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Does High-Standard Farmland Construction Promote Agricultural Green Entrepreneurship? Evidence from China

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Abstract

Farmland infrastructure investment is essential for agricultural productivity, rural development, and agricultural green transformation. However, empirical evidence on whether and how farmland infrastructure investment promotes agricultural green entrepreneurship remains limited. Exploiting China's High-Standard Farmland Construction (HSFC) program as a quasi-natural experiment, this study uses provincial panel data from 2003 to 2023 and a continuous difference-in-differences (DID) model to examine its impact on agricultural green entrepreneurship. The results show that HSFC significantly promotes both the entry and stock of agricultural green enterprises. These findings remain robust across a series of robustness tests. Mechanism analysis indicates that the HSFC program promotes agricultural green entrepreneurship through two complementary channels: entrepreneurial empowerment (through improved innovation performance, agricultural mechanization, land transfer, and financial access) and agricultural green transition (through enhanced green innovation, green finance, and reduced pesticide use). Heterogeneity analysis further shows that the positive effects of the HSFC program are more pronounced in regions with higher population density, lower human capital, and lower levels of informatization, as well as in non-main grain-producing areas. These findings highlight the entrepreneurial benefits of farmland infrastructure investment and suggest that, when supported by complementary policies, such investment can help developing countries foster agricultural green entrepreneurship and advance sustainable agricultural development. They also indicate that the environmental benefits of farmland infrastructure may emerge gradually and depend on broader green policy support.

Keywords: farmland infrastructure investment; agricultural green entrepreneurship; high-standard farmland construction program; entrepreneurial empowerment; agricultural green transition



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1. Introduction

Agricultural green entrepreneurship, characterized by ecological conservation [1] and efficient resource utilization [2], plays an important role in advancing agricultural green transition, rural revitalization, and sustainable development [3,4]. Its development depends on a range of supportive conditions, including financial support, infrastructure, technical training, policy safeguards, and environmental awareness [5,6]. Rising preferences for eco-friendly products and evolving consumption patterns have reshaped market demand and encouraged firms to engage in green entrepreneurship [7,8]. However, agricultural green entrepreneurship

in developing countries remains constrained by multiple barriers, including limited financing, inadequate infrastructure, shortages of green technologies, complex regulatory frameworks, and insufficient environmental awareness [5,9]. In view of the above constraints, farmland infrastructure investment is expected to play an effective mitigation role through multiple channels such as the improvement of production and operation conditions, reduction in operating cost, improvement of agricultural service accessibility, and optimization of the growth environment of green enterprises. However, in terms of whether such farmland infrastructure investment can indeed promote agricultural green entrepreneurship and how to understand its mechanism of action, the empirical evidence remains limited.

Farmland infrastructure investment plays a foundational role in agricultural development worldwide [10]. According to the OECD's Agricultural Policy Monitoring and Evaluation 2024 report, total support for the agricultural sector across 54 countries averaged USD 842 billion annually during 2021–2023, with approximately 12.6% allocated to essential services such as innovation, biosecurity, and infrastructure. Among these policy efforts, land consolidation in Europe has been closely associated with the governance of land fragmentation and the modernization of farm structures [11,12]. In South and East Asia, similar farmland improvement practices have been adopted to address fragmented plots, poor irrigation conditions, and inadequate rural infrastructure [13]. Advanced economies such as Japan have implemented farmland infrastructure investment initiatives aimed at strengthening the foundations of sustainable agriculture by systematically improving farming conditions and land quality [14,15]. Among these efforts, China's High-Standard Farmland Construction (HSFC) program provides a representative and compelling example of large-scale farmland infrastructure investment. According to the General Rules for High-Standard Farmland Construction (GB/T 30600-2022), high-standard farmland refers to contiguous and well-leveled cultivated land with sound infrastructure, fertile soil, suitability for mechanized farming, and strong disaster resilience. The HSFC program mainly covers farmland infrastructure construction and soil fertility improvement to remove major production constraints and enhance farmland productivity. China officially launched the HSFC program in 2011, and it has now entered a critical stage focused on improving construction quality. In China, the HSFC program is a major national initiative designed to comprehensively improve cultivation conditions [4]. Since its launch in 2011, the HSFC program had facilitated the renovation of 71.67 million hectares of farmland by the end of 2025. Meanwhile, from 2021 to 2025, the Chinese government cumulatively invested more than CNY 700 billion in the HSFC program. (The 2023 annual average exchange rate of 1 USD = 7.0467 CNY is adopted for potential currency conversion). Given its large scale, sustained fiscal support, and nationwide implementation, the HSFC program provides an excellent empirical setting for examining the relationship between farmland infrastructure investment and agricultural green entrepreneurship.

Under the dual background of deepening the concept of sustainable development and accelerating the process of agricultural green transition, agricultural green entrepreneurship has gradually developed into an emerging interdisciplinary research area of entrepreneurship, environmental economics, and innovation research [16]. Existing research suggests that agricultural green entrepreneurship is shaped by a combination of external and internal factors, including the institutional environment, policy support, infrastructure, entrepreneurial culture, human capital, green technology, and innovative business practices [3,17]. Empirical evidence further indicates that the institutional environment significantly moderates the relationship between green entrepreneurial orientation and entrepreneurial behavior [18,19]. In addition, resource bricolage across skill, customer, institutional, and network dimensions has been shown to promote green entrepreneurial activities among rural returnees [9]. Recent studies on rural entrepreneurship also highlight

that entrepreneurial activities in rural areas are embedded in local resource endowments, institutional arrangements, infrastructure conditions, and broader regional transformation processes [20–22]. Despite the above progress, from the perspective of enterprise-level analysis, the existing literature still pays insufficient attention to agricultural green enterprises. Specifically, the relevant research rarely makes a clear distinction between the entry and the stock of agricultural green enterprises, which leads to a lack of sufficient understanding of the dynamic evolution characteristics and follow-up operation trend of such enterprises in each stage of their life cycle.

Existing evaluations of the HSFC program, as a representative policy for farmland infrastructure investment, have primarily focused on grain yield enhancement [23], rural income growth [24], production efficiency [4,25], green development [4], and disaster risk mitigation [26]. Existing evidence suggests that the HSFC program increases grain output by improving the multiple-cropping index, reclaiming medium- and low-yield farmland, and reducing losses caused by droughts and floods [23,27,28]. This productivity-increasing impact is specifically pronounced on large staple crops, such as rice, wheat, and maize, and more pronounced in areas with greater grain production potential [23,29]. In addition, the HSFC program has been found to lower the cost of agricultural production, enhance the profitability of operations, increase the non-farm income opportunities and hence raise the rural household income. The effects are more pronounced in economically developed areas and regions with relatively flat terrain [30,31]. The HSFC program also promotes agricultural total factor productivity and ecological efficiency, mainly through technological progress and improvements in technical efficiency [32]. From the perspective of green development, the HSFC program contributes to fertilizer reduction and higher fertilizer use efficiency through larger operational scale, improved plot conditions, and more contiguous cultivation, with stronger effects in hilly and mountainous areas and among large-scale operators [33]. Although the existing achievements are of great significance, the focus of the existing literature is still mainly on traditional economic performance and ecological environment effects. There is still a lack of systematic investigation on whether and how the HSFC program can improve the institutional environment of agricultural green entrepreneurship and attract green enterprises. In this context, this study examines the impact of HSFC on both the entry and the stock of agricultural green enterprises. It also extends the literature on farmland infrastructure investment and contributes to research on agricultural green entrepreneurship.

Despite these advances, three important gaps remain. First, existing evaluations of the HSFC program have mainly focused on traditional outcomes such as grain yield enhancement [23,27–29,34,35], rural income growth [24,30,31], production efficiency and agricultural sustainability [25,32], green development performance [33,36], and disaster risk mitigation [26]. However, limited attention has been paid to whether farmland infrastructure investment also generates entrepreneurial effects by improving the environment for agricultural green enterprise development. In particular, little is known about whether and how the HSFC program promotes the creation and accumulation of agricultural green enterprises. Second, although the literature on agricultural green entrepreneurship has emphasized the roles of institutional support, infrastructure conditions, policy incentives, human capital, entrepreneurial resources, and green orientation [3,5,9,16–19], farmland infrastructure investment has rarely been examined as a distinct policy-driven driver of agricultural green entrepreneurship. In addition, most of the existing literature fails to effectively distinguish between enterprise entry and enterprise stock, resulting in insufficient investigation of the dynamic evolutionary patterns of agricultural green entrepreneurship in the time dimension and their long-term cumulative effect. Third, existing studies are mostly limited to descriptive interpretation and relevance analysis, and empirical evidence

with strict causal inference value is scarce. Although the HSFC program has achieved unified planning at the national level, there are still obvious inter-provincial differences in construction intensity among provinces. The characteristics of HSFC program construct a valuable quasi-natural experimental scenario for identifying the causal relationship between farmland infrastructure investment and agricultural green entrepreneurship.

To address these gaps, this study uses a provincial panel dataset for China from 2003 to 2023 and a continuous difference-in-differences (DID) model to estimate the impact of the HSFC program on agricultural green entrepreneurship. Taking 2011, the year of the program's unified launch, as the policy shock. This study examines both the entry and the stock of agricultural green enterprises, thereby capturing the flow and stock of green entrepreneurial activity. The results show that the HSFC program significantly promotes agricultural green entrepreneurship by increasing both agricultural green enterprise entry and agricultural green enterprise stock. The baseline findings remain robust after a series of tests. Mechanism analyses further indicate that HSFC promotes agricultural green entrepreneurship through two complementary channels: entrepreneurial empowerment and agricultural green transition. Specifically, the program lowers entry barriers by facilitating agricultural mechanization, improving conditions for land transfer, and strengthening access to agricultural insurance and rural financial support. Meanwhile, it accelerates the agricultural green transition through green technological innovation, green financial support, and reduced pesticide use. In addition, the positive effects are more pronounced in regions with higher population density, lower human capital, lower informatization levels, or non-main grain production positioning.

This study contributes to the literature in three respects. First, it extends the literature on agricultural green entrepreneurship by identifying the HSFC program as an important institutional and infrastructural determinant, while also enriching research on the broader effects of farmland infrastructure investment [3,5]. This study breaks through the conventional vision of the existing literature on the evaluation of the effectiveness of HSFC, which is mainly limited to traditional dimensions such as agricultural production efficiency, farmers' income. Thus, this study effectively strengthens the theoretical analysis and empirical connection between agricultural investment and green entrepreneurship [23,35]. Second, it deepens understanding of the channels through which farmland infrastructure investment promotes agricultural green entrepreneurship. This study distinguishes two complementary channels, namely entrepreneurial empowerment and agricultural green transition. It helps to clarify the specific role of the HSFC program in reducing the entry threshold of the industry, enhancing the capacity reserve of business entities, supporting the agriculture green transition, and optimizing the survival and development space of green enterprises [20,37]. Third, by distinguishing agricultural green enterprise entry and agricultural green enterprise stock, this study assesses the program effect from both dynamic and cumulative perspectives. It reduces the potential measurement bias associated with relying on a single indicator and provides a more balanced measure of entrepreneurship that captures entry expansion as well as possible exit or crowding-out effects [21,32,36,38]. In addition, this study provides convincing empirical support for the causal relationship between farmland infrastructure investment and agricultural green entrepreneurship. It adopts a quasi-natural experimental setting formed by the time node of unified implementation of the HSFC program and the differentiated distribution of implementation intensity among provinces.

