

Article

How Does High-Standard Farmland Construction Affect Agroecological Efficiency—From the Perspective of Factor Endowment

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Abstract: Based on the factor endowment theory and the agriculture-induced technological innovation theory, this study examines the impact of high-standard farmland construction (HFC) on agricultural ecological efficiency (AEE) and sustainable agricultural development. Using empirical data from 30 provinces in China between 2005 and 2022, it explores how high-standard farmland construction techniques can enhance AEE, considering factor endowment preferences and geographical characteristics. Empirical research indicates that high-standard farmland significantly enhances AEE, particularly in the eastern region, the main grain-producing areas, and the regions with less geographical fluctuation. Additionally, agricultural innovations, capital accumulation, and land circulation reinforce the benefits of such construction, whereas labor mobility has a moderating effect. Quantile regression analyses show that the impact of HFC on AEE initially increases and then diminishes, potentially due to inadequate post-management and maintenance. Consequently, the study recommends that the government enhance policy support and supervision for high-standard farmland projects, integrate agricultural technology with capital accumulation, optimize human resource allocation, guide labor mobility, and reform land transfer systems to boost AEE and sustainability.

Keywords: high-standard farmland construction; agroecological efficiency; factor endowment theory; agricultural sustainable development



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1. Introduction

Facing the growing population and changing climate conditions, how to achieve high yield, efficient, and environmentally-friendly agriculture has become a major global issue. Considering both resource-carrying capacity and environmental sustainability, many countries are now striving to promote the green transformation of agriculture by improving agroecological efficiency (AEE). For example, the United States encourages farmers to improve the long-term productivity of their land through agricultural subsidies and land conservation programs, such as the Conservation Reserve Program (CRP) [1]. Germany implements the “Land Consolidation Law” to promote agricultural land consolidation and efficient green agriculture and develop efficient and pollution-free agricultural machinery [2]. Japan’s Agricultural Modernization and Stable Operation Law supports the construction of land consolidation and farmland water conservancy facilities to boost agricultural productivity [3]. Similarly, the European Union promotes land consolidation, ecological agriculture, and sustainable development through the Common Agricultural Policy (CAP) [4]. These policies have promoted the use of green production technologies, the reduction of chemical fertilizers, and the reduction of agricultural carbon emissions, bringing significant social, economic, and ecological benefits [5].

Nevertheless, there are numerous obstacles to the process of agricultural green development, including farmers’ lack of ecological awareness, the irrational distribution of

production resources, the inadequate application of environmental laws, etc. [6]. Consequently, it is necessary to involve third parties in creating a multi-linkage and interactive policy mechanism that engages the government, markets, and farmers [7]. In recent years, many countries have attempted to improve arable land quality and AEE through high-standard farmland construction planning, which has become an important experience for the sustainable development of global agriculture.

Compared with these countries, China has both commonalities and differences in AEE. The commonality is that China attaches equal importance to the green transformation of agriculture by improving AEE and has also adopted a series of policy measures to promote HFC to improve the quality of cultivated land and AEE. The difference is that China's agricultural development faces special challenges such as uneven distribution of land resources and poor soil in some areas. In addition, China has historically relied on a labor- and capital-intensive development model [7], but with the development of the market economy and the advancement of urbanization, the continuous reduction of agricultural labor force, the reduction of arable land, and the emergence of the "non-food" phenomenon, the traditional development model is no longer sustainable [6]. Therefore, high-standard farmland construction has become an important way to improve labor efficiency and maximize land use in developing countries such as China. Further, careful research on the impact of HFC on AEE has important theoretical and practical value for formulating scientific agricultural policies, optimizing agricultural resource allocation, and promoting agricultural modernization.

Current research on AEE mainly focuses on three areas. First, from the perspective of agricultural policies and subsidies, researchers explore how policy tools, such as organizational governance [8], financial support [9], and environmental regulations [10], affect AEE and how policy adjustments can promote green development and efficient resource utilization. Second, from the perspective of agricultural resource allocation and management, researchers analyze how the allocation of agricultural science and technology input [11], agricultural land transfer [12], agricultural resource misallocation [13], and labor transfer [14] can improve AEE by optimizing resource allocation and management. Thirdly, from the perspective of environmental impact and ecological transformation, researchers study the impacts of agroecological regional differences [15], agricultural non-point source pollution [16], climate change [17], and other factors on AEE and how to improve AEE and reduce environmental impact through ecological transformation and sustainable development practices.

While these studies provide valuable insights, however, few studies directly examine the specific impact of high-standard farmland construction on AEE. In fact, according to the top-level policy design, ecological benefits are an important basis for evaluating the implementation effect of HFC, which are as important as economic benefits. However, there has been a limited comprehensive assessment of both the ecological and economic advantages of these strategies [18]. In addition, most existing studies are limited to case analysis in specific regions [19,20], which lacks broad representation. Thus, evaluating the effect of HFC on AEE still requires careful consideration and a wider perspective.

Most scholars believe that HFC can not only ensure sustainable land use and improve land yield but also enhance resource utilization by optimizing irrigation systems, soil management, and crop structures [4]. Nonetheless, other academics dispute this, arguing that the pursuit of high-standard farmland building to "connect fields and canals" may alter the land's natural topography, potentially undermining agricultural output [21]. In fact, the effectiveness of HFC is influenced by a combination of factors, including regional natural resource endowments and topography [22], which requires localized approaches to achieve comprehensive improvements in AEE [23].

According to the theory of Agricultural Induced Technological Innovation [24], different countries or regions with varied agricultural factor endowments will exhibit differences in production objectives, capacities, and the adoption of new technologies. Even with the implementation of HFC, the outcomes will vary depending on traditional agricultural

practices, the quality of the agricultural workforce, and regional topography, leading to differing levels of production efficiency and ecological impact. Obviously, when technological progress is consistent with the structure of local production factors, local endowment advantages can be effectively utilized to avoid redundancy of factor input, thereby improving both production efficiency and environmental benefits [25]. In addition, adequate financial support is fundamental for agricultural production. In areas with abundant capital resources, it is easier to implement advanced agricultural technologies, green fertilizers, and agricultural services that boost environmental protection and land use efficiency. In summary, abundant agricultural factor endowments such as technology, capital, and skilled human resources play a positive role in regulating the impact of HFC on AEE. Therefore, it is of great practical significance to integrate agricultural endowment conditions into the research framework of HFC and explore the synergistic effect between various factors and farmland policies for comprehensively improving AEE.

China is the most populous country in the world, bearing the huge food demand for nearly 20% of the world's population and playing a key role in global food security. Although China has relatively abundant agricultural resources, the uneven distribution of land resources and the poor soil in some areas pose a great challenge to agricultural production. Historically, China's agricultural production relied heavily on labor- and capital-intensive development. However, with the development of the market economy and the promotion of urbanization, China's agricultural factor endowment is changing, showing the continuous reduction of the agricultural labor force, the reduction of cultivated land, and the coexistence of the "non-grain" phenomenon, which is common in most developing countries. Clearly, the labor- and land-intensive development model is no longer sustainable, making HFC an essential path for developing countries to boost labor efficiency and maximize land use. In this context, despite a late start, China has made remarkable progress in high-standard farmland construction and cultivated land quality management, showing remarkable development [4]. Through continuous technological innovation and policy support, China has not only improved internal AEE but also set a global example. Therefore, taking China as an example to discuss the impact of HFC on AEE not only provides a scientific basis for the sustainable development of agriculture in China but also offers valuable insights for other developing countries and even the world.

In summary, this study is structured as follows:

- Using panel data from 30 provinces in China from 2005 to 2022, it systematically measures China's AEE levels and HFC, employing a fixed-effect model to explore their relationship.
- From the perspective of the factor endowment theory, it integrates HFC with factor endowment resources (technology, capital, labor, and land) to reveal the internal mechanism of HFC affecting AEE.
- To give a more precise foundation for regional policy formulation, the study takes into account the distinctions between various regional categories, which further deepens the heterogeneity analysis of HFC on AEE.
- The study decomposes AEE into agricultural technical efficiency and agricultural technological progress and discusses the direct sources of high-standard farmland's contribution to AEE improvement, providing theoretical support for optimizing agricultural resource allocation and enhancing sustainable development capacity.

2. Policy Evolution and Theoretical Analysis

On the basis of the above, this section discusses the policy framework guiding the construction of high-standard farmland and analyzes its theoretical basis and practical significance from the perspective of theory.

