

Article

The Impact Mechanism of Digital Rural Construction on Rural Social Welfare and Spatial Spillover Effects

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Abstract

The extensive progress of digital rural development in China has attracted significant scholarly interest regarding its prospective effects on rural social welfare. This paper utilizes panel data from 30 provincial-level administrative regions in China spanning 2011 to 2023 to assess the development levels of digital rural construction and rural social welfare, while examining the impact mechanism and spatial disparities of digital rural construction on rural social welfare. The results reveal that during the sample period, both digital rural development and rural social welfare in China exhibited a consistent increasing trajectory, albeit the western region remained more underdeveloped. ; digital rural development had a significant positive impact on rural social welfare, a conclusion that remains valid after multiple robustness tests and endogeneity adjustments; agricultural technological progress serves as the key transmission channel through which digital rural development influences rural social welfare; the impact of digital rural development on rural social welfare exhibits characteristics of nonlinear marginal increasing returns and spatial spillover effects. Furthermore, the welfare-enhancing effects of digital rural development vary across regions, with a more pronounced impact on rural social welfare in central and western regions as well as in areas with higher levels of economic development.

Keywords: rural social welfare; digital rural construction; digital transformation; regional heterogeneity; spatial spillover

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1. Introduction

Rural social welfare underpins rural social development and is intricately connected to the quality of life and overall well-being of rural inhabitants. Nonetheless, the social welfare system in our nation is deficient, demonstrating problems such as inadequate development and imbalance [1]. In reaction to these issues, the Ministry of Agriculture and Rural Affairs promulgated the “Opinions on Implementing the Key Work Arrangements of the Central Committee of the Communist Party of China and The State Council for Comprehensively Promoting Rural Revitalization in 2023.” This text clearly underscores the necessity of enhancing public service systems in rural regions, encompassing epidemic prevention, education, healthcare, social security, elder care, and childcare, thereby augmenting the rural social welfare framework. In 2025, the Central Committee of the Communist Party of China and the State Council issued the “Comprehensive Rural Revitalization Plan (2024–

2027),” reaffirming the objective of “creating livable, prosperous, and aesthetically pleasing villages while improving the welfare of farmers.” Simultaneously, as external environmental risks escalate and the disparity between urban and rural areas expands, it has become increasingly imperative to enhance social welfare in rural regions.

The advancement of digital rural construction presents a significant opportunity to improve rural social welfare. Following the proposal to “vigorously develop digital agriculture” in 2018, the establishment of digital villages has become a focal point in key policy frameworks. Subsequent policy documents, including the “Digital Agriculture and Rural Development Plan (2019–2025),” the “Digital Village Development Strategy Outline,” and the “Key Points of Digital Village Development Work in 2025,” have been released to direct the advancement of digital villages. The No. 1 Central Document for 2025 and 2026 explicitly introduces the “Special Action for Strengthening, Benefiting, and Enriching Agriculture in Digital Villages” and the “Action for High-Quality Development of Digital Villages.” As digital rural construction progresses, it has contributed to an increase in the income of rural residents in our country [2]. Data from the National Bureau of Statistics indicates that the per capita disposable income of rural inhabitants was 23,119 yuan in 2024 and is anticipated to increase to 24,456 yuan in 2025, signifying a year-on-year growth of 6.0%. While the construction of digital villages enhances farmers’ income, it is essential to examine whether it can also comprehensively improve the level of rural social welfare. What mechanisms facilitate this enhancement? Investigating these questions holds practical significance for advancing the Digital China strategy and the development of agricultural and rural regions.

2. Literature Review

Since the late 20th century, the body of research on rural social welfare has grown increasingly mature, with its scope expanding to conceptual definition, indicator system development, welfare level measurement, and the identification of influencing factors. First, regarding conceptual definition: welfare in a broad sense encompasses diverse forms of support—including financial resources, materials, development opportunities, and public services—designed to safeguard and improve residents’ quality of life [3]; in its narrow sense, welfare centers on safety-net protections for vulnerable groups [4]. To date, specialized scholarship focused explicitly on rural social welfare remains limited [5–7]. Second, for indicator system construction, measurement approaches fall into two primary categories: subjective evaluations derived from micro-level surveys [8–11], and comprehensive assessments based on multi-dimensional objective indicators [12–15]. Existing research has widely established that China’s social welfare level has improved steadily, exhibiting a spatial pattern of “high in the east and low in the west” [16] alongside significant spatial spillover effects [17]. Nevertheless, most measurement frameworks still follow an urban-centric logic and insufficiently capture context-specific rural attributes such as rural human settlement environments and collective economies. Third, in terms of influencing factors, educational transfer payments [18], population aging [19], and concurrent shifts in tariffs and exchange rates [20] all act as positive drivers of social welfare; however, the welfare implications of digital technology as an emerging variable remain markedly under-explored.

Existing scholarship on digital rural construction spans both macro and micro dimensions. At the macro level, theoretical research focuses on defining the connotation of digital rural construction, unpacking its operational mechanisms, identifying prevailing challenges, and proposing optimization pathways [21–23]. Empirical work prioritizes quantifying the development level of digital rural construction [24,25] and testing its impact mechanisms on macro-level targets including rural revitalization, common prosperity, and the urban-rural income gap [26–28]. At the micro level, most studies take rural

households as analytical samples to investigate how digital rural construction shapes farmers' entrepreneurship, consumption levels, and rural consumption upgrading [29–32]. Overall, the existing literature places disproportionate emphasis on the aggregate economic empowerment effects of digital rural construction, while lacking direct and systematic examination of rural social welfare. In particular, transmission channels through non-economic dimensions—such as education, healthcare, and living environments—remain insufficiently explored [33–36].

A systematic review of extant literature identifies three key research gaps: (1) Research scope. Compared with studies on general and individual social welfare, dedicated research focused specifically on rural social welfare is relatively scarce. (2) Research perspective. Most existing work examines the indirect impacts of digital rural construction, such as its effects on farmers' income growth, while few investigate its direct effect on rural social welfare. (3) Research methodology. The majority of empirical studies employ conventional linear regression models, failing to account for the non-linearity, regional heterogeneity, and spatial spillover effects of digital technology. This limitation prevents a comprehensive understanding of its underlying functional patterns. Against this backdrop, this paper integrates the capability approach with the perspective of agricultural technological progress to systematically analyze the impact mechanism of digital rural construction on rural social welfare and further explores its regional heterogeneity. The marginal contributions of this paper are threefold. First, it incorporates digital rural construction and rural social welfare into a unified analytical framework, extending the research boundaries of both fields. Second, from the lens of agricultural technological progress and by incorporating non-linear and spatial factor analysis, it conducts theoretical analysis and empirical testing on the relationship between digital rural construction and rural social welfare. Third, it puts forward targeted policy implications based on the empirical findings, providing decision-making references for advancing rural revitalization and agricultural and rural modernization, and supporting high-quality rural development.