2. Theoretical Framework and Research Hypotheses

2.1. Background of the HSFC Program

The HSFC program has been prioritized by the Chinese government as a long-term policy for implementing the national food security strategy, promoting farmland infrastruc-

ture investment, and advancing rural revitalization. The No. 1 Central Document issued in 2011 formally proposed the concept of the HSFC program at the national level. Its core goal was to achieve stable food production under drought and flood conditions, and to establish the plan as an important support for the national food security strategy. China's central government set a target of developing 66.67 million hectares of high-standard farmland by the end of 2022. Around this goal, the relevant information registration system has been strengthened, the project filing management process has been unified, and the supervision and assessment mechanism has been improved, aiming to implement standardized guidance and effective supervision of the whole process of construction. Figure 1 presents the annual area of newly constructed high-standard farmland in China from 2011 to 2023.

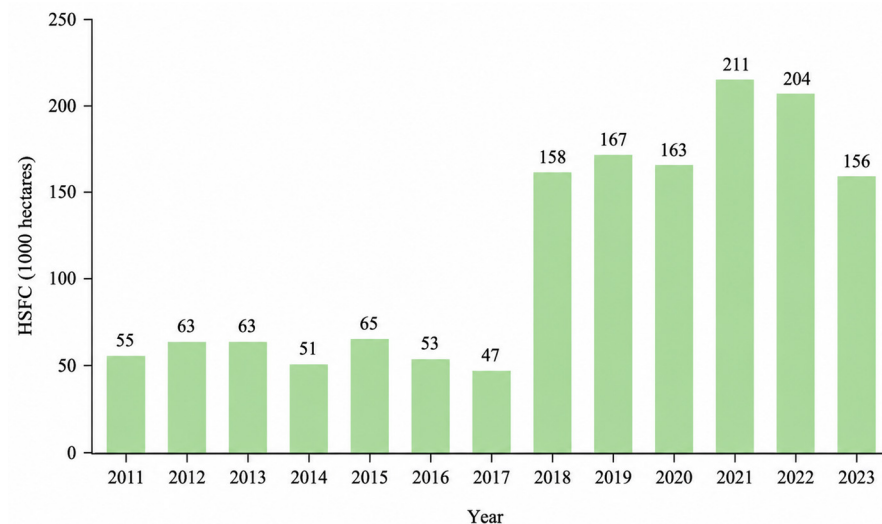


Figure 1. Annual area of newly constructed high-standard farmland in China, 2011–2023.

In subsequent years, a series of policy documents have continuously highlighted the key position of farmland infrastructure investment, and at the same time, they have focused on advocating a diversified participation pattern in the field of agricultural investment, thus further consolidating the institutional environment on which the HSFC program relies, and laying a favorable policy soil for the germination and growth of agricultural green entrepreneurship activities. On the basic goal of ensuring food supply security, the HSFC program has gradually evolved into a comprehensive policy carrier covering multiple dimensions such as the improvement of rural production conditions, the optimization of factor allocation patterns, the stimulation of entrepreneurial vitality, and the broadening of farmers' income channels [34,39]. This expanded policy function provides an institutional foundation for examining whether farmland infrastructure investment can induce agricultural green entrepreneurship.

2.2. Direct Effect of the HSFC Program on Agricultural Green Entrepreneurship

The HSFC program has significantly improved the material and technical basic conditions of agricultural production through the improvement of cultivated land quality, the optimization of production factor allocation, and the systematic upgrading of farmland infrastructure investment [34,40]. Existing research has confirmed that the plan can effectively improve the basic conditions of fields, reduce the transaction costs involved in the land transfer process, and then promote the scale and specialization of agricultural management [41]. It also provides positive support for the realization of agricultural sustainable development goals by promoting the iterative upgrading of agricultural production technology and alleviating the ecological environment pressure faced by crop planting [4,42].

Research on agricultural green entrepreneurship has increasingly emphasized how firms identify opportunities and build green competitiveness under the joint influence of environmental constraints and policy support [43]. It is generally pointed out in the existing literature that the emergence and subsequent growth of green entrepreneurship activities are largely subject to the institutional field they are embedded in and the supply of various elements and resources. At the policy level, the establishment of the subsidy mechanism and the reasonable arrangement of the regulatory framework will help to reduce the market access barriers faced by new ventures; the continuous improvement of infrastructure conditions can effectively alleviate the typical difficulties faced by rural entrepreneurs for a long time, such as narrow financing channels and limited access to technology [3,22].

From a theoretical perspective, the HSFC program may promote agricultural green entrepreneurship through multiple paths. First, farmland infrastructure investment has systematically optimized the hardware foundation of agricultural production through direct measures such as land consolidation and remediation, land leveling operations, transformation and upgrading of irrigation and drainage systems, and construction and improvement of field road networks. Such interventions can help reduce the production uncertainty faced by agricultural operators and effectively reduce operating costs [44,45]. The improvement of cultivated land quality further enhances the positive expectation of green agricultural enterprises for the level of return on investment [32,46]. Second, the continuous improvement of production conditions has enhanced the anti-risk ability and operational robustness of the regional agricultural system, thus cultivating more favorable institutional conditions and material basis for the long-term survival and development of entrepreneurial activities [44,47]. Third, with the improvement of the income level of farmers and the overall economic situation in rural areas, the HSFC program may further stimulate effective demand in the green agricultural product market, thus forming an additional incentive for the market entry and scale expansion of agricultural enterprises [48,49].

H1: *The HSFC program has a positive effect on agricultural green entrepreneurship.*

2.3. Heterogeneous Analysis of the HSFC Program on Agricultural Green Entrepreneurship

The actual results of large-scale public investment are usually not balanced among regions, but are, to a large extent, subject to the allocation of local existing factor conditions. As far as the specific field of farmland infrastructure investment is concerned, the degree of entrepreneurial response to HSFC projects is likely to show significant differences due to labor quantity, labor quality, entrepreneurial infrastructure, and grain-production designation. The above situational factors actually constitute the key moderating variables of whether the improved production and operation conditions can be effectively transformed into the driving force of agricultural green entrepreneurship in rural areas.

First, labor quantity may influence the extent to which the HSFC program promotes agricultural green entrepreneurship. From the perspective of agglomeration economies, regions with higher population density are more likely to exhibit thicker local markets, more specialized service provision, and lower search and transaction costs [50]. These conditions are particularly important for agricultural green entrepreneurship, which often depends on technological adoption, product certification systems, supply chain logistics, and access to differentiated market channels [9,18,51]. In addition, studies in the field of entrepreneurial ecosystem have pointed out that in regions where business networks and intermediary service organizations are more mature, policy-driven improvements in production conditions are more likely to translate into real entrepreneurial opportunities [52,53]. By contrast, in regions with relatively limited labor endowments and thinner local markets, the trans-

lation of improved farmland conditions into agricultural green entrepreneurship may be constrained by weaker market depth and less developed support services.

Second, labor quality may also condition the effect of the HSFC program on agricultural green entrepreneurship. Human capital shapes entrepreneurial capability, opportunity recognition, and the organization of agricultural business activities [54,55]. At the same time, lower human capital levels are usually accompanied by relatively narrow non-agricultural employment channels and a high degree of dependence of production and business activities on the agricultural sector [56]. In such situations, the HSFC program is more likely to enhance the relative attractiveness of the agricultural sector in economic activities through the improvement of farmland operating conditions, the alleviation of production and operation bottlenecks, and the improvement of expected income levels, thus forming an effective incentive for agricultural green entrepreneurship [57]. Furthermore, in regions with more severe labor constraints, farmland infrastructure investment promotes agricultural mechanization and applicable technologies. It substitutes capital for labor and thereby effectively alleviate labor shortages in agricultural production [58,59]. Labor scarcity facilitates the orderly transfer of farmland management rights and the gradual formation of a moderate-scale management pattern, thus further amplifying the efficiency improvement effect brought by farmland infrastructure investment [60,61]. Therefore, the promotional effect of the HSFC program may be more pronounced in regions with relatively lower human capital endowments.

Third, informatization, as an important dimension of entrepreneurial infrastructure, may shape the extent to which the HSFC program promotes agricultural green entrepreneurship. Digital and informational conditions are increasingly important for reducing information asymmetry, expanding market access, and accelerating the diffusion of green technologies in rural areas [26,62]. For agricultural green entrepreneurship, informatization can improve access to product information, technical knowledge, market channels, and external networks, thereby enhancing the translation of improved production conditions into viable business opportunities [62,63]. Existing studies further indicate that digital development plays an important role in promoting rural entrepreneurship, agricultural innovation, and green transformation [31,64]. The above findings highlight the importance of informatization level as a key situational variable, which may have a moderating effect on the direction and intensity of the correlation between the HSFC program and agricultural green entrepreneurship. Areas with relatively lagging information coverage often suffer from prominent structural constraints in market access, accessibility of agricultural technology services, and efficiency of industrial information dissemination. These are precisely the bottlenecks of farmland infrastructure investment. Therefore, informatization conditions may influence the overall policy effect through the dynamic trade-off between the relative strength of enabling advantages and compensation benefits. The policy response caused by HSFC program tends to show systematic differences among regions with different informatization levels.

Fourth, grain-production designation may shape the effectiveness of agricultural infrastructure investment by influencing regional development objectives, resource allocation patterns, and agricultural production priorities [34,39,65]. In China, this distinction is reflected in the functional division between main grain production areas and non-main grain production areas. Existing studies suggest that the effectiveness of agricultural infrastructure investment is closely associated with regional resource endowments, agricultural production conditions, and institutional environments, resulting in heterogeneous policy outcomes across regions [23,66]. The main grain production areas bear the core functions of ensuring the safety of the national food supply and maintaining the stability of production, so they face more stringent institutional constraints and policy requirements in

food production and cultivated land resource protection. The above constraints related to production orientation may weaken the elastic space for a region to adjust the agricultural industrial structure and tilt the resource allocation to the emerging agriculture-related industries to a considerable extent. In contrast, non-main grain production areas generally have greater flexibility in adjusting agricultural structures and developing diversified agricultural activities, allowing improvements in farmland infrastructure to be more readily transformed into entrepreneurial opportunities [67,68]. Therefore, the impact of the HSFC program on agricultural green entrepreneurship may vary systematically across regions with different grain-production designations.

H2: *The effect of the HSFC program on agricultural green entrepreneurship exhibits regional heterogeneity associated with labor quantity, labor quality, informatization, and grain-production designation.*

2.4. Mechanism of the Effect of HSFC Program on Agricultural Green Entrepreneurship

The HSFC program may foster agricultural green entrepreneurship through multiple channels. As a large-scale farmland infrastructure investment initiative, the HSFC program improves agricultural production conditions, reduces operational constraints and facilitates the agricultural green transition in production systems [69]. From the perspective of entrepreneurial development, improved infrastructure and supporting policies can enhance the capacity of potential entrepreneurs to engage in agricultural business activities [70]. From the perspective of sustainable development, the HSFC program can improve environmental quality and promote green production practices. It further creates a favorable environment for the establishment and growth of agricultural green enterprises [9]. Therefore, this study proposes two potential channels through which the HSFC program may foster agricultural green entrepreneurship: entrepreneurial empowerment and agricultural green transition.

This study adopts a reduced-form, two-step strategy for empirical channel analysis [71,72]. The baseline DID framework is informative about the overall effect of the HSFC program on agricultural green entrepreneurship, the identification of the underlying channels is more limited. Specifically, the regressions using intermediate outcomes as dependent variables may still be affected by omitted variables and other unobserved time-varying confounders. For example, the dynamic adjustment of agricultural support policies, the development process of the rural financial system, the transformation and upgrading of the industrial structure may affect the promotion of HSFC and the proposed channels in this paper. Accordingly, the mechanism analysis should be interpreted as providing suggestive evidence on plausible transmission channels rather than definitive proof of a fully identified causal mediation process.

