" to investigate the relationship between land consolidation and agricultural sustainability. We used Agricultural Total Factor Productivity (ATFP) as a measure of sustainable agricultural development and employed a continuous difference-in-differences (DID) model to identify the causal relationship between the policy and ATFP and to explore the dynamic effects and mechanisms at play. Our findings indicate that a high-standard farmland construction policy can improve ATFP and thus promote sustainable agricultural development in China. Specifically, we found that:

(1) ATFP in China demonstrated an upward trend during the period 2008–2017, with an average annual growth rate of 3.6%. This growth was driven by technological change and technical efficiency improvement, with an average annual growth rate of 2.8% for technological change and 0.7% for technical efficiency.
(2) The high-standard farmland construction policy had an average effect of 1.0% on ATFP, a result that was robust to a series of robustness tests. The effect of the policy on ATFP was time-heterogeneous, with the effect appearing only in the third year of policy implementation and showing a gradually increasing trend.
(3) The improvement of ATFP by high-standard farmland construction policies has obvious regional heterogeneity. The effect of the policy on ATFP improvement is more pronounced in central China and in provinces with higher ATFP levels.
(4) The policy improved ATFP by promoting technological change and technical efficiency improvement. The policies improve technical change by 1.3% and technical efficiency by 1.4%, and both are statistically significant at the 1% level.

6.2. Research Limitations and Prospects

Our study provides new evidence to promote sustainable agricultural development in China. However, the article still has some limitations. First, limited by the availability of data, our study data are only updated to 2017, and future data updates are needed for further research. Second, we only measured agricultural sustainability from the perspective of ATFP, and future research can study the impact study of high-standard farmland construction policy on agricultural sustainability from the perspective of green efficiency.

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