3. Theoretical Analysis and Research Hypotheses

In the 1970s, economist Amartya Sen proposed the capability approach, which innovatively reconstructs the welfare analysis framework centered on the core concepts of “functionings” and “capabilities” and puts forward the capability-functioning method. Specifically, capabilities can be regarded as the internalized accumulation of functionings, while functionings represent the external manifestation of capabilities. That is, functionings mirror the actual state of life, whereas capabilities embody the potential to achieve functional freedom in the future, forming a dynamic and interactive relationship between the two [37]. Building on this foundation, Sen identified five forms of instrumental freedoms: political freedoms, economic facilities, social opportunities, transparency guarantees, and protective security. These freedoms are interconnected and jointly expand individuals' substantive capabilities. On this basis, this paper defines social welfare as the set of conditions that enable individuals to attain a fulfilling life, and measures it through the dual lenses of functioning freedom and capability freedom, so as to achieve the holistic integration of economic and non-economic welfare. Furthermore, in light of rural development realities, data availability, and established research conventions, political freedoms and transparency guarantees represent macro-institutional arrangements. These arrangements exhibit a high degree of homogeneity across rural areas of China's provincial-level regions, while systematically comparable quantitative panel data for these dimensions remain scarce. Meanwhile, the capability approach posits that the efficiency with which individuals convert resources into functionings is jointly shaped by three categories of conversion factors: personal, social, and environmental. As a critical environmental conversion factor, the rural human settlement environment directly determines rural res-

idents' ability to translate resources such as income and public services into substantive freedoms, and constitutes an indispensable component of the capability framework. Accordingly, this article delineates functional freedom and capable freedom into four dimensions: economic conditions, social possibilities, protective safeguards, and the living environment, so establishing an analytical framework for rural social welfare. The theoretical framework is illustrated in Figure 1.

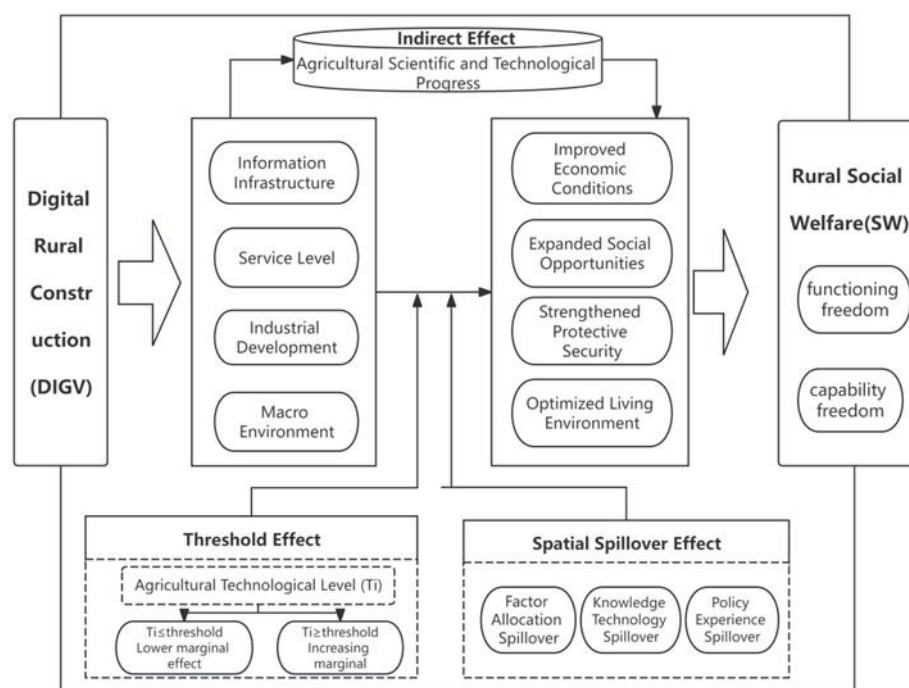


Figure 1. Theoretical framework.

3.1. The Direct Effects of Digital Rural Construction on Rural Social Welfare

Grounded in the capability approach, the essence of rural social welfare lies in the synergistic enhancement of farmers' functioning freedom and capability freedom. Specifically, it endows farmers with substantive freedom to pursue a desirable life by improving the conditions for achieving functionings and expanding the set of development opportunities. Digital rural construction reshapes agricultural and rural development by leveraging modern digital technologies [35], encompassing core components such as rural digital information infrastructure, digital rural service capacity, digital rural industrial development, and the digital rural macro-environment. It drives profound changes in rural areas across four dimensions—economic facilities, social opportunities, protective security, and human settlement environments—thereby expanding farmers' functioning freedom and capability freedom.

First, digital rural construction vigorously promotes the extension of digital information infrastructure to rural areas, breaking down geographical barriers in the circulation of traditional agricultural products. It increases online transaction volume, enables direct engagement between farmers and consumers, and improves farmers' ability to accurately grasp market demand, driving sustained growth in farmers' income. This, in turn, improves rural economic facilities and consolidates the material foundation of rural social welfare. Second, digital rural construction elevates digital service delivery in rural areas. A wide range of digital public services is extended to rural areas, breaking spatial constraints and facilitating the flow of high-quality urban education, healthcare, and employment resources to rural regions. This enables farmers to access development resources

such as skill upgrading, health security, and job matching on an equal footing, continuously strengthening human capital accumulation and expanding rural social opportunities, thus reinforcing the capability underpinning of rural social welfare. Third, digital rural construction accelerates the diversified development of rural digital industries and fosters new business forms, including digital agriculture, rural e-commerce, and rural cultural tourism. On the one hand, it drives local and nearby employment and income growth for farmers, reduces the size of low-income groups at the source, and eases pressure on basic livelihood security. On the other hand, it strengthens village-level collective economies and local fiscal capacity, expands the supply of funds for livelihood security, and thus enhances rural protective security, consolidating the safety net for rural social welfare. Fourth, digital rural construction optimizes the digital macro-environment and supports the implementation of a digital governance system for rural human settlement environments. It enables refined and long-term management of rural domestic waste disposal and village appearance maintenance, improves rural human settlement environments, and enriches the ecological connotation of rural social welfare.

H1. *Digital rural construction contributes to the improvement of rural social welfare.*

3.2. *The Transmission Mechanism of the Impact of Digital Rural Construction on Rural Social Welfare*

Digital rural construction precisely builds a bridging platform connecting the technical demands of agricultural producers with technology suppliers, realizing accurate matching of demand and supply, reducing losses in intermediate links, and improving technology conversion efficiency. Meanwhile, digital technology greatly facilitates agricultural technology innovators in accessing innovation services, injecting strong internal impetus into agricultural technology upgrading and driving continuous innovation in agricultural technologies. Agricultural technological progress can boost agricultural production efficiency by improving total factor productivity. It can also reduce the input of chemical fertilizers and pesticides to alleviate agricultural non-point source pollution and increase the added value of agricultural products. Furthermore, it fosters new business forms such as sightseeing agriculture and creative agriculture to expand non-agricultural employment space. Through multiple channels, agricultural technological progress expands farmers' functioning freedom and capability freedom, and thus promotes the improvement of rural social welfare.

H2. *Agricultural technological progress plays a mediating role in the impact of digital rural construction on rural social welfare.*

3.3. *The Threshold Effect of Digital Rural Construction on Rural Social Welfare*

The notion of capability approach posits that enhancing rural social welfare is contingent upon broadening farmers' capable agency, namely their opportunities and freedoms to participate in diverse functional activities. The influence of digital rural development on rural social welfare demonstrates a threshold effect. In the initial stage of construction, digital technology functions mainly by strengthening instrumental freedoms such as information access and market access. While it can increase farmers' income and improve daily convenience, its effect on transforming production modes and upgrading public services remains limited, resulting in a modest improvement in social welfare. However, when digital technology is deeply integrated into agricultural production and rural governance, farmers' capabilities will achieve a qualitative leap. At this stage, digital rural construction crosses the threshold and generates a multiplier effect: farmers' scope of choice in health, education, social participation and other areas expands significantly,

and rural social welfare is reinforced at both the functioning freedom and capability freedom levels, demonstrating a non-linear feature of increasing marginal returns.