2.1. Policy Evolution

HFC is a significant governmental initiative aimed at increasing agricultural productivity, providing food security, improving land use efficiency, and supporting sustainable

development. As mentioned above, countries like the United States, Germany, Japan, and the European Union have realized the importance of HFC, and have adopted a series of measures to improve agricultural production efficiency and sustainable development. In China, agriculture plays a foundational role in economic development. However, due to inefficient traditional farming practices and poor infrastructure, China faces significant agricultural production challenges. HFC in China has a distinct policy development trajectory in addition to its broad significance (Figure 1). The origin of HFC in China can be traced back to the land reform in the 1950s, but the real systematic policy was formed after China's reform and opening up. In 1988, the establishment of the Land Development and Construction Fund marked the beginning of China's focus on developing high-standard farmland and improving infrastructure like irrigation and roads. In 2005, the Chinese government first put forward the concept of "HFC" in the No. 1 Document of the Central Committee and regarded it as an important direction of agricultural development. After 2011, China began to implement HFC. For example, the Ministry of Land and Resources of China issued the National Land Renovation Plan (2011–2015) in 2011, which emphasized that in the next five years, China will focus on large-scale construction of basic farmland with a high standard of guaranteed harvest in drought and flood, vigorously promote agricultural land renovation, realize rational use of land, and improve the ecological environment [23]. By the end of 2023, China has built more than 1 billion mu of high-standard farmland and built a large number of high-quality farmlands with high and stable yields even in drought and flood. It is expected that by 2030, China will plan to build 1.2 billion mu of HFC, ultimately transforming 1.546 billion mu of permanent basic farmland into high-standard farmland.

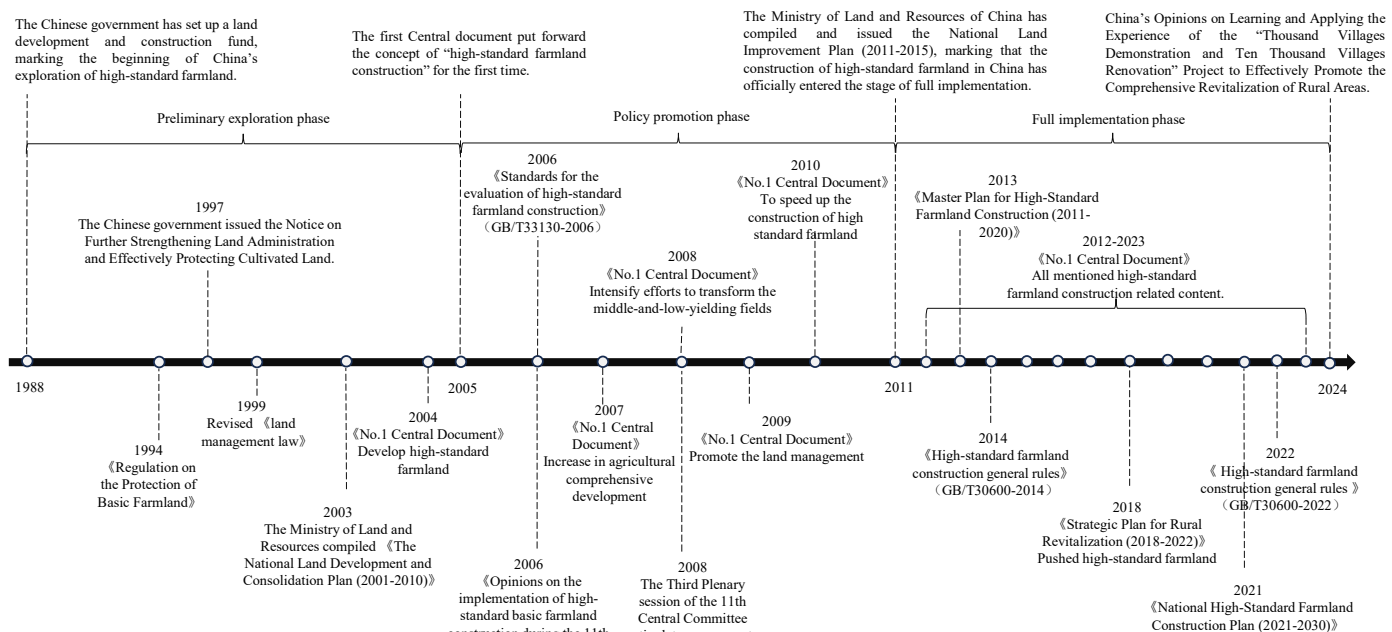


Figure 1. The development track of China's HFC [23].

China and other nations' construction experiences show that high-standard farmland construction has achieved remarkable results. The improvement of agricultural infrastructure is one of the requirements of high-standard farmland construction. Such farmland features expanded land scale and improved mechanization, boosting agricultural efficiency, adjusting agricultural structure, enhancing the ecological environment, and fostering sustainable agriculture [26]. In addition, through measures such as land leveling, irrigation, drainage facility construction, and soil improvement, the productive capacity and disaster resistance of farmland have been significantly improved, ensuring the stability and sustainability of food production. These accomplishments have created a strong basis for

sustainable agricultural development, in addition to increasing agricultural production efficiency and guaranteeing national food security.

2.2. Theoretical Analysis

2.2.1. Direct Impact of HFC on AEE

High-standard farmland refers to cultivated land that is compatible with modern agricultural production and management mode by taking specific measures, such as land leveling and supporting facilities, to improve the soil quality of cultivated land, enhance the ability of the farmland ecosystem to resist natural risks, achieve water and land conservation, ensure a high and stable yield, and maintain good ecology conditions [27]. To be specific, firstly, HFC maximizes land use efficiency by optimizing resource allocation [28]. In traditional agricultural production, the imbalance of resource allocation often leads to resource waste and low production efficiency. Through scientific planning and infrastructure improvement, such as land leveling, irrigation system optimization, field road construction, etc., HFC makes resource allocation more reasonable, effectively reduces the waste of marginal land, improves the production efficiency of unit area, and thus promotes the improvement of AEE. Secondly, HFC is a catalyst for the advancement of agricultural technology [29]. It not only includes the improvement of infrastructure but also includes the promotion and application of modern agricultural technology, such as precision agriculture technology, water-saving irrigation technology, soil improvement technology, and large-scale promotion of agricultural machinery. These technologies lead to more efficient production, reduced resource waste, and lower environmental impact. In addition, HFC significantly benefits ecological protection. Compared with traditional agriculture, high-standard farmland construction attaches great importance to the protection and restoration of the ecological environment in the planning and implementation process, such as the construction of farmland protection forest networks and the optimization of planting trees, which reduces soil erosion, nutrient loss, and the occurrence of diseases and pests [30,31]. Finally, the social effect of HFC cannot be ignored. Through HFC, agricultural production conditions have been improved, which contributes to the increase in farmers' income [32]. In addition to increasing farmers' enthusiasm for output, this improvement also improves their capacity to accept and implement new ideas and technologies, creating a positive social and economic cycle, advancing the advancement of AEE, and offering a strong basis and assurance for the development of sustainable agriculture. Based on this, hypothesis 1 is proposed:

H1: *HFC is conducive to improving AEE.*

2.2.2. The Regulating Effect of Agricultural Factor Endowment Conditions

According to the factor endowment theory, different regions differ in the relative abundance of production factors such as technology, capital, labor, and land, which determines their comparative advantages in economic activities. HFC needs to adapt to the characteristics of regional endowments to exert the expected policy effect. Therefore, agricultural endowment conditions are included in the research framework to explore the synergistic effects of production factors and farmland policies in this process.