On the one hand, the entrepreneurial empowerment channel functions by systematically lowering market entry barriers and enhancing the operational capacities of potential entrepreneurs. Existing literature indicates that the HSFC program enhances the fundamental conditions for agricultural production by comprehensively rehabilitating fragmented plots, upgrading irrigation networks, and constructing field roads, thereby significantly dampening systemic agronomic risks and facilitating land transfer and moderate-scale operations, which lowers production and transaction costs for operating entities [48,65,73,74]. The improvement in structural efficiency brought about by land consolidation and patch operation, the transformation and upgrading of field supporting facilities and the formation of standardized production conditions will help to improve the expected return level of agricultural operation, and on this basis, it will effectively promote the popularization and application of advanced agricultural machinery and intelligent production equipment, thus further strengthening the promotion effect of entrepreneurship and improving the market entry probability of agricultural enterprises [41,75]. In addition, the HSFC program is often accompanied by policy trends such as an increase in agricultural financial investment, the

strengthening of the agricultural technology extension service system, and the optimization of the rural business environment. Simultaneously, there are also public resources such as the expansion of agricultural insurance coverage and targeted financial support for rural areas, which provide a relatively stable policy expectation and financial support basis for the growth of agricultural business entities [76]. Through the combined effects of cost reduction, efficiency improvement, and eased financing constraints, the HSFC program can accelerate the entry of agricultural green enterprises.

On the other hand, the agricultural green transition channel provides an important foundation for the development of agricultural green enterprises and may support the long-term development of green ventures. Existing studies have shown that the HSFC program can effectively improve agricultural ecological efficiency through soil fertility improvement, optimal allocation of production space layout, and promotion of source pollution prevention and control measures [36,39]. Farmland infrastructure investment helps to improve the allocation efficiency of agricultural production factors, thereby reducing the application amount of chemical fertilizers and pesticides per unit area, and reducing the agricultural non-point source pollution load and carbon emission intensity [39,77]. Furthermore, the standardized agricultural infrastructural environment accelerates the diffusion and adoption of green production technologies among local actors [32,78]. As far as agricultural green enterprises are concerned, the continuous advancement of the process of agricultural green transition at the regional level is expected to create a more stable system and business environment for market players by compressing financial expenditures on environmental compliance and reducing various types of uncertainty risks faced by production and operation links, and thus have a positive impact on maintaining the scale and viability of existing green enterprises. However, relying solely on capital investment in farmland infrastructure does not necessarily bring about a statistically significant improvement in environmental-related inputs or emission indicators in the short term. Substantive changes in some environmental outcomes, especially the intensity of chemical fertilizer application and the level of agricultural carbon emissions, may require a longer adjustment process, and to a considerable extent depend on the promotion rate of green technology and the actual implementation effect of supporting incentives or compensation mechanisms for producers [69].

H3a: *HSFC fosters agricultural green entrepreneurship through improving the regional entrepreneurial environment.*

H3b: *HSFC fosters agricultural green entrepreneurship through promoting the agricultural green transition.*

3. Materials and Methods

3.1. Sample and Data Sources

This study employs a provincial panel dataset of China from 2003 to 2023 to examine the impact of the HSFC program on agricultural green entrepreneurship. The main regression sample is a balanced panel consisting of 31 provincial-level administrative regions over 21 years. The dataset is compiled from multiple official and authoritative sources, including the China Enterprise Industrial and Commercial Registration Database, the China Agricultural Statistical Yearbook, the China Rural Statistical Yearbook, the China Agricultural Machinery Industry Yearbook, the China Insurance Yearbook, the China Rural Operation and Management Statistical Report, the China Rural Policy and Reform Statistical Report, the CSMAR Database, and provincial statistical yearbooks and statistical communiques.

The dependent variables measuring agricultural green entrepreneurship and the independent variable capturing the HSFC program are primarily obtained from the China

Enterprise Industrial and Commercial Registration Database, the China Agricultural Statistical Yearbook, the China Rural Statistical Yearbook, and the China Academy for Rural Development–Qiyang China Agri-research Database (CCAD) at Zhejiang University. The control variables are compiled from official statistical yearbooks and provincial statistical communiqués. The channel variables are collected from the China Rural Statistical Yearbook, Ministry of Agriculture data, the China Agricultural Machinery Industry Yearbook, the China Insurance Yearbook, the CSMAR Database, and other authoritative statistical sources. All empirical analyses were conducted using StataMP 18.

Some channel variables contain missing observations in the early years of the sample period, particularly the number of rural financial institution branches, the transferred area of household-contracted farmland, and agricultural insurance premiums. Specifically, the transferred area of household-contracted farmland is unavailable for all provinces in 2003 and 2004. Although land transfers already existed in practice, the former Ministry of Agriculture did not establish unified national statistics on farmland transfers until 2005, and no standardized provincial aggregate data are available for 2003–2004. Agricultural insurance premiums are partially missing for some provinces from 2003 to 2006. Before the nationwide expansion of policy-based agricultural insurance in 2007, agricultural insurance was implemented mainly through scattered pilot programs, and complete provincial premium data were not reported for some regions, including Xizang. In addition, the provincial-level data on the number of business outlets of rural financial institutions for 2003 to 2006 are not complete. During this period, rural financial service outlets lacked a unified official statistical caliber. All kinds of statistical yearbooks usually only record the network information of specific types of institutions such as rural credit cooperatives and the Agricultural Bank of China, but fail to form a complete data sequence with consistent caliber and cross-provincial aggregation. Although the above missing data situation does not have a substantial impact on the construction of baseline regression samples, it does lead to a reduction in the number of effective observation samples in some channel regressions. No interpolation is applied to these missing observations.

3.2. Continuous Difference-in-Differences (DID) Model

This study employs a continuous Difference-in-Differences (DID) model to evaluate the impact of the HSFC program on agricultural green entrepreneurship. The HSFC program was launched nationwide in 2011, but its implementation intensity varied substantially across provinces. Therefore, a simple binary treatment indicator would not adequately capture cross-provincial heterogeneity in policy exposure [79–81]. Instead, this study treats HSFC as a continuous treatment and identifies its policy effects by comparing changes in agricultural green entrepreneurship across provinces with different levels of HSFC intensity during the post-policy period [81]. The baseline model is specified as follows:

$$GreenAgri_{it} = \beta_0 + \beta_1(HSFC_{it} \times Post_t) + \gamma X_{it} + \lambda_t + \mu_i + \varepsilon_{it}$$

where $GreenAgri_{it}$ denotes agricultural green entrepreneurship in province i and year t , measured by agricultural green enterprise entry and stock. $HSFC_{it}$ is the key explanatory variable, measured by the area of high-standard farmland construction in province i and year t . $Post_t$ is a post-policy dummy variable that equals 1 for years 2011 and after, and 0 otherwise, as 2011 marks the nationwide launch of the HSFC program. X_{it} denotes a vector of control variables, and γ is the corresponding coefficient vector. λ_t and μ_i denote year fixed effects and province fixed effects, respectively, and ε_{it} is the error term.

Because all provinces entered the policy regime in the same year, identification does not rely on treatment-timing variation. Rather, the identification strategy relies on within-province changes in HSFC intensity over time, after netting out province fixed effects,

common year shocks, and observed time-varying controls. Accordingly, the coefficient on $HSFC_{it} \times Post_t$ should be interpreted not as a binary treatment effect, but as the average slope of the post-policy dose–response relationship within the linear specification. In other words, this coefficient captures whether provinces with greater HSFC intensity experienced larger post-policy changes in agricultural green entrepreneurship.

The key identifying assumption is a continuous-treatment analogue of the parallel-trends assumption: in the absence of the HSFC program, provinces with different levels of HSFC intensity would have followed similar trends in agricultural green entrepreneurship, conditional on province fixed effects, year fixed effects, and observed controls. Under this assumption, β_1 captures the average effect over the observed support of treatment intensity, rather than the effect of moving from no treatment to full treatment.

Recent studies on DID models with continuous treatments note that, when treatment effects vary across intensity levels, the two-way fixed-effects estimator may recover a weighted average of dose-specific effects rather than a common marginal effect [81]. Although the treatment-timing heterogeneity emphasized in staggered-adoption DID designs is not relevant here, heterogeneity across treatment intensity levels may still affect the interpretation of the estimated coefficient. We therefore interpret the baseline estimate cautiously as a summary measure of the average policy effect over the observed distribution of HSFC intensity.

To assess whether the dose–response relationship is approximately linear, this study further estimates a nonlinear specification by introducing a quadratic interaction term:

$$GreenAgri_{it} = \beta_0 + \beta_1(HSFC_{it} \times Post_t) + \beta_2(HSFC_{it}^2 \times Post_t) + \gamma X_{it} + \lambda_t + \mu_i + \varepsilon_{it}$$

HSFC intensity is mean-centered before constructing the squared term to reduce multicollinearity. A statistically insignificant β_2 supports the linear specification, whereas a statistically significant β_2 indicates that the marginal effect varies across treatment intensity levels.

3.3. Variable Descriptions

3.3.1. Independent Variable

The core explanatory variable, HSFC, is measured by the annual area of newly constructed high-standard farmland at the province-year level and is expressed in thousands of hectares. As a continuous treatment variable, it captures cross-provincial variation in policy implementation intensity and reflects the scale of farmland infrastructure investment.

3.3.2. Dependent Variables

The dependent variable is agricultural green entrepreneurship, which refers to entrepreneurial activity carried out by enterprises engaged in environmentally friendly, resource-conserving, and sustainable agricultural production and related operations [9].

To improve transparency, agricultural green enterprises are identified from the China Enterprise Industrial and Commercial Registration Database using an intersection-based approach. Specifically, enterprise registration records are matched against official classification standards. The agricultural dimension follows the CCAD classification of agriculture-related enterprises based on the Statistical Classification of Agriculture and Related Industries (2020). The green dimension is based on green-industry enterprises identified from the same commercial registration records with reference to the Green Industry Guidance Catalogue (2019 Edition) and the Statistical Classification of Energy Conservation, Environmental Protection, and Clean Industry (2021). In the context of this study, this green dimension is associated with agricultural green development, low-carbon development, and sustainability. Therefore, an enterprise is classified as an agricultural green enterprise only if it satisfies both the agriculture-related criterion and the green-industry criterion.

In the empirical analysis, agricultural green entrepreneurship is measured using two indicators: agricultural green enterprise entry (*AG_Entry*) and agricultural green enterprise stock (*AG_Stock*). (*AG_Entry*) is measured by the number of newly established agricultural green enterprises in each province-year and captures the annual dynamism of green entrepreneurial activity [32,75]. *AG_Stock* is measured by the total number of existing agricultural green enterprises in each province-year and reflects the cumulative development of agricultural green entrepreneurship over time [75].

The application of the above two indicators enables this study to take into account both the entry and the stock dimensions of entrepreneurial activity. Specifically, (*AG_Entry*) reflects the short-term responsiveness of new firm creation to policy support and improved production conditions, whereas (*AG_Stock*) reflects the longer-term accumulation and sustainability of green entrepreneurial development [38]. Therefore, these two measures provide a more comprehensive assessment of agricultural green entrepreneurship.

3.3.3. Control Variables

Following the literature on regional agricultural development, productivity growth, and structural transformation, this study includes a set of provincial-level control variables to account for differences in resource endowments, economic structure, fiscal capacity, demographic characteristics, human capital, and technological support [30,47,82]. Specifically, we control for: (1) cultivated land area (*Land_area*), measured in 1000 hectares; (2) industrial structure upgrade (*Indu_stru*), measured as the ratio of value added in the tertiary industry to that in the secondary industry; (3) tax as a proportion of GDP (*Tax_GDP*), measured as the ratio of local tax revenue to regional GDP; (4) population density (*Pop_density*), measured in thousands of persons per square kilometer; (5) average years of education per resident (*Edu_year*); and (6) agricultural R&D expenditure (*Agr_R&D*), measured in 100 million CNY. These variables are included to account for cross-provincial differences in factor endowments, economic structure, fiscal capacity, demographic conditions, human capital, and technological support. Table 1 reports the descriptive statistics for the dependent, independent, and control variables.