H3. *The impact of digital rural construction on rural social welfare exhibits non-linear characteristics of increasing marginal effect.*

3.4. *The Spatial Spillover Effect of Digital Rural Construction on Rural Social Welfare*

On the one hand, digital networks break through geographical boundaries and enable the efficient cross-regional allocation of factors of production, including labor, capital and technology. This directly reduces inter-regional production and transaction costs, forming spatial spillovers based on economic linkages. On the other hand, knowledge spillovers including smart agricultural technologies and e-commerce operation models radiate to neighboring regions through digital social networks and industrial collaboration platforms, thereby enhancing the economic capabilities of farmers in surrounding areas. In addition, institutional innovations and policy practices developed by local governments in digital rural construction tend to trigger yardstick competition and policy imitation among adjacent areas, thus generating policy spillover effects.

H4. *The impact of digital rural construction on rural social welfare presents a spatial spillover effect.*

4. Materials and Methods

4.1. *Variable Explanation*

(1) Explained variable

Rural social welfare (SW): Grounded in the capability approach and drawing on the studies of Yang and Song (2012) [38] and Wu and Wang (2016) [39], this paper constructs an indicator system for rural social welfare. The capability approach holds that social welfare entails not only improvements in material conditions, but also enhancements in individuals' functioning freedom and capability freedom, that is, the ability of individuals to achieve their preferred lifestyles. When developing the indicator system, this paper takes rural realities and data availability into account, and selects 19 indicators covering six domains: material life, medical security, education and culture, infrastructure, social security, and ecological environment. These indicators correspond to the four core dimensions of rural social welfare: economic facilities, social opportunities, protective security, and human settlement environments. First, the economic facilities dimension corresponds to the first-level indicator of material life. Within this dimension, per capita disposable income of rural residents, the urban-rural income ratio, and the Engel coefficient are functioning outcome indicators that directly reflect the realization degree of functionings at the income and consumption levels. Per capita residential floor area serves as a capability-supporting indicator that forms the material foundation for improving quality of life. Second, the social opportunities dimension corresponds to the first-level indicators of medical security and education and culture. Outcome indicators such as the average years of schooling of rural residents reflect functioning freedom in the human capital domain. Supply-side indicators, including the number of village clinics, the number of medical beds, and the scale of teaching staff, constitute the capability support for health and development. Third, the protective security dimension corresponds to the first-level indicator of social security. The coverage rate of subsistence allowances reflects the realization degree of the basic livelihood safety net function, and expenditure on subsistence allowances provides capability support for risk resistance. Together, these elements form the safety net for substantive capabilities. Fourth, the human settlement environments dimension corresponds to the first-level indicators of infrastructure and ecological environment. The domestic waste treatment rate and number of public toilets directly reflect the realization

of livable living functionings. Indicators such as rural road area, water supply penetration rate, green coverage rate, and renewable energy utilization rate constitute the capability support for the long-term improvement of human settlement environments. Regarding the selection of weighting methods, subjective weighting approaches such as the Analytic Hierarchy Process (AHP) are susceptible to researchers' personal preferences and cannot fully meet the objective evaluation requirements of this study. The entropy weight method is a classic objective weighting technique. It determines indicator weights based on the degree of dispersion of indicator data, which effectively mitigates biases caused by subjective judgment. In addition, it is highly compatible with the structural characteristics of inter-provincial panel data and can maximally ensure the objectivity and scientific validity of evaluation results. Accordingly, this paper employs the entropy weight method to assign weights to the aforementioned dimensions and calculates the composite index of rural social welfare, which comprehensively reflects the development level of rural residents' freedom and capability freedom. The selected indicators are presented in Table 1.

Table 1. Rural Social Welfare Index System.

First-Level Indicator	Second-Level Indicator	Third-Level Indicator	Unit	Indicator Type
Material Living Standards	Income Level and Personnel Security	Per Capita Disposable Income of Rural Residents	Yuan (CNY)	+
		Urban-Rural Resident Income Ratio	Times	–
	Consumption Structure	Engel's Coefficient of Rural Households	%	–
	Living Conditions	Per Capita Residential Floor Area	m ²	+
Healthcare Security	Infrastructure Security	Number of Village Clinics	Units	+
		Number of Beds in Medical and Health Institutions per 1000 Rural Residents	Beds	+
	Workforce Security	Number of Health Technical Personnel per 1000 Rural Population	Persons	+
Education and Cultural Development	Educational Attainment	Average Years of Schooling of Rural Residents	Years	+
		Proportion of Full-time Teachers with Bachelor's Degree or Above in Rural Compulsory Education Schools	%	+
	Cultural Dissemination	Number of Rural Cultural Stations	Units	+
Rural Infrastructure	Rural Road Network	Area of Township Roads	10,000 m ²	+
	Rural Water Supply	Village Tap Water Coverage Rate	%	+
	Construction Investment	Investment in Village Public Utility Construction	10,000 Yuan (CNY)	+
Social Security	Subsistence Security	Proportion of Rural Residents Covered by Minimum Living Security (Dibao) in Total Rural Population	10,000 Persons	+
		Rural Minimum Living Security (Dibao) Expenditure	10,000 Yuan (CNY)	–
Ecological Environment	Human Settlement Environment	Harmless Domestic Waste Treatment Rate	%	+
		Number of Public Toilets	Units	+
	Ecological Conservation	Renewable Energy Utilization Rate	%	+
		Green Coverage Rate	%	+

(2) Core explanatory variables

Digital Rural Construction (DIGV): Driven by robust government promotion, digital rural construction has advanced steadily across China. Developing a well-aligned indicator system for digital rural construction requires close alignment with official policy documents and full consideration of on-the-ground rural development realities. When building the indicator system, this paper draws on the core policy frameworks outlined in the Outline of Digital Rural Development Strategy and the Digital Rural Development Report (2019), which cover rural information infrastructure, digital service supply, rural digital economy, and development support environments, as well as established research findings [40]. Fifteen indicators are selected across four dimensions to comprehensively measure the level of digital rural construction: rural digital information infrastructure, digital rural service capacity, digital rural industrial development, and digital rural macro-environment. Specifically, the digital infrastructure dimension, corresponding to rural digital information infrastructure, aligns with the policy requirement for co-construction and sharing of rural information infrastructure specified in the Outline of Digital Rural Development Strategy. This dimension comprises six indicators: rural internet penetration rate, smartphone penetration rate, radio and television penetration rate, computer penetration rate, number of agricultural meteorological stations, and length of optical cable routes. Together, these indicators capture the hardware support capacity underlying rural digitalization. Second, the rural digital industry dimension, corresponding to digital rural industrial development, is closely aligned with the strategic deployment of the “Digital Business Vitalizing Agriculture” initiative. Focusing on core application scenarios such as digital payments and online transactions, this dimension incorporates three indicators: the digital index of rural inclusive finance, e-commerce sales, and e-commerce procurement value, to reflect the actual outcomes of digital technology in empowering rural industries. Third, the digital capital input dimension, which falls under the digital rural macro-environment, addresses key policy priorities including smart agricultural technology and equipment and digitalization across the entire agricultural industrial chain. Three indicators are selected for this dimension: fixed asset investment in rural transport and postal services, share of administrative villages with postal access, and fixed asset investment in information transmission and information technology services. These indicators measure the intensity of financial and supporting guarantees for digital rural construction. Fourth, the rural digital service dimension, corresponding to digital rural service capacity, centers on the policy objective of deepening inclusive digital services in rural areas. It includes three indicators: length of rural postal delivery routes, per capita electricity consumption in rural areas, and per capita expenditure on transportation and communications among rural residents. These indicators capture the coverage breadth and penetration depth of digital services extending to rural areas. The full composition of the indicator system is detailed in Table 2.