1. Agricultural technology innovation

Technological progress theory emphasizes that technological innovation is a key driver for economic growth and efficiency improvement [33]. The integration of agricultural production with technological advancements has altered the production function, optimizing the output-to-input ratio [34]. For instance, in China, the contribution of agricultural scientific and technological progress rose from 54.5% in 2012 to 62.4% in 2023 [35], demonstrating that technological innovation is a powerful engine for modern agricultural development, significantly impacting the efficiency and sustainability of agricultural production in developing countries. Modern agricultural technology can be integrated into HFC to promote

ecological efficiency by reducing resource waste and pollution and improving agricultural production precision and efficiency. Moreover, technological innovation spreads across regions through various channels [36], and high-standard farmland areas, as test beds for new technologies, not only transform local practices but also inspire neighboring regions through demonstration effects, amplifying the positive impact on AEE. Finally, the diffusion effect of technological innovation further stimulates innovation vitality in the agricultural field, promotes the upgrading and transformation of the agricultural industry chain [37], and leads the development of agriculture in a more intelligent, efficient, and green direction. Based on this, hypothesis 2 is proposed:

H2: *The improvement of agricultural technology innovation can strengthen the positive impact of HFC on AEE.*

2. Agricultural capital stock

From the perspective of capital deepening, the increase in agricultural capital stock is essentially the deepening process of agricultural capital [38]. This deepening is reflected not only in the quantity of capital but also in its quality. HFC, as a capital-intensive investment, relies on sufficient capital stock to provide the necessary material and technical support, and then it can realize effective resource allocation and maximize production efficiency. Specifically, an increase in the capital stock helps to achieve economies of scale in agricultural production [39]. In HFC, concentrated investment of capital can effectively reduce the average cost per unit product and improve the diversity of services and products to achieve the optimal allocation of resources and improve production efficiency in a wider range. The realization of a scale economy can not only enhance the overall competitiveness of agricultural production but also promote the long-term stable growth of AEE. In addition, the growth of agricultural capital stock is accompanied by the progress and innovation of agricultural technology [40]. The accumulation of capital provides the necessary financial support for the research, development, and promotion of new technologies, and the application of new technologies further enhances capital efficiency. In HFC, the combination of capital and technology has fundamentally transformed agricultural practices, such as precision agriculture and intelligent irrigation systems. These technologies not only boost the precision and efficiency of agricultural production but also reduce resource waste and environmental impact, thereby improving AEE. Based on this, hypothesis 3 is proposed:

H3: *The increase in agricultural capital stock can enhance the positive impact of HFC on AEE.*

3. Labor mobility

According to the factor endowment theory, labor outflow from the agricultural sector directly reduces the labor supply in agriculture, thereby affecting the efficiency of agricultural production [41]. The digital economy has created more flexible job opportunities, leading many workers to seek better income outside rural areas, which makes them more willing to leave the countryside and land. With the outflow of more capable and healthy labor, agriculture is facing an increasingly severe shortage of human resources, resulting in higher labor costs. In response, agriculture increasingly relies on mechanization and automation to maintain productivity and reduce dependence on human labor [42]. While increased investment in capital and technology can alleviate labor shortages in the short term, over-reliance on non-renewable resources such as chemical fertilizers, pesticides, and irrigation can lead to soil degradation and water pollution, which in turn affects the long-term sustainability and ecological efficiency of agriculture. Additionally, although migrant workers leave agricultural production, they often maintain part-time involvement as a risk management strategy against non-agricultural market uncertainties [43]. Although this mode of part-time employment provides additional security, it also limits the input of labor in agricultural production, affecting the technical progress of agricultural production and the effect of large-scale management. Finally, land, as an important material basis and

symbol of social status for farmers, is often regarded as an inseparable family asset [43]. Even in the case of a large outflow of the labor force, farmers still tend to retain land ownership rather than transfer or lease it to professional farmers, which to a certain extent hinders the effective integration and large-scale management of land resources and thus affects the overall productivity and efficiency of agriculture. Based on this, hypothesis 4 is proposed:

H4: *The increase in labor migration will weaken the promotion effect of HFC on AEE.*

4. Land circulation

Land circulation refers to the transfer and reconfiguration of land use rights among farmers or between farmers and enterprises through market mechanisms or policy guidance [44], and existing studies have proved that land circulation also has certain ecological benefits [45]. Specifically, on the one hand, land circulation can optimize land resource allocation and reduce land fragmentation [46]. In the traditional small-scale peasant economy, the land is scattered and small in scale, which makes it difficult to achieve large-scale management and modern management. Through land circulation, land can be concentrated in the hands of business entities with higher management ability and technical level to achieve economies of scale. Large-scale operation helps to adopt advanced agricultural machinery and technology, reduce production costs, improve production efficiency, and reduce resource waste and environmental pollution, thus improving AEE [29]. On the other hand, land circulation promotes specialized and cooperative management and improves the overall efficiency of agricultural production [47]. Through specialization and cooperative management, agriculture will make full use of resources and technological advantages to achieve optimal productivity. After land circulation, large-scale management entities can better the division of labor and cooperation, achieve specialized production and scientific management of crops, optimize resource allocation, reduce repeated inputs and waste of resources, and improve the ecological efficiency of agricultural production [28]. Based on this, hypothesis 5 is proposed:

H5: *The improvement of land circulation can strengthen the promotion effect of HFC on AEE.*

In summary, based on the above theoretical assumptions, the research route is illustrated in Figure 2.

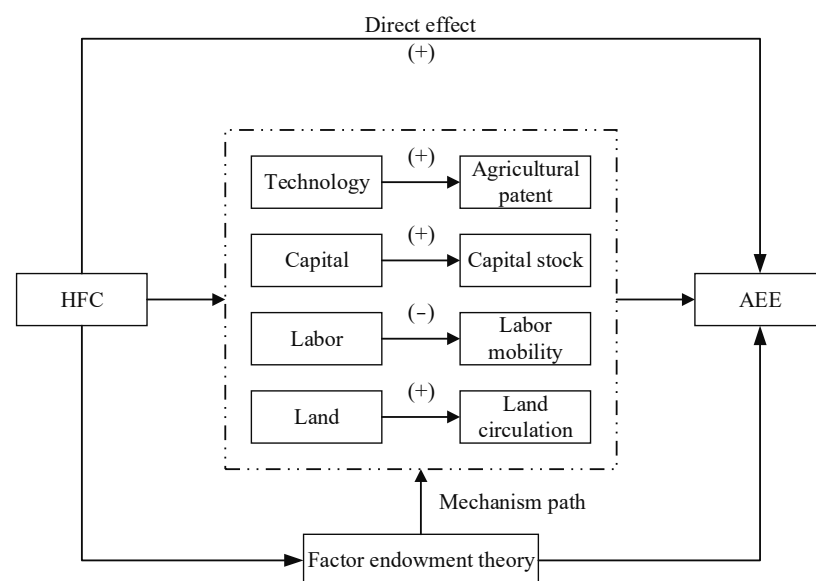


Figure 2. Theoretical framework.

3. Research Design

3.1. Data Selection

3.1.1. Explanatory Variables

High-standard farmland construction (HFC). Existing studies on the measurement of HFC can be divided into two categories: one is to directly adopt the ratio of HFC area to cultivated land area or the ratio of investment in comprehensive agricultural development to cultivated land area as an explanatory variable [48]. The other type is indirect from the perspective of policy implementation, using the DID model to study HFC data as policy variables [28,49]. According to the regression model set above, the ratio of agricultural comprehensive development investment to cultivated land area is selected as the explanatory variable, and the ratio of HFC area to cultivated land area is selected as the substitute variable for the robustness test. The measurement results of HFC are shown in Figure 3. From 2005 to 2022, HFC shows a steady upward trend.

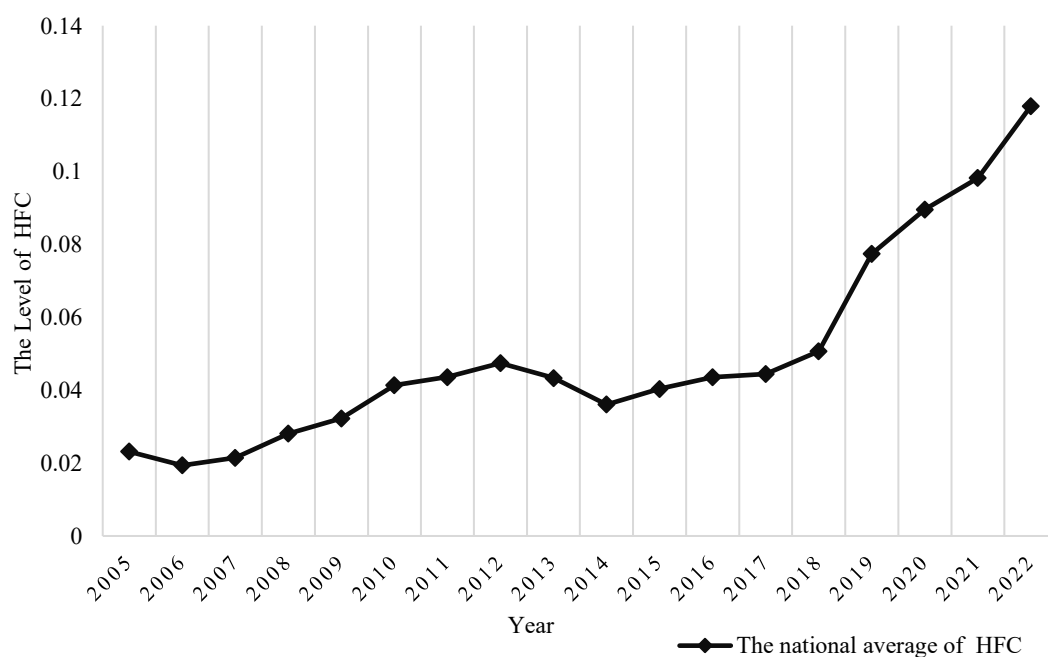


Figure 3. The national average development level of HFC. Note: The national average development level of HFC is ascertained by computing the annual mean values across the 30 provinces in China.