Table 1. Descriptive statistics.

Variable	Unit	Mean	S.D.	Obs
Dependent variables				
Agricultural green enterprise entry (<i>AG_Entry</i>)	count	788.478	1322.536	651
Agricultural green enterprise stock (<i>AG_Stock</i>)	count	3988.015	5149.807	651
Independent variable				
High-standard farmland construction (<i>HSFC</i>)	1000 hectares	90.099	98.360	651
Control variables				
Cultivated land area (<i>Land_area</i>)	1000 hectares	4091.07	3198.913	651
Industrial structure upgrade (<i>Indu_stru</i>)	ratio	1.252	0.687	651
Tax as proportion of GDP (<i>Tax_GDP</i>)	ratio	0.079	0.027	651
Population density (<i>Pop_density</i>)	1000 persons/km ²	0.435	0.657	651
Average years of education per resident (<i>Edu_year</i>)	year	8.782	1.252	651
Agricultural R&D expenditure (<i>Agr_R&D</i>)	100 million CNY	4.297	6.682	651

Note: All variables are measured at the provincial level for 31 provincial-level administrative regions in China over the period 2003–2023. Data source: Dependent and independent variables (*AG_Entry*, *AG_Stock*, *HSFC*) are compiled from the China Enterprise Industrial and Commercial Registration Database, the China Agricultural Statistical Yearbook, the China Rural Statistical Yearbook, and the China Academy for Rural Development—Qiyuan China Agri-research Database (CCAD), Zhejiang University. Control variables are compiled from official statistical yearbooks and provincial statistical communiques.

3.3.4. Channel Variables

To examine the channels through which the HSFC program affects agricultural green entrepreneurship, the channel variables are divided into two categories: entrepreneurial empowerment variables and agricultural green transition variables.

The entrepreneurial empowerment variables include: (1) the number of patent grants (*Pat_grants*), measured as the number of patents granted in each province-year based on official Chinese patent statistics; (2) total agricultural machinery power (*Agr_mac*), measured in GW; (3) the transferred area of household-contracted farmland (*Transfer_area*), measured in 1000 hectares; (4) agricultural insurance premiums (*Agr_insur*), measured in million CNY; and (5) the number of rural financial institution branches (*Rural_fin*). These variables are used to capture whether the HSFC program improves the technological, mechanization, land reallocation, risk-sharing, and financial conditions that support agricultural green entrepreneurship.

The agricultural green transition variables include: (1) green utility model patent applications (*Green_pat*), measured as the number of green utility model patent applications in each province-year; (2) pesticide use (*Pest_use*), measured in tons; (3) chemical fertilizer use (*Fert_use*), measured in tons per 1000 hectares of cultivated land; (4) agricultural film use (*Film_use*), measured in tons; (5) agricultural carbon emissions (*Carbon_emiss*); and (6) the green finance index (*Green_fin*). The green finance index is a dimensionless composite indicator constructed using the entropy-weighting method. These variables are used to assess whether the HSFC program promotes agricultural green entrepreneurship by fostering greener production conditions and creating a more supportive environment for sustainable development. Table 2 reports the original values of all channel variables, whereas $\ln(Pat_grants)$ and $\ln(Green_fin)$ are used in the channel regressions to reduce skewness and improve model fit [83].

Table 2. Descriptive statistics: Channel variables.

Variable	Unit	Mean	S.D.	Obs
Entrepreneurial empowerment variables				
The amount of patent grants (<i>Pat_grants</i>)	count	49,472.737	98,926.682	651
Total power of agricultural machinery (<i>Agr_mac</i>)	GW	29.842	27.881	651
Transferred area of household-contracted farmland (<i>Transfer_area</i>)	1000 hectares	755.016	876.421	589
Agricultural insurance premium (<i>Agr_insur</i>)	million CNY	1316.392	1784.667	643
Rural financial branch number (<i>Rural_fin</i>)	count	2367.408	1592.049	527
Agricultural green transition variables				
Green utility model patent applications (<i>Green_pat</i>)	count	2202.829	4151.343	651
Pesticide use (<i>Pest_use</i>)	ton	50,140.799	41,325.028	651
Chemical fertilizer use (<i>Fert_use</i>)	tons/1000 hectares	340.714	122.571	651
Agricultural film use (<i>Film_use</i>)	ton	72,155.232	65,295.266	651
Agricultural carbon emissions (<i>Carbon_emiss</i>)	kiloton	2596.243	1926.601	651
Green finance index (<i>Green_fin</i>)	—	28.766	12.574	651

Note: The green finance index (*Green_fin*) is a dimensionless composite score constructed by entropy-weighted aggregation of standardized indicators and therefore has no physical unit. The number of observations for agricultural insurance premium (*Agr_insur*, $n = 643$), the transferred area of household-contracted farmland (*Transfer_area*, $n = 589$), and rural financial branch number (*Rural_fin*, $n = 527$) is smaller than the full sample size ($n = 651$) because of missing data in the early sample years. Data source: Entrepreneurial empowerment variables are drawn from the China Rural Statistical Yearbook, Ministry of Agriculture data, the China Agricultural Machinery Industry Yearbook, and the China Insurance Yearbook. Agricultural green transition variables are obtained from the CSMAR Database, the China Rural Statistical Yearbook, and other authoritative statistical sources.

4. Empirical Results and Analysis

4.1. Baseline Regression

Table 3 reports the baseline regression results. Columns (1) and (3) report the estimates without provincial-level control variables, while columns (2) and (4) further include provincial-level controls. Across all specifications, the coefficient on (HSFC $\times$ Post) is positive. For agricultural green enterprise entry (*AG_Entry*), the coefficient is positive and statistically significant in both columns (1) and (2), at the 10% and 5% levels, respectively. For agricultural green enterprise stock (*AG_Stock*), the coefficients are positive in both columns (3) and (4).

Table 3. Baseline regression results.

	AG_Entry	AG_Entry	AG_Stock	AG_Stock
	(1)	(2)	(3)	(4)
HSFC $\times$ Post	3.783 * (2.126)	4.450 ** (1.814)	12.597 (7.433)	15.155 ** (5.693)
Land_area		−0.290 *** (0.043)		−1.087 *** (0.202)
Indu_stru		−79.023 (302.357)		−696.659 (1200.986)
Tax_GDP		7820.536 * (3875.909)		19,327.208 (15,292.634)
Pop_density		−1705.958 ** (748.028)		−7103.501 ** (2868.507)
Edu_year		−138.543 (198.187)		−584.832 (701.469)
Agr_R&D		44.394 ** (21.549)		272.739 *** (84.775)
Constant	526.020 *** (147.476)	2913.969 (1811.030)	3114.057 *** (515.735)	13,780.510 ** (6416.004)
Controls	No	Yes	No	Yes
Year FE	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes
Obs.	651	651	651	651
R ²	0.676	0.715	0.779	0.838

Note: Standard errors clustered at the provincial level are reported in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

In terms of economic magnitude, the estimate in Column (2) indicates that, after 2011, a one-unit increase in HSFC, measured as 1000 hectares, is associated with an increase of about 4.45 in the number of newly established agricultural green enterprises in a province-year. Similarly, the estimate in Column (4) implies an increase of about 15.16 in the stock of agricultural green enterprises in the provincial stock. These results suggest that the HSFC program stimulates both the entry and accumulated stock of agricultural green enterprises.

After incorporating the control variables, the estimation results of *AG_stock* have improved in statistical significance. This change suggests that the differences in land resource endowments, population structure characteristics, and regional innovation capabilities among provinces may introduce interference factors, and then form a certain degree of concealment for the identification of cumulative policy effects. Overall, the baseline findings are consistent with the basic judgment that the HSFC program can improve the basic conditions of production and reduce the constraints of business links, indicating that the plan creates a more favorable external environment for agricultural green entrepreneurship [84,85]. These results provide initial support for H1.

However, the baseline estimates may still be affected by endogeneity. One of the core concerns is the reverse causal relationship caused by selective policy allocation: those provinces that have strong agricultural basic conditions, high administrative execution efficiency, or have a large stock of green business entities before the implementation of the policy may

obtain a higher intensity of HSFC resource tilt in the later policy promotion process. If so, the estimated coefficient on $HSFC \times Post$ may partly capture endogenous variation in policy intensity rather than the causal effect of HSFC itself. The next subsection therefore examines this issue through a series of identification diagnostics and endogeneity tests.

4.2. Parallel Trend and Placebo Tests

A key identifying assumption of the continuous DID framework is that, in the absence of the policy intervention, provinces with different levels of HSFC exposure would have followed similar trends in agricultural green entrepreneurship, conditional on province fixed effects, year fixed effects, and observed control variables [86]. Figure 2 presents the event-study estimates used to assess the parallel trends assumption. Figure 2a reports the dynamic effects on agricultural green enterprise entry, while Figure 2b reports the corresponding effects on agricultural green enterprise stock. In both panels, the coefficients in the pre-policy periods are statistically indistinguishable from zero, which lends support to the parallel trends assumption. After policy implementation, the estimated coefficients become positive and gradually increase, suggesting that the effect of the HSFC program emerges progressively over time rather than appearing immediately.

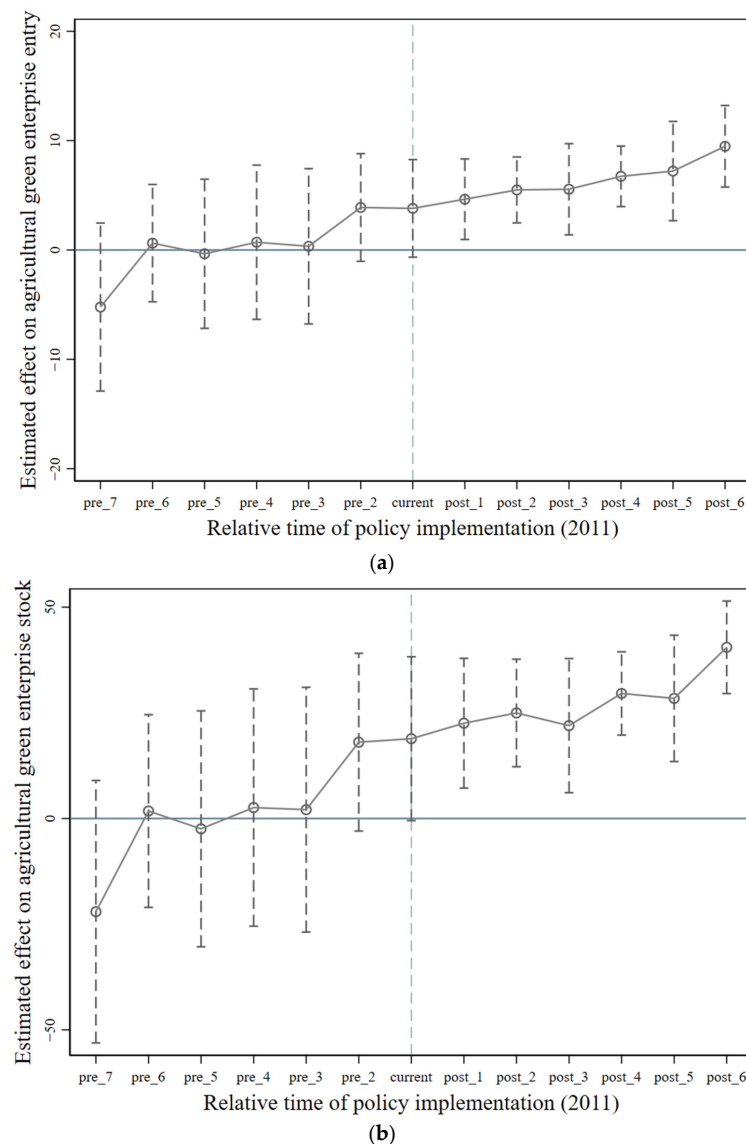


Figure 2. Event-study estimates for the parallel trends test: (a) Agricultural green enterprise entry. (b) Agricultural green enterprise stock.