Table 2. Index System for Digital Rural Construction.

First-Level Indicator	Second-Level Indicator	Third-Level Indicator	Unit	Indicator Type
Digital Rural Information Infrastructure	Smartphone Penetration Rate	Number of Mobile Phones per 100 Rural Households	Units	+
	Internet Penetration Rate	Number of Rural Broadband Internet Access Subscribers	10,000 Households	+
	Radio and Television Penetration Rate	Proportion of Actual Cable Radio and Television Subscribers in Total Rural Households	%	+
	Computer Penetration Rate	Number of Computers per 100 Rural Households	Units	+

Digital Rural Service Level	Agricultural Meteorological Observation Stations	Number of Environmental Meteorological Observation Stations	Units	+
	Communication Capacity	Length of Optical Cable Lines	km	+
	Information Technology Service Coverage	Length of Rural Delivery Routes	km	+
	Per Capita Rural Electricity Consumption	Total Rural Electricity Consumption/Total Rural Population	kWh/person	+
	Digital Service Consumption Level	Per Capita Transportation and Communication Expenditure of Rural Residents	Yuan (CNY)/person	+
Digital Rural Industrial Development	Rural Online Payment Level	Rural Inclusive Finance Digital Index	—	+
	Digital Transaction Level	E-commerce Sales Volume	100 Million Yuan (CNY)	+
		E-commerce Procurement Volume	100 Million Yuan (CNY)	+
Digital Rural Macro Environment	Transportation and Postal Industry Investment	Fixed Asset Investment in Rural Transportation, Warehousing and Postal Industries	100 Million Yuan (CNY)	+
	Communication Service Level	Proportion of Administrative Villages with Postal Service	%	+
	Information Technology Investment	Fixed Asset Investment in Information Transmission, Software and Information Technology Services	100 Million Yuan (CNY)	+

(3) Mediating variables

The chosen mediating variable in this article is the degree of agricultural science and technology (Ti). Utilizing the methodologies of scholars Li et al. (2023) [41] and Zhang and Li (2024) [42], it is quantified by the count of agricultural science and technology patents. A greater rating indicates an elevated level of agricultural research and technology.

(4) Control variables

This research also includes the following control variables to mitigate the influence of external influences on rural social welfare: government functions (Gov), degree of openness (Ope), regional ecological environment (Env), and regional industrial structure (Ind). The government function (Gov) is quantified by the ratio of public budget expenditure within the government's fiscal framework to the regional GDP. The openness to the external environment (Ope) is defined by the ratio of a region's total import and export volume to its GDP. The regional ecological environment (Env) is determined by the ratio of the area designated for soil erosion management to the entire area of the province. The regional industrial structure (Ind) is defined by the ratio of the production value of the tertiary sector to that of the secondary sector.

4.2. Sources and Processing of Data

The information in this article is primarily derived from sources including the China Statistical Yearbook, China Rural Statistical Yearbook, Urban Construction Statistical Yearbook, China Electronic Information Industry Statistical Yearbook, China Tertiary Industry Statistical Yearbook, Peking University's Digital Inclusive Finance Index, the National Bureau of Statistics, and the China Economic Information Network Statistical Database. The descriptive statistics of all relevant variables involved in this study are presented in Table 3.

Table 3. Descriptive Statistics of Relevant Variables.

Variable Name	Variable Symbol	Sample Size (N)	Mean	Std. Dev	Min	Max
Digital Rural Construction	DIGV	390	0.6098	0.1234	0.1526	0.8452
Rural Social Welfare	SW	390	0.4493	0.0689	0.2721	0.6194
Government Function	Gov	390	0.2472	0.1018	0.1066	0.6430
Degree of Opening-up	Ope	390	0.3097	0.3891	0.0131	2.6345
Regional Ecological Environment	Env	390	0.2213	0.1432	0.0031	0.5970
Regional Industrial Structure	Ind	390	0.9049	0.0521	0.7387	0.9989

4.3. Model Setting

(1) Fixed effects model

To investigate the impact of digital rural construction on rural social welfare, based on theoretical analysis and data characteristics, the following fixed effect model is constructed:

$$SW_{i,t} = \alpha_0 + \alpha_1 DIGV_{i,t} + \alpha_2 Controls_{i,t} + \mu_i + \nu_t + \varepsilon_{i,t} \quad (1)$$

In Equation (1), i denotes the province, t signifies the year, $SW_{i,t}$ indicates rural social welfare, $DIGV_{i,t}$ reflects the amount of digital village construction, and $Controls_{i,t}$ encompasses other control variables. μ_i denotes individual fixed effects, ν_t denotes time fixed effects, and $\varepsilon_{i,t}$ represents the random error term.

(2) Mediating effect model

To study the transmission mechanism of the impact of digital rural construction on rural social welfare and further conduct a mediation effect analysis, referring to the method of Hao Aimin (2022) [40], taking the level of agricultural science and technology (T_i) as the mediating variable, the following mediation effect model is constructed:

$$Ti_{i,t} = \beta_0 + \beta_1 DIGV_{i,t} + \beta_2 Controls_{i,t} + \mu_i + \nu_t + \varepsilon_{i,t} \quad (2)$$

In Equation (2), $Ti_{i,t}$ represents the level of agricultural science and technology, β_1 represents the degree of impact of digital village construction on the level of agricultural science and technology, and the meanings of the other variables are the same as above.

(3) Threshold effect model

To examine the threshold effect of the impact of digital village construction on rural social welfare, the following panel threshold model is set:

$$SW_{i,t} = \phi_0 + \phi_1 DIGV_{i,t} \times I(T_{i,t} \leq \theta) + \phi_2 DIGV_{i,t} \times I(T_{i,t} > \theta) + \phi_c Controls_{i,t} + \mu_i + \varepsilon_{i,t} \quad (3)$$

In Equation (3), T represents threshold variables such as digital rural construction and agricultural science and technology level, and $I(\cdot)$ is an indicator function with values of 1 or 0. If the conditions within the parentheses are met, it is 1; otherwise, it is 0.

(4) Spatial metrological model

The construction of digital villages, relying on digital technology as the core driving force, breaks the geographical distance limitations between regions, promotes the cross-regional flow of elements, and thereby triggers a radiation and driving effect on surrounding or related areas, generating a spatial spillover effect (Liu and Wang 2025 [43]). Therefore, to explore the spatial spillover effect of digital village construction on rural social welfare, the following spatial Durbin model is constructed:

$$SW_{i,t} = \alpha_0 + \rho WSW_{i,t} + \alpha_1 DIGV_{i,t} + \theta_1 WDIGV_{i,t} + \alpha_2 Controls_{i,t} + \theta_2 Controls_{i,t} + \mu_i + \nu_t + \varepsilon_{i,t} \quad (4)$$

In Equation (4), W denotes the spatial weight matrix. Both the spatial contiguity matrix and the economic-geographic nested matrix are employed for empirical testing in this paper. ρ represents the spatial autoregressive coefficient of the explained variable, and θ_1 and θ_2 respectively denote the spatial overflow coefficients of the core explanatory variable and the control variable.