3.1.2. Explained Variables

Agroecological efficiency (AEE). AEE is an important index to evaluate the sustainable development ability of agriculture. It covers both ecological and economic efficiency, aiming to produce more quantity and higher quality agricultural products or services with fewer natural resources in the process of agricultural production while having the least negative impact on the environment and agricultural consumption [8]. Specifically, the measure of AEE is as follows:

- (1) Assumption of returns to scale. Because of the regional differences in China's agricultural development, there are significant differences in the stages of agricultural development in different provinces, which are manifested by diminishing, constant, or increasing returns to scale [50]. To more accurately measure the level of AEE, this study chooses the variable return to scale (VRS) method for in-depth analysis. The specific reasons are first, more accurate efficiency evaluation. The VRS model allows different decision units (DMU) to differ in terms of returns to scale, which makes the evaluation results more accurate and closer to the actual situation. In agricultural production, changes in returns to scale are common because agricultural production is often affected by land, climate, technology, and other factors, and changes in these

factors may lead to changes in returns to scale. Second, flexibility and adaptability. The VRS model provides more flexibility because it allows the model to adjust its returns to scale assumptions to the specific circumstances of each DMU. This adaptation is particularly important for agricultural production, as agricultural systems often face changing natural conditions and operating environments.

- (2) Measure model. In academic circles, the super-efficient SBM-DEA model with unexpected output has been widely used because of its scientificity and practicability. This model is also selected as a tool to measure AEE in this study.
- (3) The index system. Referring to the existing studies [8,51,52], this study constructed an index system including the input index of “labor, mechanical power, chemistry, irrigation, land, energy, and waste resource utilization”, the expected output index of “economic output and ecological output”, and the non-expected output index of “agricultural non-point source pollution and agricultural carbon emission”. These indicators together constitute a comprehensive index system for measuring AEE. See Table 1 for specific indicators. Different from most studies, this study especially included waste recycling as one of the input indicators, which not only helps to improve the rural environment but also realizes the recycling of resources and promotes the sustainable development of agriculture by using the waste from the biogas digester as a pesticide additive and fertilizer.

Table 1. Index system of AEE ¹.

Primary Index	Secondary Index	Three-Level Index	Units	Author Accounting note
Input index	Labor force	Employment in agriculture	Thousands of people	Ecological-economic × agricultural production workers/animal husbandry fishery production
	Mechanical power	Total power of agricultural machinery	Megawatt	/
	Chemistry	Fertilizer application amount, pesticide application amount, and agricultural film application amount after folding	Ten thousand tons	Synthesis by entropy weight method
	Irrigation	Effective irrigated area	khm ²	/
	Land	Cultivated area	khm ²	Crop sown area
Expected output	Energy	Agricultural diesel use	Ten thousand tons	/
	Recycling of waste	Biogas project	Million cubic meters	/
Expected output	Economic	Gross agricultural output value	Hundred million yuan	Based on 2005, excluding the interference of price factors
	Ecology	Agricultural carbon sink	Ten thousand tons	Carbon sink coefficient synthesis
Unexpected output	Agricultural non-point source pollution	Fertilizer loss, ineffective use of pesticides, residual amount of agricultural film	Ten thousand tons	Loss coefficient and residual factor synthesis
	Agricultural carbon emission	Agricultural carbon emission	Ten thousand tons	Carbon emission coefficient synthesis

¹ All indicators are calculated by the authors themselves.

Figures 4 and 5 clearly show the evolution of AEE in 30 provinces of China in 2005 and 2022. As can be seen from the figure, the distribution of AEE presents significant regional differences. Specifically, during this period, the AEE value of the Beijing area is always

at a high level, showing its excellent performance in agricultural production practices and efficient resource utilization. At the same time, although Shanghai and Qinghai have experienced a declining trend of AEE, their AEE development level is still in the leading position compared with other provinces in China, which is consistent with the study of Deng and Chao (2022) [53]. Except for the above regions, the AEE of most provinces is at a medium level. This shows that although the AEE in these regions has made some progress, there is still a large room for improvement. Their development is generally positive, but there is still a need to further optimize agricultural practices, improve the efficiency of resource use, and make agriculture more sustainable and environmentally friendly.

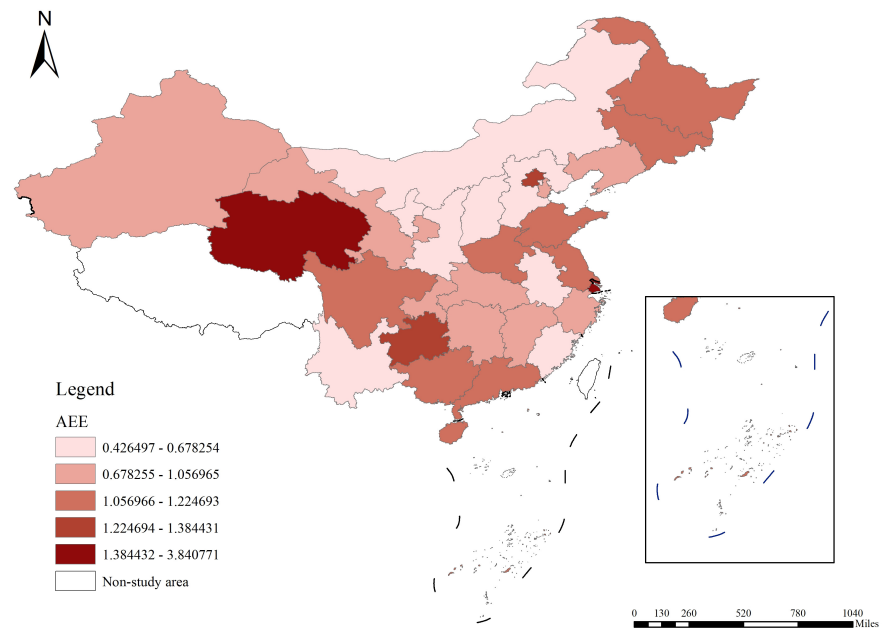


Figure 4. AEE level in 2005. Note: The data are from the National Geographic Information Public Service Platform (<https://www.tianditu.gov.cn/> (accessed on 31 July 2024)), and the audit number is GS (2024) 0650. Due to space limitations, the development level of agroecological efficiency in China is only shown in 2005 and 2022. Figure 5 is the same as Figure 4.