This dynamic pattern is consistent with the nature of the policy intervention. HSFC is a large-scale farmland infrastructure investment program, and its effects are unlikely to materialize immediately. The effects of improvements in irrigation systems, land consolidation, field road network construction and continuous optimization of basic conditions of agricultural production on entrepreneurial activities tend to unfold progressively, which is mainly due to the adaptive adjustment of production and management system and the development of emerging market opportunities. There is no evidence of significant pre-trends, and the coefficients keep increasing after the policy. This strengthens the credibility of the baseline identification strategy.

Figure 3 reports the placebo test results. In the placebo exercise, treatment intensity is randomly reassigned across provinces, and the model is re-estimated 2000 times. Figure 3a presents the placebo estimates for agricultural green enterprise entry, and Figure 3b presents those for agricultural green enterprise stock. The resulting coefficients are centered around zero and remain substantially smaller than the baseline estimates reported in Table 3. These findings suggest that the positive baseline effects are unlikely to be driven by random shocks or spurious correlations, thereby reinforcing the credibility of the identification strategy. Collectively, the event-study and placebo tests indicate that the main results are unlikely to reflect differential pre-policy trends or chance correlations in the data.

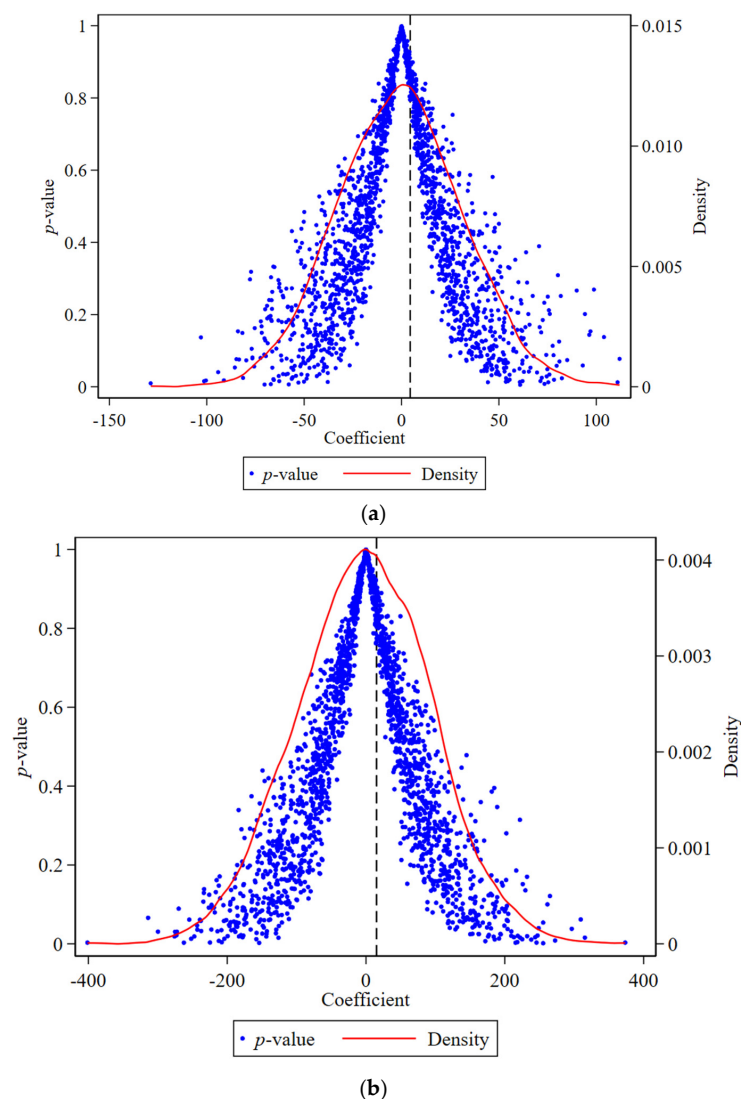


Figure 3. Placebo test results: (a) Agricultural green enterprise entry. (b) Agricultural green enterprise stock. Note: The dashed vertical line indicates the corresponding baseline estimate.

4.3. Robustness Tests

To assess the robustness of the baseline results, this study performs a series of additional tests. These tests include the Oster (2019) [87] bounding approach, a lagged specification, instrumental variable estimation, bootstrap inference, an alternative share-based measure of HSFC, a narrowed sample window, and a nonlinear dose–response test. Across these alternative specifications, the estimated effect of the HSFC program remains positive and statistically significant, indicating that the main findings are robust. A key empirical concern is that HSFC intensity may not have been exogenously assigned across provinces. Accordingly, the next subsection first examines endogeneity-related concerns, including omitted variable bias, dynamic adjustment, and potential reverse causality.

4.3.1. Endogeneity Analyses

The baseline regressions control for a range of observable provincial characteristics and include province and year fixed effects. Even so, the estimates may still be affected by omitted variables and potential reverse causality. A key concern lies in selective policy allocation. Provinces with stronger pre-policy agricultural conditions, administrative capacity, or entrepreneurial foundations may have been more likely to receive more intensive HSFC support after 2011. Specifically, provinces with stronger pre-policy green entrepreneurial foundations, including a larger existing agricultural green enterprises stock, may have been better positioned to secure HSFC investment, in which case the coefficient on $HSFC \times Post$ would partly reflect endogenous policy targeting. More precisely, if provinces with a stronger initial green entrepreneurial base were also more successful in obtaining HSFC resources, the estimated policy effect would be upward biased by pre-existing provincial advantages rather than reflecting only the causal effect of HSFC itself. To further address these concerns, this study applies the Oster (2019) [87] bounding method, a lagged specification, and an instrumental variable approach.

First, omitted variable bias is evaluated using the Oster (2019) method [87]. The upper bound of R_{max} is set to 1.3 times the baseline R^2 , and 2 times the baseline R^2 is additionally used as a sensitivity check. The estimated δ values are -1.233 for agricultural green enterprise entry and -2.119 for agricultural green enterprise stock. In absolute value, both estimates are greater than 1. These findings imply that selection on unobservables would need to be stronger than selection on observables to fully explain away the baseline effects. The negative signs further suggest that selection on unobservables would have to operate in the opposite direction to selection on observables. Under alternative R_{max} assumptions, the bounded coefficients remain positive and do not cross zero. This suggests that omitted variable bias is unlikely to overturn the main conclusion.

Second, to account for the possibility that the effects of HSFC emerge with a time lag, the contemporaneous interaction term is replaced with its one-period lag. Columns (1) and (2) of Table 4 report the results for *AG_Entry* and *AG_Stock*, respectively. The coefficients on $L1.HSFC \times Post$ are 5.057 and 18.326, respectively, and both are statistically significant at the 5% level. These findings indicate that the positive effects of the HSFC program remain robust under the lagged specification.

Third, an instrumental variable (IV) is employed to further alleviate potential endogeneity concerns. The interaction between the area of medium–low-yield farmland in 2010 and the post-policy dummy is used as an instrument for $HSFC \times Post$. This strategy is motivated by the fact that HSFC investment was not randomly assigned across provinces. Even after controlling for fixed effects and observed covariates, implementation intensity may still be correlated with unobserved provincial factors. Examples include governance capacity, project application ability, and pre-existing entrepreneurial conditions, which also affect agricultural green entrepreneurship. In essence, the IV approach is used be-

cause fixed effects and observed controls alone cannot fully rule out endogenous policy intensity driven by unobserved provincial characteristics. For empirical purposes, the key empirical problem is not merely whether provinces implemented HSFC. The intensity of implementation after 2011 may depend on time-varying provincial advantages in policy application, administrative coordination, and pre-existing development conditions. Such factors are difficult to observe directly and may not be fully absorbed by a standard DID framework with fixed effects. The IV strategy is therefore used to isolate the exogenous component of HSFC intensity that is induced by pre-policy land conditions rather than by contemporaneous entrepreneurial dynamics.

Table 4. Robustness test: lagged specification and instrumental variable results.

	Lagged HSFC $\times$ Post		First Stage		Second Stage	
	AG_Entry	AG_Stock	HSFC $\times$ Post	HSFC $\times$ Post	AG_Entry	AG_Stock
	(1)	(2)	(3)	(4)	(5)	(6)
L1.HSFC $\times$ Post	5.057 ** (2.122)	18.326 ** (6.926)				
MLYF ₂₀₁₀ $\times$ Post			1.460 *** (0.162)	1.460 *** (0.162)		
HSFC $\times$ Post					6.757 *** (2.110)	25.062 *** (7.160)
Constant	2634.313 (2023.019)	12,419.682 * (6961.617)				
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	620	620	651	651	651	651
R ²	0.724	0.849	0.774	0.774	0.172	0.284
Excluded F	-	-	80.884	80.884	-	-

Note: Columns (3) and (4) report the first-stage regressions, in which the dependent variable is HSFC $\times$ Post. The instrumental variable is MLYF₂₀₁₀ $\times$ Post, where MLYF denotes medium-low-yield farmland. Columns (5) and (6) report the second-stage 2SLS estimates. Standard errors clustered at the provincial level are reported in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

The relevance condition is straightforward. Provinces with a larger stock of medium-low-yield farmland before the policy rollout had greater objective need and physical scope for subsequent high-standard farmland construction. This pre-policy land endowment therefore predicts the intensity of post-2011 HSFC implementation. The exogeneity argument rests on temporal ordering and conditional independence. The area of medium-low-yield farmland is measured in 2010, before the implementation period considered in this study, and is therefore predetermined with respect to post-2011 changes in agricultural green entrepreneurship. Conditional on province fixed effects, year fixed effects, and provincial controls, the identifying assumption is that pre-policy medium-low-yield farmland affects post-policy agricultural green enterprise development primarily through its effect on HSFC intensity rather than through other direct channels. Beyond the exclusion restriction itself, the practical value of this instrument is that it shifts identification away from contemporaneous provincial entrepreneurial performance and toward pre-policy land conditions that shaped implementation need. Furthermore, because the instrument is based on pre-policy land conditions rather than contemporaneous entrepreneurial performance, it helps mitigate the reverse-causality concern that provinces with a larger pre-existing stock of green enterprises may have been more successful in securing HSFC support after 2011.

Columns (3) and (4) of Table 4 report the first-stage results. The coefficient on the instrumental variable is significantly positive, and the excluded first-stage F-statistic is 80.884, far above the conventional threshold of 10, indicating limited concern about weak

instruments. Columns (5) and (6) present the second-stage results. The coefficients on the instrumented $\text{HSFC} \times \text{Post}$ variable are 6.757 for agricultural green enterprise entry and 25.062 for agricultural green enterprise stock, respectively, both significant at the 1% level. These findings are consistent with the baseline estimates and further support the robustness of the main results.

The IV results are important because they help alleviate the concern that the baseline findings are driven by reverse causality from pre-existing provincial entrepreneurial strength to subsequent HSFC allocation. By focusing on the component of HSFC intensity predicted by pre-policy land conditions, the IV estimates make it less likely that the results simply reflect the ability of already stronger provinces to secure more policy support. Collectively, they provide additional support for a causal interpretation in which higher HSFC intensity promotes agricultural green entrepreneurship.