5. Results

5.1. The Spatio-Temporal Evolution Trends of Digital Village Construction and Rural Social Welfare

Based on the entropy method for calculating the construction of digital villages and the level of rural social welfare, this paper will analyze the spatio-temporal evolution trends of the overall situation in China and the three major regions of the east, central and west from the temporal and spatial dimensions (see Table 4).

The creation of digital villages in China has exhibited a consistent rising trajectory from 2011 to 2023. The national average value of digital village construction is 0.61, increasing from 0.44 to 0.71, with an average yearly growth rate of 4.02%. This signifies that within the context of the rural revitalization strategy, China has attained significant accomplishments in digital village construction, and the digital transformation of rural regions has been progressively developing. Digital applications are perpetually proliferating. Regionally, the extent of digital rural construction exhibits considerable disparities. The eastern area is superior to other regions and exceeds the national average. The statistics in the center region are essentially equivalent to the national average, whilst the western region is positioned at the lowest tier. This unequivocally illustrates that the digital gap persists. The eastern provinces, leveraging their robust economic basis, comprehensive infrastructure, and advanced Internet technology, spearhead the development of digital communities. The development of the digital economy in western provinces is comparatively hindered by their geographical constraints and resource restrictions, resulting in the nascent stage of digital village construction.

Rural social welfare has had an improving trajectory from 2011 to 2023. The national rural social welfare rate increased from 0.39 in 2011 to 0.51 in 2023, reflecting an average yearly growth rate of 2.15% and an average value of 0.45. This signifies the ongoing endeavors in the development of rural social welfare in our nation. The welfare security of rural dwellers has progressively enhanced, resulting in an improved quality of life. Nonetheless, significant opportunities for enhancement in rural social welfare persist. Regionally, the eastern region exhibits superior economic strength relative to other regions. Local budgets possess adequate investment in rural social welfare, hence offering more comprehensive welfare assurances for rural inhabitants. Conversely, the center region, characterized as a conventional agricultural zone, is inferior to the eastern region for economic growth and financial capacity. The government prioritizes rural development in the central area and has consistently invested in rural social welfare, resulting in the central region's social welfare level being surpassed only by that of the eastern region. The economic infrastructure in the western region is fragile, and the development of rural social welfare faces significant challenges. The government has augmented financial assistance for social welfare in rural parts of the western region via legislative initiatives including transfer payments. Nevertheless, owing to reasons such as substantial historical debt and a complicated geographical landscape, limitations persist in infrastructure development and the service provision capacity of rural social welfare in the western region, highlighting a pronounced disparity with other regions.

Table 4. Digital Rural Construction and the Development Level of Rural Social Welfare.

	DIGV				SW			
	Eastern Re- gion	Central Re- gion	Western Re- gion	National Average	Eastern Re- gion	Central Re- gion	Western Re- gion	National Average
2011	0.5212	0.4404	0.3436	0.4437	0.4475	0.4031	0.3537	0.3932
2012	0.5624	0.4869	0.3931	0.4890	0.4521	0.4117	0.3655	0.4038
2013	0.5951	0.5197	0.4353	0.5245	0.4631	0.4234	0.3822	0.4115
2014	0.6191	0.5495	0.4775	0.5574	0.4744	0.4362	0.3986	0.4228
2015	0.6457	0.5893	0.5249	0.5926	0.4828	0.4447	0.4106	0.4279
2016	0.6643	0.6041	0.5484	0.6115	0.4912	0.4510	0.4107	0.4375
2017	0.6801	0.6228	0.5727	0.6306	0.5080	0.4648	0.4233	0.4489
2018	0.6878	0.6451	0.5941	0.6469	0.5209	0.4794	0.4384	0.4651
2019	0.7005	0.6557	0.6030	0.6578	0.5282	0.4884	0.4520	0.4716
2020	0.7080	0.6670	0.6171	0.6684	0.5298	0.4856	0.4597	0.4740
2021	0.7176	0.6853	0.6432	0.6896	0.5386	0.5053	0.4627	0.4839
2022	0.7273	0.6966	0.6562	0.7027	0.5497	0.5108	0.4737	0.4926
2023	0.7338	0.7092	0.6690	0.7129	0.5545	0.5248	0.4839	0.5080
Mean	0.6587	0.6055	0.5445	0.6098	0.5031	0.4638	0.4242	0.4493
Ranking	1	3	4	2	1	2	4	3

Note: The above values are the average values of each year.

5.2. Benchmark Regression Results

Table 5 displays the benchmark regression estimation outcomes of digital rural development on rural social welfare. Subsequent to the Hausman test, this research opts for the fixed-effect model for estimate. Models (1) to (3) present the estimation results of the pooled effect model, fixed effect model, and random effect model, respectively. The coefficient of the core explanatory variable, digital rural construction (DIGV), is significantly positive across all specifications. In Model (2), the regression coefficient of DIGV is 0.2283 and is statistically significant at the 1% level. This indicates that a one-unit increase in digital rural construction is associated with a 0.2283-unit rise in rural social welfare, reflecting a significant positive association between the two variables. This finding suggests that provinces with higher levels of digital rural construction tend to have more developed information infrastructure, more advanced digital rural industries, and higher information access efficiency, and are accompanied by relatively higher levels of rural social welfare. This result is consistent with H1.

Among the control variables, the regression coefficients of regional ecological environment, industrial structure upgrading, and the level of opening-up are all significantly positive, indicating significant positive correlations with the level of rural social welfare. On the one hand, a sound ecological environment is itself an important component of rural social welfare, as it provides rural residents with a high-quality living environment. Meanwhile, favorable ecological endowments are conducive to the development of new business forms such as eco-agriculture and rural tourism, which are associated with higher farmer incomes and improvements in rural infrastructure and public service levels, thus exerting a positive influence on rural social welfare. On the other hand, the transformation of the industrial structure toward diversification and modernization is linked to broader employment channels and higher farmer incomes, which correspond to progress in rural public services including education and healthcare. In addition, opening up helps break down regional market barriers, bringing external capital, advanced technologies and modern operational concepts to rural areas, which may compensate for the weak industrial foundation in some regions. The regression coefficients of the remaining control variables are not statistically significant, suggesting no discernible effect on rural social welfare.

Table 5. Estimation Results of Benchmark Regression Model.

	(1) Mixed Effects Regression	(2) Fixed Effects Regression	(3) Random Effects Regression
DIGV	0.2449 *** (10.80)	0.2283 *** (6.79)	0.2449 *** (11.12)
Gov	0.0506 (1.03)	0.0222 (0.49)	0.0149 (0.33)
Ope	−0.0168 *** (−2.59)	0.0095 ** (2.37)	−0.0146 ** (−2.21)
Env	−0.0699 * (−1.95)	0.0298 * (1.98)	−0.0698 ** (−2.14)
Ind	0.436 *** (4.21)	0.2791 *** (3.42)	0.4775 *** (4.99)
Province		Controlled	
Year		Controlled	
Constant Term	−0.0864 *** (−0.92)	0.0383 * (0.48)	−0.1154 * (−1.34)
Observations	390	390	390
R ²	0.4467	0.7979	0.3439

Note: *, **, and *** represent significance levels of 10%, 5%, and 1% respectively; The figures in parentheses are robust standard errors, the same below.