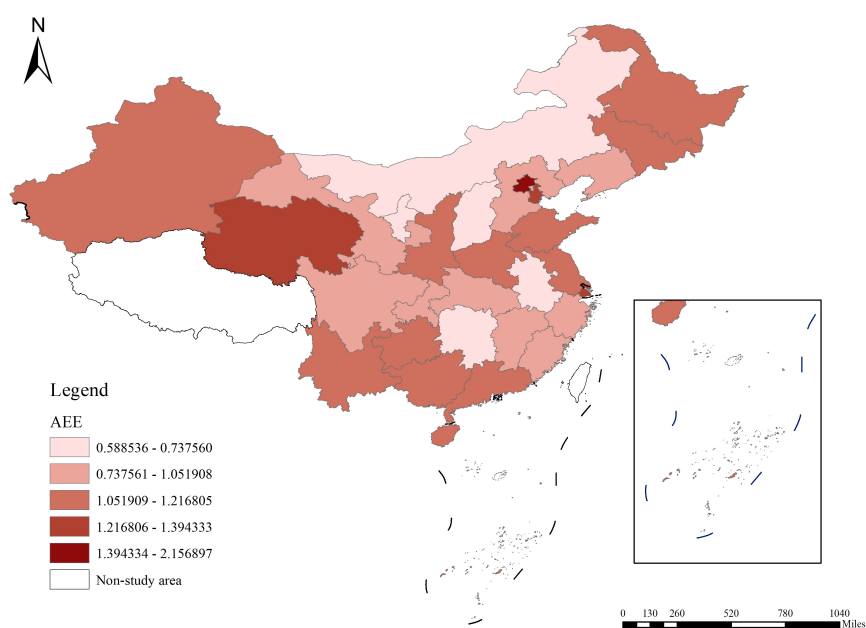


Figure 5. AEE level in 2022.

3.1.3. Moderating Variables

According to the factor endowment theory, different countries or regions have differences in the endowment of production factors, which will affect their comparative advantages in economic activities [54]. Only when the agricultural policy is consistent with the local production factor structure can the local endowment advantages be effectively utilized and the redundancy of factor input be avoided. Therefore, from the four perspectives of technology, capital, labor, and land, the mechanism of HFC on AEE is explored. The variables are measured as follows:

- (1) Agricultural technology innovation. Technology is one of the core driving forces for the development of modern agriculture. This study refers to the measurement method proposed by Cao and Wang (2024) [55] and selects the number of agricultural patent applications to measure agricultural technological innovation. The research data are processed as follows: First, the patents related to agriculture are selected by the National Patent Classification (IPC) system through the State Intellectual Property Office of China. Secondly, the patent data are divided into three types: total agricultural patent applications (TAP), agricultural invention patent applications (IAP) and new agricultural patent applications (NAP). Finally, the three types of data are sorted into each province for follow-up research. Data unit: thousand.
- (2) Agricultural capital stock. Agricultural capital is the important basis of agricultural production and management activities, which plays a vital role in improving agricultural production efficiency and sustainable development. Fixed capital input is one of the key indicators to measure the actual agricultural production capacity, which includes not only tangible assets such as land, buildings, machinery, and equipment but also the accumulation of intangible assets such as technology and knowledge [56]. The investment of fixed capital can provide the necessary material and technical support for agricultural production to enhance the ability to resist risks and the market competitiveness of agriculture. Therefore, based on fully considering capital depreciation, the study chooses the perpetual inventory method to measure agricultural capital (CAP) [57].

$$\begin{cases} K_{i,t} = K_{i,t-1} + \frac{I_{i,t}}{P_{i,t}} - D_{i,t} \\ D_{i,t} = \delta_t K_{i,t-1} \end{cases} \Rightarrow K_{i,t} = K_{i,t-1}(1 - \delta_t) + \frac{I_{i,t}}{P_{i,t}} \quad (1)$$

Among them, $K_{i,t}$ and $K_{i,t-1}$ represent the agricultural capital stock of the current period and the agricultural capital stock of the previous period, respectively, and choose the agricultural fixed asset investment of the current year divided by the asset investment price index; I_t represents the current asset investment, and the fixed investment in agriculture, forestry, animal husbandry, and fishery are chosen. δ represents the depreciation rate of each year, and 5.42% is chosen for calculation. $P_{i,t}$ is the asset investment price index, and the production price index of agricultural products is chosen for the study [38].

- (3) Labor mobility. In the measurement methods of existing studies [44,58,59], the ratio of labor migration to the total outbound labor force is selected as the substitute variable of labor flow. According to the scope of migration, the labor migration is divided into three parts: the labor migration from outside the township and within the county (OTWC), the labor migration from outside the county and within the province (OCWP), and the labor migration from outside the province (OP).
- (4) Land circulation. Land is the basic means of production for agriculture and provides space for growing crops. Regarding the measurement method proposed by Zhang et al. (2024) [60], the proportion of rural household contracted arable land transfer area in total contracted arable land management area is selected as the substitute variable of land circulation (LAN).

3.1.4. Control Variables

Concerning existing studies [8,29,48], the measurement methods and units of control variables in this study are shown in Table 2. The reasons for its selection are as follows: (1) Labor force level (LF), which is one of the indispensable basic elements of economic activities, and the change of its scale directly affects the level of regional economic development and other socio-economic indicators. (2) Industrialization level (IND), a higher level of industrialization usually means more advanced production technology and higher labor productivity. (3) Information level (INF). With the development of information technology, information level plays an important role in improving production efficiency and service quality. (4) Rural household income (IRH). Changes in the income level of rural residents may affect the choice of agricultural production mode and the investment decisions of farmers. (5) Agricultural disaster rate (ADR), natural disasters not only cause direct losses to agricultural production but also affect the income level of farmers.

Table 2. Control variables information.

Variable	Code	Definition	Unit
Labor force level	LF	Logarithmized number of employed persons	Thousands of people
Industrialization level	IND	The ratio of industrial production to GDP	/
Informatization level	INF	The ratio of the total volume of post and telecommunications services to GDP	/
Rural household income	IRH	Per capita disposable income of rural residents	Ten thousand yuan/person
Agricultural disaster rate	ADR	The ratio of crop damage area to sown area	/

3.1.5. Descriptive Analysis

Due to the serious lack of data in Tibet, Hong Kong, Macao, and Taiwan, 30 provinces in China from 2005 to 2022 are selected as research samples. The research data mainly come from relevant statistical materials and annual reports such as the China Statistical Yearbook, China Rural Statistical Yearbook, China Grain Yearbook, and China Fiscal Yearbook. In addition, the missing parts of HFC data are manually collected and collated from provincial government website documents and letters. Agricultural patent data comes from the State Intellectual Property Office and is manually sorted by the author. The descriptive statistics of variables are shown in Table 3.

Table 3. Descriptive statistics.

Variable	Number	Mean	SD	Min	Median	Max
HFC	540	0.0499	0.109	0.00	0.02	1.19
AEE	540	1.0308	0.424	0.41	1.05	3.84
AEE – EC	540	1.0235	0.372	0.28	1.00	5.43
AEE – TC	540	1.5265	2.009	0.68	1.07	18.95
LF	540	7.5782	0.786	5.55	7.65	8.86
IND	540	0.3378	0.086	0.10	0.35	0.56
INF	540	0.0695	0.115	0.01	0.05	2.51
IRH	540	1.0881	0.688	0.19	0.98	3.97
ADR	540	0.1859	0.145	0.00	0.15	0.94
TAP	540	2.0183	2.663	0.01	1.02	14.67
IAP	540	0.8771	1.269	0.00	0.43	8.13
NAP	540	1.1412	1.586	0.00	0.51	10.55
CAP	540	2.8251	3.678	0.01	1.24	21.63
OTWC	540	0.1143	0.128	0.02	0.11	2.92
OCWP	540	0.0970	0.144	0.02	0.09	3.35
OP	540	0.1095	0.268	0.00	0.07	6.05
LAN	540	25.1959	18.523	0.86	21.78	91.11

3.2. Research Models

In order to explore the direct impact of HFC on AEE, the research's baseline model is set as follows:

$$AEE_{it} = \alpha_0 + \alpha_1 HFC_{it} + \alpha_2 Controls_{it} + \mu_{it} + u_{it} + \varepsilon_{it} \quad (2)$$

In the Formula (2), AEE_{it} is the level of AEE of province i in period t ; HFC_{it} is the HFC level of province i in period t ; $Controls_{it}$ represents all the control variables used in the study, which are labor force level (LF), industrialization level (INDIND), informatization level (INF), per capita disposable income of rural residents (IRH) and agricultural disaster rate (ADR). μ_{it} and u_{it} are regional effect and time effect, respectively. ε_{it} is the random error term. α_i ($i = 0, 1, 2$) is the variable coefficient.