4.3.2. Nonlinear Dose–Response Test

Table 5 presents the estimates from the quadratic specification introduced in Section 3.2. Because HSFC is mean-centered before its squared term is constructed, the coefficient on $\text{HSFC} \times \text{Post}$ in this specification captures the marginal effect at the sample mean of HSFC intensity, which makes it incomparable with the coefficient from the baseline linear model. In both columns, the coefficients on $\text{HSFC} \times \text{Post}$ are positive and statistically significant, whereas the coefficient on $\text{HSFC}^2 \times \text{Post}$ is negative and statistically significant. For agricultural green enterprise entry, the estimated coefficients are 8.142 for $\text{HSFC} \times \text{Post}$ and -0.011 for $\text{HSFC}^2 \times \text{Post}$; for agricultural green enterprise stock, the corresponding estimates are 28.125 and -0.038 . These coefficients are statistically significant at the 1% level.

Table 5. Robustness test: nonlinear dose-response test.

	AG_Entry	AG_Stock
	(1)	(2)
HSFC $\times$ Post	8.142 *** (2.188)	28.125 *** (6.541)
HSFC ² $\times$ Post	-0.011 *** (0.003)	-0.038 *** (0.009)
Constant	2541.348 (1806.919)	12,444.843 * (6347.508)
Controls	Yes	Yes
Year FE	Yes	Yes
Province FE	Yes	Yes
Obs.	651	651
R ²	0.729	0.849

Note: This table reports estimates from the quadratic continuous DID specification including $\text{HSFC} \times \text{Post}$ and $\text{HSFC}^2 \times \text{Post}$. HSFC is mean-centered before constructing the squared term. Accordingly, the coefficient on $\text{HSFC} \times \text{Post}$ represents the marginal effect at the sample mean of HSFC intensity and is not directly comparable to the corresponding coefficient in the baseline linear specification. Standard errors are reported in parentheses. * $p < 0.10$, *** $p < 0.01$.

The results indicate a concave post-policy dose–response relationship between HSFC intensity and agricultural green entrepreneurship. Provinces with stronger HSFC implementation experienced larger increases in both the entry and stock of agricultural green enterprises. However, the marginal effect of additional HSFC intensity diminishes at higher treatment levels. This pattern is consistent with diminishing marginal returns to policy intensity over the observed range of the data.

The quadratic specification therefore refines the baseline interpretation rather than overturning it. While the linear model captures the overall positive effect of HSFC intensity,

the nonlinear estimates indicate that this effect is not constant across the treatment distribution. The baseline continuous DID coefficient should thus be interpreted as a summary measure of the average dose–response effect over the observed support of HSFC intensity. This coefficient does not represent a common marginal effect applying uniformly across provinces. Collectively, the nonlinear results strengthen the interpretation of the baseline estimates while leaving the paper’s main conclusion unchanged.

4.3.3. Bootstrap Inference, Alternative HSFC Measure, and Narrowed Time Window

Table 6 reports the results of additional robustness checks. Columns (1) and (2) present the bootstrap results based on 1000 replications. As expected, the point estimates are consistent with those derived from the baseline specification. Meanwhile, the bootstrapped standard errors verify the statistical significance and indicate significance at the 1% level for both the entry and stock of agricultural green enterprise. This indicates that the baseline results are not sensitive to sampling variation.

Table 6. Robustness test: bootstrap inference, alternative measurement of HSFC, and narrowed time window.

	1000 Bootstrap		Alternative Measurement of HSFC		Narrowed Window (2003–2019)	
	AG_Entry	AG_Stock	AG_Entry	AG_Stock	AG_Entry	AG_Stock
	(1)	(2)	(3)	(4)	(5)	(6)
HSFC × Post	4.450 *** (1.032)	15.155 *** (2.984)				
HSFC share × Post			90.752 * (50.950)	364.252 ** (170.706)		
HSFC × Post					1.995 *** (0.714)	8.895 *** (3.078)
Constant	2913.969 ** (1230.196)	13,780.510 *** (4008.378)	4831.524 ** (2236.699)	20,280.743 ** (8589.171)	1043.766 (626.750)	5737.955 * (2883.348)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	651	651	651	651	527	527
R ²	0.715	0.838	0.656	0.799	0.825	0.907

Note: Columns (1)–(2) report bootstrap results based on 1000 replications. Columns (3) and (4) use an alternative share-based measure of HSFC. Columns (5) and (6) restrict the sample period to 2003–2019 to exclude potential disturbances associated with the COVID-19 pandemic. Standard errors are reported in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Columns (3) and (4) implement a robustness check based on an alternative measurement of independent variable. In the baseline specification, the interaction term is constructed using the total area of HSFC and the post-2011 dummy. The total area based measure is then replaced with a share based measure, namely the interaction between the share of HSFC to the total farmland and the post-2011 dummy. The estimated coefficients are 90.752 for agricultural green enterprise entry and 364.252 for agricultural green enterprise stock, and both remain statistically significant. These results suggest that the main findings do not hinge on the specific measurement of HSFC program.

Columns (5) and (6) restrict the sample period to 2003–2019, resulting in 527 observations, to exclude potential disturbances associated with the COVID-19 pandemic during 2020–2023. Under this narrower time window, the coefficient on HSFC × Post remains significantly positive, with values of 1.995 for agricultural green enterprise entry and 8.895

for agricultural green enterprise stock, both significant at the 1% level. These results further confirm the robustness of the estimated policy effects.

4.4. Heterogeneity Analysis

The effect of the HSFC program on agricultural green entrepreneurship may differ across regional contexts. To examine the heterogeneous effect proposed in H2, the analysis is conducted along four dimensions: labor quantity, labor quality, informatization, and grain-production designation. In the empirical analysis, labor quantity, labor quality, and informatization are proxied by population density, human capital level, and informatization level, respectively. For each of these proxy variables, the sample is divided into high- and low-value groups based on the sample median. Grain-production designation is identified according to the Outline of the Medium- and Long-Term Plan for National Food Security (2008–2020), and the sample provinces are accordingly divided into main grain production areas and non-main grain production areas.

4.4.1. Heterogeneity by Labor Quantity

Table 7 reports the heterogeneity results by labor quantity, proxied by population density. The coefficient on $HSFC \times Post$ is significantly positive only in the high-population-density group, with estimated values of 7.485 for agricultural green enterprise entry and 23.300 for agricultural green enterprise stock. In the low-population-density group, the coefficients are small and statistically insignificant. These results indicate that the positive effect of the HSFC program is stronger in provinces with higher labor quantity. A plausible explanation is that densely populated regions tend to have better market accessibility, denser economic networks, and stronger agglomeration effects, which make it easier to translate improvements in farmland conditions into entrepreneurial opportunities [50]. These findings are consistent with H2.

Table 7. Heterogeneity analysis by labor quantity.

	AG_Entry		AG_Stock	
	High PD	Low PD	High PD	Low PD
	(1)	(2)	(3)	(4)
HSFC $\times$ Post	7.485 ** (2.743)	0.350 (0.993)	23.300 *** (7.520)	0.865 (2.842)
Constant	−3151.764 (5611.027)	1175.870 (1352.849)	−1985.101 (15,121.935)	422.745 (5298.178)
Controls	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes
Obs.	326	325	326	325
R ²	0.733	0.862	0.861	0.939

Note: Population density (PD) is used as a proxy for labor quantity. The sample is split at the median. Observations above the median are classified as the *high-PD* group, and those below the median are classified as the *low-PD* group. Standard errors clustered at the provincial level are reported in parentheses. ** $p < 0.05$, *** $p < 0.01$.

4.4.2. Heterogeneity by Labor Quality

Table 8 reports the heterogeneity results by labor quality, proxied by human capital level. The estimated coefficients are larger in the low-human-capital group. For agricultural green enterprise entry, the coefficient on $HSFC \times Post$ is 4.627 and significant at the 10% level in the low-human-capital group, whereas the estimate in the high-human-capital group is positive but statistically insignificant. For agricultural green enterprise stock, the coefficients are 8.102 in the high-human-capital group and 15.096 in the low-human-capital group, both significant at the 10% level. Overall, these estimates suggest that the

effect of the HSFC program appears relatively more pronounced in provinces with lower human capital endowment, possibly because infrastructure improvements generate larger marginal benefits where local production constraints are more binding. These findings provide evidence of heterogeneous effects by labor quality and are consistent with H2.

Table 8. Heterogeneity analysis by labor quality.

	AG_Entry		AG_Stock	
	High HCL	Low HCL	High HCL	Low HCL
	(1)	(2)	(3)	(4)
HSFC $\times$ Post	2.529 (1.658)	4.627 * (2.640)	8.102 * (4.654)	15.096 * (8.713)
Constant	6259.588 * (3667.764)	527.510 (777.329)	23,935.383 * (13,260.229)	1063.841 (2981.750)
Controls	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes
Obs.	339	310	339	310
R ²	0.751	0.847	0.874	0.936

Note: Human capital level (HCL), measured as the ratio of higher-education enrollment to total population, is used as a proxy for labor quality. The sample is split at the median. Observations above the median are classified as the high-HCL group, and those below the median are classified as the low-HCL group. Standard errors clustered at the provincial level are reported in parentheses. * $p < 0.10$.

4.4.3. Heterogeneity by Informatization

Table 9 presents the heterogeneity results by informatization, which is proxied by informatization level. The coefficient on HSFC $\times$ Post is significantly positive in both groups. For agricultural green enterprise entry, the estimated coefficients are 2.295 and 5.599 in the high- and low-informatization groups, respectively. For agricultural green enterprise stock, the corresponding coefficients are 10.262 and 17.312. These results suggest that the HSFC program has a stronger effect in provinces with lower informatization levels. One possible explanation is that regions with lower informatization tend to face more severe information frictions and lower factor allocation efficiency. In such settings, improvements in farmland infrastructure may yield larger marginal returns by relaxing production constraints and reducing coordination costs. These findings provide evidence of heterogeneous effects by informatization and are consistent with H2.

Table 9. Heterogeneity analysis by informatization.

	AG_Entry		AG_Stock	
	High INF	Low INF	High INF	Low INF
	(1)	(2)	(3)	(4)
HSFC $\times$ Post	2.295 ** (0.881)	5.599 ** (2.479)	10.262 *** (3.601)	17.312 ** (6.646)
Constant	1632.377 (1188.374)	7592.223 *** (2330.950)	6826.638 (5235.539)	32,363.016 *** (7679.676)
Controls	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes
Obs.	325	323	325	323
R ²	0.848	0.730	0.917	0.846

Note: Informatization level (INF), measured as the ratio of total post and telecommunications business volume to GDP, is used as a proxy for informatization. The sample is split at the median. Observations above the median are classified as the high-INF group, and those below the median are classified as the low-INF group. Standard errors clustered at the provincial level are reported in parentheses. ** $p < 0.05$, *** $p < 0.01$.

4.4.4. Heterogeneity by Grain-Production Designation

Table 10 reports the heterogeneity analysis by grain-production designation. Following the Outline of the Medium- and Long-Term Plan for National Food Security (2008–2020), the sample is divided into main grain-producing areas and non-main grain-producing areas. In non-main grain-producing areas, the coefficient on $HSFC \times Post$ is 0.006 for agricultural green enterprise entry and 0.022 for agricultural green enterprise stock, with both coefficients significant at the 1% level. By contrast, the corresponding coefficients for main grain-producing areas are positive but statistically insignificant.

Table 10. Heterogeneity analysis by grain-production designation.

	AG_Entry		AG_Stock	
	Main Grain Production Areas	Non-Main Grain Production Areas	Main Grain Production Areas	Non-Main Grain Production Areas
	(1)	(2)	(3)	(4)
HSFC $\times$ Post	0.002 (0.002)	0.006 *** (0.001)	0.006 (0.007)	0.022 *** (0.005)
Constant	2.795 (4.481)	3.766 *** (1.174)	13.418 (17.057)	15.938 *** (5.295)
Controls	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes
Obs.	273	378	273	378
R ²	0.715	0.841	0.840	0.907

Note: Main grain-producing areas and non-main grain-producing areas are classified according to the Outline of the Medium- and Long-Term Plan for National Food Security (2008–2020). Standard errors clustered at the provincial level are reported in parentheses. *** $p < 0.01$.