5.3. Robustness Assessment and Endogeneity Evaluation

(1) Robustness assessment

To verify the robustness of the aforementioned baseline regression results, this paper employs three approaches for further testing. First, time window adjustment. Following the method of Fu et al. (2024) [44], to mitigate bias in regression results caused by policy shifts, this paper excludes observations from the 2018–2020 period and re-estimates the regression model. The results are presented in Column (1) of Table 6. The regression coefficient of DIGV is 0.2578, indicating that each one-unit increase in digital rural construction corresponds to a 0.2578-unit rise in rural social welfare. The result is statistically significant at the 1% level and broadly consistent with the baseline finding, confirming the robustness of the conclusions in this paper. Second, exclusion of municipality samples. According to the Digital Rural Index data released by the Digital Rural Project Team of the Institute for New Rural Development at Peking University, Beijing, Tianjin and Shanghai are excluded from the statistical scope, while sample counties in Chongqing remain covered by the dataset (Li and Li, 2024 [45]). As a municipality directly under the central government, Chongqing differs substantially from ordinary provinces in terms of political status, economic development level, policy support intensity and technological capacity, which may affect the research conclusions. Accordingly, this paper excludes the Chongqing municipality sample and conducts further regression analysis on the remaining 379 observations using the fixed-effect model. The specific results are shown in Column (2) of Table 6, which demonstrates that the regression coefficient of DIGV remains significantly positive at the 1% level. Third, two-sided winsorization. To eliminate interference from outliers, the data are processed with 1% two-sided winsorization before re-estimation. As shown in Column (3) of Table 6, the regression coefficient of DIGV is 0.2436, meaning that each one-unit increase in digital rural construction corresponds to a 0.2436-unit rise in rural social welfare and is statistically significant at the 1% level. This further verifies the robustness of the baseline regression results.

Table 6. Robustness Test and mediating Effect test.

	(1)	(2)	(3)	(4)	(5)	(6)
	Adjusted Time Window	Excluding Municipalities	Two-Sided Winsorization	Instrumental Variable Approach	System GMM	Ti
DIGV	0.2578 *** (7.03)	0.2252 *** (6.70)	0.2436 *** (8.88)	0.2851 *** (7.21)	0.3275 *** (3.13)	0.2009 *** (6.94)
L.SW					0.6278 ** (2.66)	
First-stage regression IV				0.8574 *** (32.01)		
Kleibergen-Paap rk LM statistic				275.55 [0.000]		
Kleibergen-Paap rk Wald F statistic				1024.50 {16.38}		
AR(1) test <i>p</i> -value					0.001	
AR(2) test <i>p</i> -value					0.783	
Hansen test <i>p</i> -value					0.755	
Control variables	YES	YES	YES	YES	YES	YES
Constant term	0.0818 (0.85)	0.0569 (0.72)	0.1320 (0.98)	0.0019 (0.02)	0.4131 (1.42)	0.1336 *** (2.73)
Observations	300	377	360	390	360	390
R ²	0.7695	0.8025	0.8246	0.9396	—	0.6146

Note: ** and *** represent significance levels of 5% and 1% respectively; The figures in parentheses are robust standard errors, Values in parentheses are robust standard errors; values in square brackets are *p*-values; values in curly brackets are the Stock-Yogo critical value at the 10% significance level for the weak identification test.

(2) Endogeneity test

Endogeneity issues generally stem from two primary sources. The first is omitted explanatory variables. To mitigate the endogeneity caused by this problem, this paper includes as many factors influencing rural social welfare as possible in the control variables, and constructs a dynamic panel system GMM model for re-estimation to reduce the impact of omitted variables. The second is reverse causality. In practice, improvements in rural social welfare may contribute to the advancement of digital rural construction.

1. System GMM

To address endogeneity from omitted variables, this paper introduces the first-order lag of rural social welfare (L.SW) to construct a dynamic panel system GMM model for re-estimation. The results are reported in Column (5) of Table 6. Digital rural construction exerts a positive effect on rural social welfare, indicating that rural social welfare in the previous period is associated with its level in the current period. In addition, the *p*-values of the AR(2) test and the Hansen test for the system GMM estimation are both greater than 0.1, suggesting no serial autocorrelation in the residuals and validating the selected instrumental variables. This confirms that the core hypotheses of this paper are still held after accounting for the omitted variable issue.

2. Instrumental Variable Approach

This paper adopts the first-order lag of the core explanatory variable as the instrumental variable and performs estimation using the two-stage least squares (2SLS) method. The selection of the instrumental variable is based on two considerations. On the one hand, the level of digital rural construction in the previous period is highly correlated with its current

level, which ensures the relevance between the instrumental variable and the endogenous explanatory variable. On the other hand, the previous period's digital rural construction level does not directly affect the current year's rural social welfare, thus satisfying the exogeneity requirement for the instrumental variable. Column (4) of Table 6 reports the effect of digital rural construction on rural social welfare after addressing endogeneity with the instrumental variable method. For the under identification test of the null hypothesis that the instrumental variable is insufficiently identified, the p -value of the Kleibergen-Paap rk LM statistic is 0.000, which significantly rejects the null hypothesis. For the weak identification test, the Kleibergen-Paap rk Wald F statistic exceeds the critical value at the 10% significance level of the Stock-Yogo weak identification test, indicating that the instrumental variable used in this paper is valid. Furthermore, the estimated coefficient of DIGV is significantly positive at the 1% level and is larger than the baseline regression coefficient of 0.2283, which further verifies the robustness of the previous results.

5.4. Analysis of Mechanism of Action

Based on the theoretical analysis in the previous text, the essence of digital rural construction is to promote the improvement of agricultural science and technology progress through the advancement of digital technology, and thereby empower rural social welfare. To verify this mechanism, this paper references pertinent literature and employs the quantity of local agricultural science and technology patents as a metric for assessing the level of agricultural science and technology, thereby investigating the mechanism by which digital village construction influences rural social welfare. Column (5) of Table 6 shows that digital rural construction has a significant positive association with agricultural technological progress, which effectively supports H2 of this paper.

By leveraging technologies including artificial intelligence and the Internet of Things (IoT), digital rural construction contributes to the digital development of the entire agricultural industrial chain and all dimensions of rural areas. It helps improve agricultural production efficiency and resource utilization efficiency, and facilitates the large-scale, specialized and intensive development of agriculture. These changes are associated with enhanced agricultural benefits and exert a positive influence on the improvement of rural social welfare.

5.5. Threshold Effect Analysis

This study utilizes the mediating variable [46] as the threshold variable and employs the threshold regression model to elucidate the nonlinear effects of digital rural construction on farmers' social welfare. The Bootstrap sampling approach was initially employed to ascertain the quantity of thresholds. The findings in Table 7 indicate that the threshold variable for digital rural construction notably exceeded the single threshold test. A regression analysis was performed using the degree of agricultural science and technology as the threshold variable, with the findings presented in Table 8. As is evident from Table 8, the single threshold test for agricultural technological level yields a statistically significant result. Once the threshold value is crossed, the positive effect of digital rural construction on rural social welfare is enhanced, exhibiting a significant non-linear pattern of positive impact with increasing marginal effect. This suggests that the dynamic effect of digital rural construction on rural social welfare is shaped not only by its own development level, but also by the moderating effect of agricultural technological level. This finding is consistent with H3.

Table 7. Threshold Self-sampling Test.

Explanatory Variable	Threshold Type	F-Statistic	p-Value	Critical Values		
				1%	5%	10%
DIGV	Single Threshold	34.19	0.0416	41.7419	32.2257	26.9501
	Double Threshold	17.98	0.2163	61.5177	39.7634	30.0529

Table 8. Threshold Regression Results.