Further, based on assumptions 2–5 above, starting from the factor endowment theory, this study explores the regulating role of factor endowments such as technology, capital, labor, and land as moderating variables (MEC) in HFC. The moderating effect model is set as follows:

$$AEE_{it} = \beta_0 + \beta_1 HFC_{it} + \beta_2 MEC_{it} + \beta_3 HFC_{it} \times MEC_{it} + \beta_3 Controls_{it} + \mu_{it} + u_{it} + \varepsilon_{it} \quad (3)$$

Different from Formula (2), Formula (3) is based on the addition of moderating variable (MEC), and the interaction term between explaining variable (HFC) and moderating variable (MEC) which carries out the mechanism test. Among them, MEC is the moderating variable in the model, representing agricultural technological innovation (TEC), agricultural capital stock (CAP), labor mobility (LAB) and land circulation (LAN). β_i ($i = 0, 1, 2, 3$) is the variable coefficient.

4. Result Analysis

4.1. Baseline Regression Results

In the regression analysis of the baseline model, the research first investigates the regression results when only control variables are introduced without introducing fixed effects of time and region, as shown in columns (1) and (2) of Table 4. The results show that the regression coefficient of HFC (HFC) is significantly positive, which indicates that HFC has a positive impact on the improvement of AEE. To improve the accuracy and reliability of the study, regional fixed effects and time-fixed effects are gradually incorporated into the model to more accurately capture the potential impact of these variables on the study results. Columns (3), (4), and (5) of Table 4 respectively show the regression results of fixed time only, fixed region only, and fixed time and region at the same time. It is found that the regression coefficient of HFC is still significantly positive, which further validates the important role of HFC in promoting the development of AEE. It is worth noting that with the gradual introduction of control variables, the coefficient size of HFC remains relatively stable, which indicates that the research results have high robustness. This is also consistent with the study of Li et al. (2024) [18]. Hypothesis 1 is proved.

Table 4. Baseline regression results.

	<i>AEE</i> (1)	<i>AEE</i> (2)	<i>AEE</i> (3)	<i>AEE</i> (4)	<i>AEE</i> (5)
<i>HFC</i>	1.6575 *** (0.1511)	1.4326 *** (0.1811)	0.7817 *** (0.2014)	0.3242 ** (0.1616)	0.3501 * (0.1815)
Control variables	No	Yes	Yes	Yes	Yes
Year	No	No	Yes	No	Yes
Region	No	No	No	Yes	Yes
<i>N</i>	540	540	540	540	540

Note: Standard errors in parentheses; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. The same as below.

4.2. Robustness Test

To further verify the robustness of the previous baseline regression results, the following four methods are adopted for verification:

First, the control variable lags one stage. Referring to the research method of Wang et al. (2023) [61], the one-stage lag method of control variables is selected for the robustness test, which can effectively reduce the endogeneity problem in model estimation. The test results are shown in column (1) of Table 5. The influence coefficient of HFC on AEE is still significantly positive at the level of 10%, and the baseline regression results are robust.

Table 5. Robustness test results.

	<i>AEE</i> The Control Variable Lags One Stage (1)	<i>AEE</i> Replace Explanatory Variable (2)	<i>AEE</i> Replace the Model (3)	<i>AEE</i> Add Control Variable (4)
<i>I.AEE</i>			0.7991 *** (0.0705)	
<i>HFC</i>	0.3083 * (0.1738)		0.2650 ** (0.1800)	0.3421 * (0.1764)
<i>HFC'</i>		0.1993 * (0.1191)		
Control variables	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
Region	Yes	Yes	Yes	Yes
AR(1)			0.053	
AR(2)			0.337	
Hansen			0.405	
<i>N</i>	510	540	510	540

Note: Standard errors in parentheses; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. The same as below.

Second, replace the explanatory variable. To enhance the reliability and robustness of the study, the measurement method of HFC is changed, and the ratio of HFC area to cultivated land area is now used as an alternative explanatory variable for supplementary analysis. The test results are shown in column (2) of Table 5. The influence coefficient of HFC area on AEE is significantly positive at the level of 10%. This once again verifies that HFC has a positive effect on improving AEE.

Third, replace the model. Considering the estimation bias and endogeneity problems that may be encountered in the traditional fixed-effect regression model, the System GMM regression model is used as the replacement model [62], and the test results are shown in column (3) of Table 5. The influence coefficient of HFC area on AEE is still significantly positive at 5%, indicating that the baseline regression results are robust.

Fourth, add a control variable. By adding other possible control variables to the model, it is possible to check whether the coefficients of the core explanatory variables remain significant. If the coefficients and significance of the core explanatory variables do not change significantly after the addition of the control variables, this increases the confidence of the model results. The government's financial expenditure is the key factor in promoting the development of HFC, which can not only provide the necessary material basis for agriculture but also promote the significant improvement of AEE. The ratio of the government's general budget expenditure to the gross regional product is used as a measure to quantify the government's agricultural support and is included in the baseline regression model. The regression results are shown in column (4) of Table 5. HFC has a significant positive impact on AEE, and its impact coefficient is significant at the significance level of 10%. The size of the influence coefficient has no significant change compared with the baseline regression result, which once again verifies the robustness of the regression results.

4.3. Endogeneity Analysis

Considering the possible endogeneity problem of the model, referring to the existing literature [63], the two methods of DID estimation and weak endogenous subsample are selected in this study to correct the biased estimation caused by endogeneity.

4.3.1. Exogenous Impact—High Standard Farmland Construction Policy

As one of the important strategies of China's agricultural development, the formal implementation of HFC can be traced back to 2011. In the same year, the Chinese government issued the National Land Improvement Plan (2011–2015), marking the full start of HFC. The plan not only provides clear guidelines for farmland construction but also lays a solid foundation for the sustainable development of China's agriculture. To further study the effect of this policy on AEE, a continuous DID model is used to analyze the effect. The continuous DID model is set as follows:

$$AEE_{it} = \alpha_0 + \alpha_1 HFC_{it} * Post_{it} + \alpha_2 Controls_{it} + \mu_{it} + u_{it} + \varepsilon_{it} \quad (4)$$

Taking 2011 as the policy time point, the interaction term ($HFC * Post$) between the investment amount of agricultural comprehensive development per unit area and the virtual variable at the policy implementation time point is constructed. When $t > 2010$, $Post_{it}$ is 1; otherwise, the value is 0.

The regression results are shown in column (1) of Table 6. The influence coefficient of HFC policy on AEE is 0.3434 and is significantly positive at the level of 10%, which is consistent with the baseline regression result, indicating that HFC can indeed promote the development of AEE in China. Given the absence of a control group and experimental group in the continuous DID model, three years before and after the policy intervention are selected as the time window for existing studies [64], and flexible estimation is adopted for testing. The results are shown in column (2) of Table 6: Before the implementation of the policy, the influence coefficient of HFC on AEE was negative and not significant. However, after the implementation of the policy, the influence coefficient of HFC on AEE is positive and significant, which fully indicates that the policy has a positive impact on AEE.

Table 6. Endogenetic analysis.

	<i>AEE</i> <i>DID</i> (1)	<i>AEE</i> Flexible Estimation (2)	<i>AEE</i> Weak Endogenous Subsample (3)
<i>HFC</i>			0.1820 * (0.1030)
<i>HFC * Post</i>	0.3434 * (0.1753)		
<i>Pre_3</i>		−2.1124 (0.9971)	
<i>Pre_2</i>		−1.6770 (1.1688)	
<i>Current</i>		1.8929 ** (0.7402)	
<i>Post_1</i>		1.9680 *** (0.6596)	
<i>Post_2</i>		2.2778 *** (0.8188)	
<i>Post_3</i>		2.0733 ** (0.9407)	
Control variables	Yes	Yes	Yes
Year	Yes	Yes	Yes
Region	Yes	Yes	Yes
<i>N</i>	540	540	270

Note: Standard errors in parentheses; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. The same as below.

4.3.2. Weak Endogenous Subsample

By dividing the median AEE, the sample is divided into two sub-samples: high AEE and low AEE, and the low AEE is selected as the weak endogenous sample for the regression test. The rationality of this approach lies in the fact that areas with high AEE may be affected by multiple positive factors, which may not be fully considered, thus introducing the endogeneity problem. Areas with low AEE are also affected by multiple factors, but these factors may not have significant impacts on AEE [65]. Therefore, the selection of this subsample can more accurately identify the impact of HFC on AEE. The regression results are shown in column (3) of Table 6. The impact coefficient of HFC on AEE is significant at the significance level of 10%; that is, when only the sub-samples with low AEE are considered, the positive impact of HFC on AEE is significant.