These results indicate that the positive effect of HSFC on agricultural green entrepreneurship is more pronounced in non-main grain-producing areas. A more reasonable interpretation is that the rigid constraints of grain production in such areas are relatively light, and there is more room for operation in the adjustment of agricultural industrial structure and the diversification of business models. Therefore, the improvement of farmland infrastructure is easier to be transformed into practical entrepreneurial opportunities, thus promoting the entry and scale expansion of agricultural green enterprises. These findings provide evidence of heterogeneous effects by grain-production designation and are consistent with H2.

4.4.5. Discussion of Heterogeneity Results

The heterogeneous effects can be understood by considering differences in labor quantity, labor quality, informatization, and grain-production designation across regions. First, the more significant policy effects of high-population-density regions are likely to benefit from their relatively abundant labor reserves and the resulting agglomeration economic advantages. Such areas usually have a more mature demand base, a more complete logistics transportation network, and a more robust production service supporting system. Therefore, after the improvement of farmland basic conditions, agricultural entrepreneurship activities can often germinate and expand more smoothly. Accordingly, when promoting the HSFC program in high-population-density regions, emphasis should be placed on the improvement of land remediation efficiency, the improvement of agricultural machinery and equipment, and the strengthening of water-saving irrigation infrastructure. Simultaneously, attention ought to be paid to the effective connection with the existing logistics network and the agricultural green value chain system [34].

Second, the more pronounced effect in low-human-capital regions suggests that the HSFC program may play a compensatory role in areas with relatively weak labor quality and entrepreneurial foundations. In such areas, the channels of non-agricultural employment are usually narrow, and farmers and various agricultural business entities tend to be more dependent on agricultural production and related business activities. Therefore, the improvement of farmland basic conditions is more likely to stimulate a stronger entrepreneurial willingness and effectively enhance the feasibility of entrepreneurial behavior. However, for such areas, farmland infrastructure investment should form a closer relationship with vocational skills improvement plans, entrepreneurial ability training courses, environmentally friendly technology promotion services, and organizational support means to ensure that the improvement of production conditions can truly precipitate a sustainable entrepreneurial ability foundation.

Third, the larger estimated effect in low-informatization regions indicates that the marginal impact of farmland infrastructure improvement may be greater where information frictions are more severe. In such areas, the absence of digital infrastructure and a lack of rural information public services often restrict the market access channel, the optimal allocation of production factors, and the orderly organization of business activities. The HSFC program may hedge the above constraints to a considerable extent through the improvement of basic production conditions and the reduction of business barriers, and then show a more prominent policy-driven effect at the level of agricultural green entrepreneurship. This suggests that, in low-informatization regions, farmland infrastructure investment should be coordinated with the expansion of the rural broadband network, the promotion of digital inclusive financial services, the construction and operation of agricultural information platforms, and the cultivation of digital literacy for farmers.

Fourth, the stronger policy response in non-main grain production areas reflects that the entrepreneurial promotion effect of the HSFC program is also regulated by regional agricultural production orientation: in areas where the agricultural management system is relatively less constrained by the rigidity of grain production, the upgrading of infrastructure is more likely to open up more abundant development space for industrial diversification exploration, organizational model innovation, and the breeding of green business entities. This finding also suggests that in the main grain production areas, it is necessary to more carefully coordinate the multi-objective relationship between food security tasks and agricultural green transformation and entrepreneurial ecological cultivation in the process of policy formulation.

From a policy perspective, the core implication of the above heterogeneity is that farmland infrastructure investment should not be regarded as an isolated intervention tool, especially in regions with relatively low human capital or weak informatization. The policy design idea with more promotion value should be to upgrade farmland infrastructure investment and combine it with a series of supporting capacity cultivation measures. This framework is not only applicable to China but also has reference significance for other developing economies facing similar rural structural constraints. Such supporting measures can cover the following directions: digital skills training and entrepreneurship guidance for farmers and new agricultural business entities, technology promotion services related to green production standards and market access, and closer integration between rural finance and information service platforms. It should be particularly emphasized that the allocation of the above-mentioned auxiliary policies should be differentiated according to the actual constraints of each region, with identical cross-regional unified implementation models avoided.

This kind of integrated promotion path is expected to further lead the compensatory effect presented by the lagging region to a more lasting endogenous growth track. Specif-

ically, by integrating farmland infrastructure investment with human capital cultivation and digital support policies, the risk of local entrepreneurship development relying on direct state funding or subsidy measures for a long time can be prevented to a considerable extent. To avoid excessive dependence on fiscal transfer payments, the allocation of policy resources should be more inclined to capacity building, public service provision, and market access facilitation, rather than focusing on direct fiscal allocations in the long run. From a more macro perspective, the above ideas also mean that the governance evaluation of the HSFC program should eliminate the narrow orientation of simply focusing on the scale of the project, and pay more attention to its systematic effects in promoting agricultural green entrepreneurship and rural revitalization.

5. Channel Regressions

To further explore how the HSFC program may promote agricultural green entrepreneurship, this study conducts a set of channel regressions focusing on entrepreneurial empowerment and agricultural green transition. Following the baseline specification, the dependent variable is replaced with a series of channel-related outcome variables, while the same set of controls, province fixed effects, and year fixed effects is retained.

These analyses are not formal causal mediation tests; rather, they provide suggestive evidence on plausible channels through which HSFC may influence agricultural green entrepreneurship. Because the intermediate-outcome equations may still be affected by omitted variables, time-varying confounders, simultaneity, and measurement error, the results should be interpreted as supportive rather than definitive evidence on transmission mechanisms.

Both entrepreneurial empowerment and agricultural green transition are broad channels involving multiple specific sub-pathways. Due to data limitations, the empirical analysis relies on representative indicators to capture these broader channels, rather than testing each specific transmission channel separately. Although the baseline DID estimates are informative about the overall policy effect of the HSFC program, the channel regressions are more vulnerable to omitted-variable bias and other forms of unobserved confounding. Therefore, the results reported below should be interpreted as evidence on theoretically relevant associated pathways rather than as conclusive proof of a fully identified causal transmission mechanism.

5.1. Entrepreneurial Empowerment Channel

Table 11 reports the results for the entrepreneurial empowerment channel. The coefficient on $HSFC \times Post$ is positive and statistically significant in all columns. Entrepreneurial empowerment here refers to improved conditions for agricultural business formation and operation. In column (1), the positive and significant coefficient on patent grants indicates that the HSFC program is associated with stronger local innovation capacity, which may improve the technological foundation for agricultural entrepreneurship. In column (2), the significantly positive coefficient of agricultural machinery suggests that the program promotes the adoption of agricultural machinery, thereby improving production efficiency and reducing operational constraints [88]. This effect is also economically meaningful. A 1000-hectare increase in HSFC is associated with an increase of 3.207 GW in agricultural machinery power, which is equivalent to about 10.7% of the sample mean provincial machinery stock. This result suggests a non-trivial improvement in production-supporting capital rather than a merely statistical effect. In column (3), the increase in the transferred area of household-contracted farmland implies that the program may facilitate land transfer and support the development of moderate-scale agricultural operations [40,60], which are important for standardized and market-oriented green production. The estimated increase in transferred farmland is likewise economically relevant, given the close connection between

land transfer, scale operation, and the organizational basis of agricultural entrepreneurship [60]. In column (4), the positive effect on agricultural insurance premiums suggests enhanced risk-sharing capacity and improved protection for agricultural production. In column (5), the increase in rural financial branches indicates that the HSFC program may improve the local financial service environment and expand access to external financing. This also points to improved rural financial service availability at the provincial level [89].

Table 11. Channel regressions: entrepreneurial empowerment.

	ln(Pat_Grants)	Agr_Mac	Transfer_Area	Agr_Insur	Rural_Fin
	(1)	(2)	(3)	(4)	(5)
HSFC × Post	0.001 * (0.000)	3.207 *** (0.614)	2.570 *** (0.569)	5.550 *** (1.363)	0.964 ** (0.371)
Constant	9.423 *** (0.877)	3930.073 *** (1207.975)	1591.401 (1167.732)	6651.133 *** (2193.739)	2986.486 *** (1025.433)
Controls	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes	Yes
Obs.	651	651	589	643	527
R ²	0.982	0.972	0.892	0.871	0.977

Note: *Pat_grants* denotes the number of patent applications granted in each province-year according to Chinese official patent statistics; $\ln(\text{Pat_grants})$ is its natural logarithm. Since *Pat_grants* is strictly positive in the sample, $\ln(\text{Pat_grants})$ is used instead of $\ln(1 + \text{Pat_grants})$. *Agr_mac* denotes the total power of agricultural machinery. *Transfer_area* denotes the transferred area of household-contracted farmland, its comparable provincial data are unavailable for 2003 to 2004. *Agr_insur* means the agricultural insurance premium; some provincial observations are unavailable for 2003 to 2006. *Rural_fin* denotes the number of rural financial institution branches, which provincial statistics are unavailable for some provinces between 2003 to 2006. Standard errors clustered at the provincial level are reported in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

These findings indicate that the HSFC program may strengthen agricultural entrepreneurial conditions by reducing operating constraints, improving production and management conditions, facilitating scale operation, and enhancing access to insurance and finance. Thus, the findings lend support to H3a.

5.2. Agricultural Green Transition Channel

Table 12 reports the results for the agricultural green transition channel. The coefficient on HSFC × Post is 4.821 for green utility model patent applications and is significant at the 5% level, suggesting that the HSFC program promotes green innovation. The coefficient on pesticide use is −35.261 and significant at the 1% level, implying the program reduces pesticide application. In addition, the coefficient on the green finance index is positive and significant at the 5% level, suggesting that the HSFC program is associated with an improvement in green financial development.

Agricultural green transition mainly refers to the diffusion of green technologies, a reduction in environmentally harmful input dependence, and an improvement in green financial support. In column (1), the positive coefficient of green utility model patent applications suggests that the HSFC program promotes green technological innovation and strengthens the technological foundation for agricultural green entrepreneurship [90]. In column (2), the negative coefficient of pesticide use indicates that the program helps reduce dependence on chemical inputs, thereby making green production practices more feasible [91]. Collectively, the significant changes in green patenting and pesticide use suggest meaningful improvements in the local green production environment. In column (6), the positive coefficient of the green finance index suggests that the HSFC program is associated with improved green financial development, which may strengthen the external support environment for green entrepreneurship.

Table 12. Channel regressions: agricultural green transition.