Threshold Variable	Explanatory Variable	Coefficient	Control Variables	R ²	Observations
Ti	DIGV(Ti ≤ 1.04)	0.3003 *** (16.18)	Controlled	0.8185	390
	DIGV(Ti > 1.04)	0.3502 *** (19.25)			

Note: *** represent significance levels of 1%; The figures in parentheses are robust standard errors.

5.6. Analysis of Spatial Spillover Effects

To investigate the spatial spillover effect of digital rural construction on rural social welfare, it is essential to first ascertain the existence of such an effect, necessitating a set of tests to identify the specific configuration of the spatial model. Accounting for economic distance, industrial linkages, cross-regional factor mobility and other relevant factors, this study employs two spatial weight matrices: the spatial contiguity matrix and the economic-geographic nested matrix. First, we compute the Moran's I and Geary's C statistics for the Digital Rural Construction Index and the Rural Social Welfare Index over the 2011–2023 period using both matrices. The results reveal that both indices present significant positive spatial autocorrelation under either weight matrix, which supports the adoption of spatial econometric models. Subsequently, a series of Lagrange Multiplier (LM) tests is performed. As reported in Table 9, all test statistics are statistically significant at the 1% level, indicating that the Spatial Durbin Model (SDM) is the more appropriate specification. Furthermore, both the Likelihood Ratio (LR) tests and Wald tests pass the significance test at the 1% level, further confirming that the SDM cannot be reduced to the Spatial Error Model (SEM) or the Spatial Lag Model (SAR). Finally, the Hausman test concludes that the SDM with two-way fixed effects is the optimal model choice.

Table 9. Test Results.

Test Method	Test Name	Test Statistic	
		Spatial Contiguity Matrix	Economic-Geographic Nested Matrix
LM Test	LM-Error	137.373 ***	45.832 ***
	Robust LM-Error	23.319 ***	20.024 ***
	LM-Lag	115.444 ***	26.937 ***
	Robust LM-Lag	13.91 ***	11.128 ***
LR Test	LR-Both-Ind	589.3678 ***	748.3961 ***
	LR-Both-Time	297.3799 ***	751.7134 ***
	LR-SDM-SAR	275.69 ***	422.14 ***
	LR-SDM-SEM	273.42 ***	415.51 ***
Wald Test	Wald-SDM-SAR	20.17 ***	40.63 ***
	Wald-SDM-SEM	16.46 ***	28.08 ***
Hausman Test	Hausman	20.72 ***	15.84 **

Note: ** and *** represent significance levels of 5% and 1% respectively; The figures in parentheses are robust standard errors.

Building on the above model selection and test results, we decompose the total effect into direct and indirect effects to more comprehensively measure the spatial spillover effects of digital rural construction on rural social welfare. As reported in Table 10, regardless of whether the spatial contiguity matrix or the economic-geographic nested matrix is adopted, both the direct and indirect effects of digital rural construction on rural social welfare are positively significant at the 1% significance level. In particular, the magnitude of the indirect effect is more pronounced, and the spillover intensity is stronger under the economic-geographic nested matrix, which verifies Hypothesis 4. This finding implies that digital rural construction is not only positively correlated with local rural social welfare, but also presents a positive spatial association with rural social welfare in geographically adjacent or economically linked regions. Compared with mere geographical adjacency, provinces with similar economic development levels and close industrial linkages exhibit stronger spatial correlation. The potential mechanism is that cross-regional factor mobility, agricultural technology diffusion, and e-commerce industrial chain collaboration generate stronger radiation effects among regions with tight economic connections.

Table 10. Results of Spatial Durbin Model Verification.

Variable Name	Direct Effect		Indirect Effect		Total Effect	
	Spatial Contiguity Matrix	Economic-Geographic Nested Matrix	Spatial Contiguity Matrix	Economic-Geographic Nested Matrix	Spatial Contiguity Matrix	Economic-Geographic Nested Matrix
DIGV	0.1011 *** (3.21)	0.1246 *** (3.30)	0.2265 *** (4.71)	0.3036 *** (2.40)	0.3276 *** (7.01)	0.4281 *** (3.78)
Gov	0.0413 (0.92)	0.0050 (0.13)	0.1097 *** (3.33)	−0.0781 (−0.38)	0.1510 ** (1.76)	−0.0731 (−0.36)
Ope	−0.0083 (−1.10)	0.0140 *** (3.94)	0.0271 * (1.68)	−0.1100 *** (−5.66)	0.0182 (0.99)	−0.0960 *** (−4.91)
Env	0.0156 (0.54)	0.0093 (0.35)	0.0273 (0.57)	0.2938 ** (2.27)	0.0429 (1.06)	0.3031 ** (2.38)
Ind	0.2592 *** (3.10)	0.2780 *** (3.68)	0.2486 * (1.68)	0.1650 (0.51)	0.5079 ** (3.31)	0.4430 (1.43)

Note: *, **, and *** represent significance levels of 10%, 5%, and 1% respectively; The figures in parentheses are robust standard errors.

5.7. Heterogeneity Analysis

Due to significant differences in economic development levels, resource endowments and other factors among various regions in our country, there is also regional imbalance in the development levels of digital rural construction and rural social welfare. This consequently results in regional disparities in the effects of digital village construction on rural social welfare across various areas. This article will examine two aspects: geographical location and the diversity of economic development levels.

Given the pronounced gap between the eastern region and other regions, this paper follows the regional classification criteria for eastern, central and western regions issued by the National Bureau of Statistics, and draws on the research of scholars including Zhao et al. (2020) [47] to divide the 30 provinces nationwide into two groups: the eastern region and the central and western regions. We then investigate whether geographical heterogeneity affects the welfare-enhancing effect of digital rural construction on rural social welfare. As shown in Columns (1) and (2) of Table 11, digital rural construction has a significant positive association with rural social welfare in the eastern region. Benefiting from its advanced economic foundation, the eastern region got an early start and achieved rapid progress in digital rural construction, and has reached relative maturity in digital infrastructure development and digital talent reserves. As a result, investment in digital

rural construction can be rapidly translated into tangible improvements in rural social welfare, presenting a remarkable welfare-enhancing effect. Compared with the eastern region, the effect of digital rural construction on rural social welfare in the central and western regions is not statistically significant. A plausible explanation is that constrained by relatively lagging economic development and inadequate digital infrastructure, the welfare effects of digitalization have not been fully unleashed in these regions.

In regions at different economic development levels, the application effects of digital technologies in agricultural and rural sectors also vary widely, which further shapes the welfare-enhancing performance of digital rural construction. Referring to the research of scholars such as Li and Zhou (2021) [48], this paper calculates the average per capita real GDP of each province over the sample period, and divides the provinces into three groups by tercile: economically developed regions, moderately developed regions, and economically underdeveloped regions. We then examine whether heterogeneity in economic development level influences the welfare-enhancing effect of digital rural construction. As presented in Columns (3) to (5) of Table 11, the coefficient of digital rural construction in economically developed regions is significantly positive at the 1% level, with a larger magnitude than that in economically underdeveloped regions. This indicates that through the deep integration of digital technology with diverse business formats such as agricultural production, rural tourism and smart elderly care, economically developed regions have generated synergistic effects and exerted a positive impact on social welfare. By contrast, restricted by the dual constraints of intensifying population aging and infrastructure gaps, policy preferences in economically underdeveloped regions have not been effectively converted into increments in rural social welfare, resulting in a weaker effect than that in economically developed regions.

Table 11. Results of Heterogeneity Regression.