4.4. Heterogeneity Analysis

To further clarify the effects of HFC on AEE, the heterogeneity effects of different regions, grain functional areas, topographic conditions, and quantile regression are discussed. This not only enriches the understanding of the effects of HFC but also provides a more refined perspective for policy making.

4.4.1. Heterogeneity of Geographical Regions

Due to the significant differences in economic development level and soil type in different regions, the effect of HFC may be affected to different degrees [29]. Therefore, the samples are divided into three regions: east, middle, and west to explore their different performances. The results are shown in columns (1)–(3) of Table 7. The HFC in the eastern region has the most significant effect on the improvement of AEE, and its impact coefficient is significantly positive at the level of 1%. On the one hand, because the eastern region has a higher level of economic development and advanced technology, it is easier to promote high-quality development of the agricultural economy. On the other hand, the eastern region is mainly plain, and HFC can play its economic utility. In contrast, the impact of central and western regions is not significant or the effect is poor, which reflects the special challenges and constraints faced by the central and western regions in the implementation of HFC, such as the complex terrain in the western region, mainly hills and mountains, high renovation costs, the existing financial investment and construction transformation, and upgrading, which are far from reaching the threshold of “high standard”. As a result, the improvement effect of yield and ecological efficiency is limited.

Table 7. Heterogeneity analysis.

	<i>AEE East (1)</i>	<i>AEE Middle (2)</i>	<i>AEE West (3)</i>	<i>AEE PA (4)</i>	<i>AEE SA (5)</i>	<i>AEE PSA (6)</i>	<i>AEE FLU>1 (7)</i>	<i>AEE FLU≤1 (8)</i>
<i>HFC</i>	0.5910 *** (0.1853)	0.0292 (0.8584)	−8.1350 *** (2.3500)	0.2780 * (0.4358)	0.6402 *** (0.2370)	−8.6743 *** (2.2015)	−7.7724 *** (2.1336)	0.5512 *** (0.1598)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Region	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
<i>N</i>	216	162	162	234	126	180	198	342

Note: Standard errors in parentheses; * $p < 0.10$, *** $p < 0.01$. The same as below. *FLU* is divided into the following criteria: First, prerequisites. The altitude of 500 m is regarded as the benchmark mountain height in China. Second, the basis for division. When the relief degree is several times of 1, it indicates the height of several reference mountains, and when the relief degree is less than 1, it indicates the relief of less than one reference mountain. So let us divide *FLU* into greater than 1 or less than 1.

4.4.2. Heterogeneity of Grain Functional Areas

According to their own agricultural characteristics and geographical conditions, various provinces in China have formed different grain function regions, such as main grain-

producing areas, main sales areas, and production and sales balance areas [28]. The different agricultural function positioning in these regions determines that there may be significant differences in the mechanism and effect of HFC. Therefore, according to the different characteristics of agricultural functions in each province, the study divided the sample areas into three categories: the main grain-producing area (*PA*), the main grain sales area (*SA*) and the grain production and sales balance area (*PSA*) and conducted a regression analysis, respectively. Specific regression results are shown in Table 7 (4) to (6). In major grain-producing areas, the construction of HFC has a significant effect on the improvement of AEE, and its influence coefficient is significantly positive at the level of 10%. This indicates that in areas where grain production is the main function, HFC can effectively promote the improvement of AEE. In contrast, the HFC in the main grain sales areas has a more significant impact on AEE, and its impact coefficient is significantly positive at 1%. This result reflects the strong demand for efficient eco-agricultural technologies in the main grain sales regions and the positive role of high-standard farmland in meeting this demand. However, in the grain production and sales balance area, the impact of HFC presents a negative effect, and the impact coefficient is significantly negative at a 1% level. On the one hand, due to the poor natural conditions, fine cultivated land, and large altitude difference in these regions, the existing investment intensity and transformation of HFC are not enough, and the infrastructure has not been effectively changed and the soil fertility conditions have not been improved, making HFC unable to play a role in promoting AEE. On the other hand, it also shows that promoting HFC in areas with congenital insufficient agricultural development conditions, such as hills and mountains, has a limited impact on agriculture. In these areas, we should consider promoting other ways of agricultural technological progress to achieve high-quality and sustainable agricultural development according to local conditions.

4.4.3. Heterogeneity of Terrain Conditions

As mentioned above, topographic conditions may affect the positive effect of HFC on AEE [66]. In order to further explore how terrain conditions affect the effects of HFC on agroecological efficiency, the study refers to the measurement method proposed by Bai and Zhang (2021) [67], selects Arc/Info software to analyze the altitude of provinces, calculates the absolute and relative fluctuation, and obtains the final geographical fluctuation (*FLU*). Specifically, according to geographical fluctuation, the samples are divided into two categories: large fluctuation ($FLU > 1$) and small fluctuation ($FLU \leq 1$), in order to test whether there are differences between HFC and AEE under different terrain conditions. The results are shown in columns (7) and (8) of Table 7. In areas with large geographic fluctuation, HFC inhibited the development of AEE, which may be because, in areas with rugged terrain, the implementation of HFC is faced with more technical challenges, such as increased risk in soil erosion and difficulty in irrigation system construction. These challenges not only increase construction costs but may also diminish the potential benefits of HFC. In the regions with small geographic fluctuation, the construction of HFC promotes the development of AEE, and the flat or gentle slope terrain helps to implement modern agricultural measures such as irrigation and fertilization more effectively, thus improving crop yield and resource utilization efficiency. In addition, good topographic conditions also help to reduce the management costs of maintaining high-standard farmland and further improve the AEE. This is consistent with the study of Qian et al. (2024) [29].

4.4.4. Quantile Regression

Quantile regression can capture conditional effects of dependent variables at different levels by estimating quantiles of conditional distributions to more accurately reflect the nonlinear relationship between variables [68]. The advantage of this approach is that it provides the distribution of the dependent variables under different conditions rather than just focusing on the mean change. Therefore, four key quantiles of 0.2, 0.4, 0.6, and 0.8 are selected to investigate the potential effects of HFC on AEE. The results are shown in

Table 8. At the lower quantiles (i.e., 0.2 and 0.4), the positive impact of HFC on AEE not only exists obviously but also is statistically significant, which indicates that in areas with low eco-efficiency, HFC can produce a significant improvement effect. However, at the higher quantiles (0.6 and 0.8), although HFC also shows a positive effect, this effect does not reach statistical significance, indicating that the marginal benefits brought by HFC are relatively limited in those regions that already have high ecological efficiency.

Table 8. Quantile regression.

	<i>AEE</i> P15 (1)	<i>AEE</i> P20 (2)	<i>AEE</i> P25 (3)	<i>AEE</i> P30 (4)	<i>AEE</i> P35 (5)	<i>AEE</i> P40 (6)	<i>AEE</i> P45 (7)	<i>AEE</i> P60 (8)	<i>AEE</i> P80 (9)
<i>HFC</i>	0.1695 ** (0.0669)	0.1816 *** (0.0607)	0.1934 *** (0.0731)	0.1960 ** (0.0767)	0.1389 ** (0.0694)	0.1281 ** (0.0615)	0.0845 (0.0835)	0.0178 (0.1172)	0.0468 (0.2353)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Region	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
<i>N</i>	540	540	540	540	540	540	540	540	540

Note: Standard errors in parentheses; ** $p < 0.05$, *** $p < 0.01$. The same as below. P is a percentage, representing different quantile levels, such as P15, representing a 15% quantile level.

Further, to understand this phenomenon more deeply, we focus on the decimal points around 0.2 and 0.4. Through detailed regression analysis, the study finds that the influence coefficient of HFC on AEE showed a trend of “first increasing and then decreasing”. This finding reveals that in the process of promoting AEE, the marginal utility of HFC does not increase linearly, but there is an optimal interval. Within this range, HFC can most effectively promote the improvement of AEE, but its marginal utility gradually weakens when it exceeds this range. This result has important implications for the government, which emphasizes that the current ecological efficiency level of the region should be considered when planning HFC projects to ensure the effective allocation of resources and maximize benefits. At the same time, it also suggests that HFC can be used as a powerful policy tool for ecologically inefficient areas, while for regions that have reached high ecologically efficient levels, more diversified strategies need to be explored to promote sustainable agricultural development.