	Green_Pat	Pest_Use	Fert_Use	Film_Use	Carbon_Emiss	ln(Green_Fin)
	(1)	(2)	(3)	(4)	(5)	(6)
HSFC × Post	4.821 ** (2.012)	−35.261 *** (10.889)	−0.043 (0.056)	−10.836 (24.877)	−0.163 (0.493)	0.00006 ** (0.00003)
Constant	4209.016 * (2431.053)	10,347.495 (25,622.627)	299.380 (188.715)	37,699.201 (67,139.941)	2170.871 (1420.033)	−1.37608 *** (0.071)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	651	651	651	651	651	651
R ²	0.855	0.970	0.922	0.951	0.977	0.996

Note: *Green_pat* denotes green utility model patent applications. *Pest_use* denotes pesticide use. *Fert_use* denotes chemical fertilizer use, measured in tones per thousand hectares. *Film_use* denotes agricultural film use, measured in tones. *Carbon_emiss* denotes agricultural carbon emissions. *Green_fin* denotes the green finance index, a dimensionless composite index constructed using the entropy-weighting method; $\ln(\text{Green_fin})$ is its natural logarithm and is used as the dependent variable in column (6). Since *Green_fin* is strictly positive in the sample, $\ln(\text{Green_fin})$ is used instead of $\ln(1 + \text{Green_fin})$. Because the estimated coefficient for $\ln(\text{Green_fin})$ is small in magnitude, the result in column (6) is reported to five decimal places. Standard errors clustered at the provincial level are reported in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Simultaneously, the coefficients, in column (3)–(5), on fertilizer use, agricultural film use, and agricultural carbon emissions are statistically insignificant. The results reflect that, compared with other environment-related input factors and emission dimensions, the role of the HSFC program in promoting agricultural green transition seems to be more concentrated in the activeness of green innovation activities, a reduction in chemical pesticide use, and the development of green financial systems. A more reasonable inference is that the main direction of the HSFC program is to improve farmland infrastructure investment, while the substantial decline in fertilizer use, agricultural film use, and agricultural carbon emissions usually depends on the renewal of production technology systems, the optimization of input management systems, and the coordination of corresponding supporting policy tools [92]. Based on this, the environmental benefits may need to be released gradually after a certain time lag. This inference also implies that although an improvement in physical infrastructure can create the necessary preconditions for the green transformation of production methods, it is not sufficient to automatically generate immediate and complete carbon emission reduction results.

The statistically significant decrease in the amount of pesticide use may be due to the promotion of standardized farming models and the convenient application of green plant protection technologies brought about by an improvement in farmland patch remediation and field supporting facilities. Compared with indicators such as fertilizer use, agricultural film use, or agricultural carbon emissions, the above adjustments are easier to implement in a shorter implementation cycle. Therefore, it is inferred that the downward trend of pesticide use intensity may take precedence over the changes in other environmental inputs and emission indicators in time series.

The above results suggest that the HSFC program may have a positive impact on agricultural green transition at the regional level by promoting the diffusion and dissemination of environmentally friendly technologies, reducing the dependence on high pollution input factors, and enhancing the support of green financial services, thus creating a more favorable external environment for agricultural green entrepreneurship. These findings lend support to H3b.

6. Conclusions and Policy Implications

6.1. Main Conclusions

Using provincial panel data from 2003 to 2023 and a continuous difference-in-differences (DID) design, this study examines the impact of the HSFC program on agricultural green entrepreneurship. Based on the baseline results, a series of robustness checks, channel analyses, and heterogeneity tests, three main conclusions emerge.

First, the HSFC program has significantly promoted both the entry and the stock of agricultural green enterprises. This positive effect is robust across a range of alternative specifications, including lagged HSFC variables, instrumental variable estimation, bootstrap inference, an alternative HSFC measure, exclusion of the COVID-19 shock years, and a nonlinear dose–response specification. These findings indicate that the HSFC program has a robust and positive effect on agricultural green entrepreneurship.

Second, a channel analysis provides evidence consistent with two broad channels: entrepreneurial empowerment and agricultural green transition. The optimization of the local entrepreneurial environment by the HSFC program is mainly achieved through the following paths: improving the level of innovation output in the agricultural field, promoting the process of agricultural mechanization, expanding the transferred area of household-contracted farmland, strengthening the agricultural risk guarantee system, and improving the coverage and accessibility of rural financial services. The above empirical results suggest that farmland infrastructure investment at the agricultural land level helps to consolidate the basic conditions of agricultural entrepreneurship at the production side, the organizational structure side, and the financial support side. In terms of the ecological dimension, the plan has also promoted the agricultural green transition, which is embodied in an increase in green utility model patent application activities, a reduction in chemical pesticide application, and the gradual development of green financial systems. However, the estimated effect of the plan on indicators such as fertilizer use, agricultural film use, and agricultural carbon emissions did not pass the statistical significance test. This results show that the environmental improvement effect brought about by the HSFC program shows obvious selective characteristics in different dimensions, rather than having a consistent positive impact in all fields.

Third, the effect of the HSFC program exhibits substantial heterogeneity across regional conditions. In provinces with higher population density, the above positive effects show a more obvious increasing trend, which reflects that the higher the frequency of market interaction and the stronger the demand base, the greater the entrepreneurial returns caused by farmland infrastructure investment. At the same time, provinces with low human capital levels show a stronger effect range, which means that the HSFC program may play a compensatory role in those areas where the initial conditions of entrepreneurship are relatively weak. In addition, regardless of whether the informatization level is high or low, the plan can significantly promote agricultural green entrepreneurship. However, the estimation effect is greater in provinces with a low level of informatization. This result suggests that in areas where information congestion and factor allocation distortions are more prominent, the marginal revenue space that farmland infrastructure investment can release may be more considerable. Furthermore, compared with main grain production areas, the policy effects of non-main grain production areas are more prominent. This shows that in areas with wider space for upgrading agricultural production structure and greater potential for diversification of green business forms, the optimization of farmland infrastructure will be more likely to be transformed into considerable entrepreneurial gains.

6.2. Policy Implications

Based on the above findings, several policy implications can be drawn. First, the government should continue to advance the HSFC program and further broaden its policy positioning [93,94]. In addition to its role in improving farmland conditions and agricultural production capacity, the HSFC program should also be incorporated into the policy framework for agricultural green entrepreneurship, agricultural modernization, and rural revitalization [95]. This requires maintaining stable investment in HSFC while placing greater emphasis on its entrepreneurial and green development effects in policy design and implementation. Meanwhile, the performance evaluation system for the HSFC program should be expanded [96]. The traditional performance evaluation system often focuses on the single dimension of cultivated land ownership, project implementation progress, grain output capacity and so on. The empirical findings of this study show that the HSFC program also contains more far-reaching significance in promoting agricultural green entrepreneurship and rural comprehensive revitalization. Therefore, it is necessary for the evaluation paradigm of HSFC governance to gradually shift from a quantity-oriented framework centered on area compliance and project completion to a quality-oriented framework that takes into account the vitality of rural green business systems. At the specific implementation level, the indicators related to green entrepreneurship should be included in the normal monitoring and evaluation system of land remediation projects. In the future, policy evaluation should further introduce multi-dimensional indicators such as the number of green enterprise registrations, technological innovation capabilities, the level of reduction of environmentally harmful inputs, and the degree of green financial development, so as to more comprehensively measure the comprehensive effectiveness of the economic and ecological values carried by the program.

Second, greater attention should be given to the entrepreneurial empowerment effects generated by the HSFC program [97]. Given that the empirical results show that the HSFC program improves innovation output, agricultural mechanization, land transfer, agricultural insurance, and rural financial accessibility, related supporting measures should be strengthened in a coordinated manner. Policymakers can enhance the links between the HSFC program and agricultural technology extension, machinery service systems, land transfer market development, agricultural insurance expansion, and inclusive rural finance, thereby translating infrastructure improvements into stronger entrepreneurial support [62,98]. In addition, complementary green policy instruments should be introduced to strengthen the agricultural green transition effects of the HSFC program [99]. Although the empirical evidence shows that the HSFC program promotes applications for green utility model patents, reduces pesticide use, and improves green financial development, its effects on fertilizer use, agricultural film use, and carbon emissions are not statistically significant. This suggests that the environmental benefits of HSFC may be indirect and may depend on complementary policies, technological diffusion, and behavioral adjustment over time. Therefore, it is necessary to combine the HSFC program with more targeted measures, such as fertilizer reduction programs, support for environmentally friendly agricultural materials, the adoption of low-carbon technologies, and specialized green financial services [37,77]. It is also possible that some environmental effects are non-linear or slow to emerge, so HSFC should be viewed as an enabling platform instead of a stand-alone environmental policy instrument.

Third, policy implementation can be further optimized according to regional characteristics [100]. In view of the fact that regions with high population density, low human capital, and low informatization and non-main grain production areas show stronger effect range in the estimation results, policy resources can be moderately tilted to such regions in the process of project implementation and supporting measures layout. However, it

should be noted that this does not mean that a uniform policy plan is applied to all lagging or highly responsive regions. On the contrary, decision makers should implement differentiated promotion strategies based on the main constraints of each region revealed by the heterogeneity analysis. In terms of densely populated areas, the HSFC program can more effectively meet the actual needs of the local market and provide support for the growth of agricultural green industries. At the specific operational level, in areas with high population density, the policy framework should focus on strengthening the market coordination mechanism, improving the logistics network connection, promoting the vertical extension of the value chain, and cultivating the agglomeration community of green agricultural enterprises, so that the results of the improvement of farmland conditions can be more smoothly transformed into the substantive expansion of entrepreneurial scale under the combined effect of strong agglomeration effect and demand basis [101]. In view of provinces with low human capital, we can further increase support in the cultivation of entrepreneurial skills, the popularization of applicable technologies, and the construction of rural cooperative organizations. In such areas, policy design should integrate farmland infrastructure investment and human resource development into a coordinated intervention combination. At the specific implementation level, we can focus on the special training of farmers, the exploration and cultivation of local entrepreneurial backbones, the collaborative construction of cooperative economic organizations, and the strengthening of grassroots agricultural technology service networks, so as to gradually transform the compensatory function of HSFC into a sustainable endogenous entrepreneurial growth momentum [102]. For areas with low-informatization regions, strengthening the construction of digital infrastructure and rural information service systems will help to fully release the potential of entrepreneurship promotion contained in the HSFC program. In such areas, decision makers should pay more attention to the organic combination of infrastructure projects with digital access capabilities, market information interaction platforms, and farmers' digital literacy improvement measures to effectively alleviate the resource matching obstacles caused by information asymmetry [103]. As far as non-main grain production areas are concerned, the promotion of the HSFC program can be more closely embedded in the development of diversified green agricultural industries tailored to local conditions, thereby enabling upgraded cultivated land resources to be more efficiently converted into sustainable business opportunities. Based on the above policy orientations, such adjustments will help to promote the governance model of the HSFC program to eliminate its traditional single construction orientation, and to build a result-driven governance framework focusing on stimulating entrepreneurial empowerment, agricultural green transition, and long-term resilience of rural commercial ecosystems. Therefore, the policy signal transmitted by the heterogeneity analysis is not limited to revealing the differences in the degree of benefit in different regions. The deeper meaning is that the differentiated regional endowment conditions determine the combination of farmland infrastructure investment, market mechanism matching, human capital accumulation, and digital convenience measures. Simultaneously, supporting measures should be formulated to match the developmental path of local industries.

6.3. Research Limitations and Future Prospects

There are still some deficiencies in data structure and channel identification in this study. Although the provincial panel data are suitable for evaluating the policy effects of the HSFC program, they cannot fully capture the behavioral responses of individual firms and farmers. Therefore, how farmland infrastructure investment affects agricultural green entrepreneurship through micro-behavioral mechanisms has not yet been fully revealed. Although the channel analysis provides evidence on entrepreneurial empowerment and

agricultural green transition, these results should be interpreted as suggestive rather than definitive evidence. In addition, the various environmental indicators observed in this study are not completely consistent in the direction of effect, which means that the effect of an agricultural green transition caused by the HSFC program may be gradual and subject to the coordination of supporting policy conditions to a considerable extent. In terms of fertilizer use, agricultural film use, and agricultural carbon emissions, no statistically significant changes are detected.

To address these limitations, follow-up research may use enterprise-level, county-level, or farmer-level data to accurately reveal the micro-mechanism behind agricultural green entrepreneurship. Simultaneously, future work can further distinguish the differences between various types of enterprise forms and organizational structures and incorporate more dimensions of environmental and technical indicators into the analysis system, thereby achieving a more comprehensive evaluation of the impact of the HSFC program over a longer period. Further attention may also be given to heterogeneity by farm type when more comparable classifications and data become available across regions. In addition, future research can focus on the impact of the HSFC program on the change in total agricultural carbon emissions and the broader process of agricultural green transition.

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