	(1)	(2)	(3)	(4)	(5)
	Eastern Region	Central and Western Regions	Economically Developed Regions	Economically Moderately Developed Regions	Economically Underdeveloped Regions
DIGV	0.2828 *** (2.51)	0.0760 (0.47)	0.2761 *** (6.65)	0.2402 (1.61)	0.1891 *** (2.70)
Control Variables	Yes	Yes	Yes	Yes	Yes
Constant Term	−0.3903 (−1.30)	0.2416 (1.28)	−0.9263 (−7.18)	0.0878 (0.44)	−0.1356 (−0.63)
Observations	156	234	130	130	130
R ²	0.8317	0.8124	0.5548	0.8257	0.6873

Note: *** represent significance levels of 1%; The figures in parentheses are robust standard errors.

6. Discussion

Building on Sen's capability approach, this study investigates the mechanism underlying the impact of digital rural construction on rural social welfare, focusing on how digital inputs translate into rural residents' substantive development capabilities. While extant literature predominantly examines the economic outcomes of digital rural construction, including farmer income, agricultural productivity, industrial upgrading and common prosperity [49–51], this paper adopts a capability-based perspective to explore its welfare implications. From the capability approach perspective, social welfare depends not merely on income levels but on individuals' ability to convert available resources into valuable life states [38]. Accordingly, digital rural construction improves welfare not only

by generating economic returns, but more critically by optimizing the conditions for resource-to-welfare conversion and turning digital resources into tangible development opportunities. Specifically, digital platforms strengthen capability freedom by expanding access to production inputs, market information and employment; digital education, telemedicine and online public services advance functioning freedom by broadening basic service access. Conceptually, rural social welfare differs from common prosperity. The latter emphasizes equalized distributional outcomes [52], whereas the former centers on the process of achieving functioning freedoms [53]. This capability perspective complements existing common prosperity-focused studies [36] by unpacking how digital technologies reshape access to development opportunities.

The conversion of digital technologies into welfare gains hinges on effective integration with agricultural production systems. This study identifies agricultural technological progress as a core transmission channel. Digital rural construction infuses data resources, digital platforms and information technologies into agricultural innovation systems, improving the efficiency of agricultural R&D, diffusion and application, and strengthening the absorptive capacity of production systems [47]. In turn, technological progress enhances household welfare by boosting productivity, reducing production costs, improving operational stability and building risk resilience. Unlike prior studies that highlight digital finance, e-commerce expansion and industrial integration as mechanisms [54,55], this paper underscores the foundational role of production-side digitization in the welfare conversion process.

Spatial analysis reveals pronounced spatial correlation in the welfare effects of digital rural construction, with indirect effects outweighing direct effects. Unlike traditional production factors, digital technologies feature strong information connectivity and knowledge spillovers [48]: locally developed digital agriculture practices, technological models and service systems generate externalities via economic linkages and interregional cooperation, so welfare gains accrue largely from network connectivity rather than local construction alone [56]. Notably, the stronger indirect effect does not stem exclusively from technology diffusion; policy interactions, interregional economic ties and spatial weight specification may also contribute, requiring further mechanistic exploration. The insignificant welfare effect in central and western regions further indicates that digital diffusion does not automatically translate into welfare improvements, but is constrained by local digital infrastructure, human capital endowments and technological absorptive capacity. Future research can leverage digital rural pilot policies, micro-survey data and network connectivity data to delineate the conditions and boundaries of digital welfare effects.

Overall, this study makes three theoretical contributions. First, it extends digital rural research beyond economic performance to capability and welfare perspectives, unpacking the deeper logic of digital technology's impacts on rural development. Second, it identifies the mediating role of agricultural technological progress, highlighting productive capacity enhancement as a critical foundation for welfare conversion. Third, it documents the spatial diffusion pattern of digital welfare effects, offering new analytical insights into the formation of digital economy spatial externalities.

Nevertheless, several limitations of this study should be acknowledged. First, the entropy weight method used to construct the comprehensive index system mitigates bias from subjective weighting. Yet welfare measurement inherently entails value judgments, meaning it cannot fully capture the normative importance of different welfare dimensions. Future work can further optimize the index system by integrating subjective and objective weighting approaches such as the analytic hierarchy process. Second, due to data availability constraints at the provincial level, some variables are still measured with proxy indicators. Follow-up studies can conduct multi-dimensional validation using county-level microdata, household survey data and remote sensing data to improve meas-

urement precision. Third, despite the application of two-way fixed effects and spatial econometric models alongside multiple robustness and endogeneity tests, potential endogeneity cannot be fully ruled out. Furthermore, no dedicated tests or adjustments have been carried out for the serial autocorrelation and cross-sectional dependence that are prevalent in provincial panel data. Future research can implement quasi-experimental designs such as difference-in-differences based on digital rural pilot policies to enhance causal identification.

7. Conclusions

Using panel data from 30 provincial-level administrative regions in China over the period 2011–2023, this paper constructs separate evaluation index systems for digital rural construction and rural social welfare. We conduct a comprehensive empirical analysis employing a suite of models including the two-way fixed effects model, mediating effect model, threshold regression model and Spatial Durbin Model, and address endogeneity concerns via the instrumental variable approach and system GMM. The main findings are summarized as follows: First, throughout the sample period, both digital rural construction and rural social welfare in China exhibit a steady upward trend and present a shared spatial pattern of “high in the east and low in the west”, with the eastern region outperforming the central and western regions on both indicators. Digital rural construction has a significant positive impact on rural social welfare. This conclusion remains valid after a battery of robustness checks including time window adjustment, exclusion of municipality samples, and two-sided winsorization, as well as endogeneity corrections. Second, agricultural technological progress serves as the core transmission channel through which digital rural construction enhances rural social welfare. The application of digital technologies accelerates the innovation and diffusion of agricultural technologies, boosts agricultural production efficiency and industrial upgrading, and thereby drives multi-dimensional improvements in rural social welfare. Meanwhile, the impact of digital rural construction on rural social welfare does not follow a simple linear pattern. When the level of agricultural technology is taken as the threshold variable, the effect presents non-linear characteristics of increasing marginal returns. In addition, digital rural construction generates significant positive spatial spillover effects, which can radiate and elevate rural social welfare in geographically adjacent and economically linked regions. Third, the welfare effects of digital rural construction show pronounced regional heterogeneity. From the two dimensions of geographical location and economic development level, its promotional effect is more prominent in the eastern region and economically developed regions, while the welfare-enhancing effect has not been fully realized in the central and western regions and moderately developed regions. Building on empirical results and research conclusions, this paper proposes the following policy implications: First, strengthen digital infrastructure construction. Increase financial input and policy support, attract telecommunications enterprises to participate in rural network development, reduce costs and establish a long-term maintenance mechanism, so as to consolidate the hardware foundation of digital welfare services. Second, advance digital rural industrial development. Set up special funds to support the R&D and application of smart agricultural technologies, improve farmers’ digital literacy through skill training, build a digital system covering the entire agricultural product industrial chain, foster characteristic industrial clusters, and stimulate rural economic vitality. Third, improve the macro-environment for digital rural construction. Strengthen the application of digital technologies in rural ecological monitoring and governance, refine ecological compensation and resource allocation mechanisms, and promote a virtuous cycle between ecological improvement and welfare enhancement. Fourth, upgrade digital rural service capacity. Standardize the development of rural e-commerce platforms, build an efficient logistics and distribution system,

integrate digital cultural resources, empower rural cultural revitalization through social platforms, and enhance farmers' sense of material gain and spiritual belonging.

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