4.5. Adjustment Effect Test

4.5.1. Agricultural Technology Innovation

The total number of agricultural patent applications, the number of agricultural invention patent applications, and the number of new agricultural patent applications are respectively used to characterize agricultural technological innovation, and they are included in the model (2) as a moderating variable for testing. The test results are shown in columns (1)–(3) of Table 9. Specifically, the interaction coefficient ($HFC * TAP$) between the total number of agricultural patent applications and HFC is 0.2801, which is positive at the significance level of 1%. The interaction term coefficient ($HFC * IAP$) between the number of agricultural invention patent applications and HFC and the interaction term coefficient ($HFC * NAP$) between the number of new agricultural patent applications and HFC are 0.7749 and 0.3197, respectively, which are significantly positive at the significance level of 5%. The results verify the optimization of agricultural technology and helped to play the role of HFC in promoting AEE. By comparing the interaction coefficient of the two types of patents, it is found that compared with the innovation of the new type of agricultural patent, the agricultural invention patent shows a stronger ability to promote ecological efficiency because of its higher technical threshold and more far-reaching innovation value. In summary, the research results are consistent with the findings of Cao and Wang (2024) [55], that is, the improvement of agricultural technological innovation, especially the

contribution of agricultural invention patents, has an important strengthening effect on the improvement of AEE in HFC. Hypothesis 2 is proved.

Table 9. Technology and Capital.

	<i>AEE</i> (1)	<i>AEE</i> (2)	<i>AEE</i> (3)	<i>AEE</i> (4)
<i>HFC</i>	0.1513 (0.2371)	0.2708 (0.2275)	0.0334 (0.2362)	1.4025 *** (0.3297)
<i>HFC * TAP</i>	0.2801 *** (0.0883)			
<i>TAP</i>	−0.0017 (0.0092)			
<i>HFC * IAP</i>		0.7749 *** (0.1855)		
<i>IAP</i>		0.0025 (0.0163)		
<i>HFC * NAP</i>			0.3197 ** (0.1543)	
<i>NAP</i>			0.0007 (0.0154)	
<i>HFC * CAP</i>				0.4306 *** (0.1212)
<i>CAP</i>				0.0380 *** (0.0089)
Control variables	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
Region	Yes	Yes	Yes	Yes
<i>N</i>	510	540	510	540

Note: Standard errors in parentheses; ** $p < 0.05$, *** $p < 0.01$. The same as below.

4.5.2. Agricultural Capital Stock

The adjustment effect of agricultural capital accumulation is tested, and the results are shown in column (4) of Table 9. Specifically, the interaction term coefficient (*HFC * CAP*) between agricultural capital stock and HFC is positive at the significance level of 1%. This shows that when agricultural capital accumulation increases, it can effectively strengthen the promotion role of HFC on AEE, indicating the important role of capital input in the process of modern agricultural transformation. This not only reveals that capital accumulation is an integral part of the transformation of modern agriculture but also highlights its key role in enhancing agricultural infrastructure, fostering technological innovation, and increasing overall agricultural productivity. The research results are consistent with the findings of Chen and Peng (2024) [28]. Hypothesis 3 is proved.

4.5.3. Labor Mobility

Columns (1)–(3) of Table 10 show the moderating effect of labor mobility. Specifically, The coefficients of the interaction term between the labor migration from outside the township and within the county the labor migration from outside the township and within the county and HFC (*HFC * OTWC*), the interaction term coefficient between the labor migration from outside the county and within the province the labor migration from outside the county and within the province and HFC (*HFC * OCWP*), and the interaction term coefficient between the labor migration from outside the province and HFC (*HFC * OP*) are all in the significance water of 1%. This indicates that the increase in labor out-migration weakens the positive impact of HFC on AEE. The possible reason is that with the advancement of urbanization, more rural workers choose to go out to work to make ends meet. However, the flow of rural population, especially the cross-regional flow (such as outside the county or province), reduces the local area and then leads to the abandonment of arable land, which is unfavorable to the development of HFC. HFC usually

requires certain human resources for maintenance and management, and the reduction of labor force reduces the management level of these farmlands, thus weakening the positive impact of HFC on AEE [69]. Hypothesis 4 is proved.

Table 10. Labor and Land.

	AEE (1)	AEE (2)	AEE (3)	AEE (4)
HFC	1.3738 *** (0.2628)	0.3435 * (0.1785)	−1.5317 ** (0.7007)	1.3796 *** (0.5239)
HFC * OTWC	−16.1161 *** (2.9485)			
OTWC	−0.4194 *** (0.1228)			
HFC * OCWP		−29.1912 *** (6.5282)		
OCWP		−0.7826 *** (0.1959)		
HFC * OP			−19.0719 *** (7.0115)	
OP			−0.5173 *** (0.1973)	
HFC * LAN				0.0203 ** (0.0092)
LAN				0.0014 (0.0023)
Control variables	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
Region	Yes	Yes	Yes	Yes
N	510	540	510	540

Note: Standard errors in parentheses; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. The same as below.

4.5.4. Land Circulation

Column (4) of Table 10 shows the regulatory effects of land circulation. Specifically, the interaction term coefficient ($HFC * LAN$) between land circulation and HFC is positive at the significance level of 5%. This finding means that the optimization of land circulation, as an important means of resource allocation, can effectively promote the implementation effect of HFC on AEE. The possible reason is that land circulation enhances the efficiency and sustainability of agricultural production by promoting the concentration and scale management of land resources. This trend of concentration helps to overcome the inherent limitations of small-scale agricultural production in resource allocation and production scale and provides a more solid foundation for HFC [23]. Therefore, the strengthening of land circulation enables agricultural producers to make more effective use of land resources and realizes the significant improvement of HFC on the AEE. Hypothesis 5 proved.

4.6. Extended Analysis

From the decomposition of AEE, the increase in AEE is equal to the product of changes in agricultural technical efficiency and changes in agricultural technological progress [70]. In the AEE accounting system, agricultural technological progress is defined as the evolution of the production frontier, usually through the introduction of innovative agricultural technologies and ideas, resulting in significant improvements in agricultural production levels. On the other hand, the efficiency of agricultural technology is reflected in the adoption and imitation of existing agricultural technology to improve the efficiency of technology application, thereby increasing agricultural output and bringing the agricultural production process closer to the optimal production frontier [70]. Therefore, the problem of promoting AEE by HFC, whether the mechanism behind it is to optimize agricultural

technical efficiency or promote agricultural technological progress, or the two “dual-track promotions” remains to be further studied.

To further explore this issue, agricultural technical efficiency ($AEE - EC$) and agricultural technical progress ($AEE - TC$) are respectively taken as dependent variables to analyze the impact of the policy of HFC. The regression results are shown in Table 9. The influence coefficients of HFC on agricultural technical efficiency and agricultural technical progress are both positive and pass the significance test. This indicates that HFC can not only directly improve the efficiency of agricultural production but also stimulate technological innovation and promote the progress of agricultural technology. There are two possible explanations: First, HFC is a process of improving land factor quality in various ways. When the input quantity of other factors remains unchanged, agricultural technical efficiency will continue to improve with the improvement of land factor quality. Second, HFC effectively connects small farmers with agricultural mechanization through centralized contiguous management and improving agricultural disaster resistance. This connection will not only improve agricultural technical efficiency but also promote the promotion and application of new agricultural technologies and thus improve the level of agricultural technological progress. By comparing the influence coefficients of agricultural technical efficiency ($AEE - EC$) and agricultural technical progress ($AEE - TC$) in Table 11, it is found that the influence coefficient of HFC on agricultural technical progress is greater than that on agricultural technical efficiency; that is, the improvement path of AEE in China at this stage mainly depends on agricultural technical progress.

Table 11. EC and TC.

	<i>AEE-EC</i> (1)	<i>AEE-TC</i> (2)
<i>HFC</i>	0.3243 * (0.1879)	0.7813 ** (0.3857)
Control variables	Yes	Yes
Year	Yes	Yes
Region	Yes	Yes
<i>N</i>	540	540

Note: Standard errors in parentheses; * $p < 0.10$, ** $p < 0.05$. The same as below.

5. Discussion

AEE is regarded as an important indicator of agricultural economic benefit, ecological benefit, and development quality. Among the factors influencing AEE, policy measures receive significant scholarly attention. Enhancing cultivated land quality is central to achieving high-quality agricultural development, prompting countries to prioritize land protection and productivity. Both developed and developing countries are seeking a balance point for agricultural development in order to achieve the dual goals of environmental protection and economic benefits. In the United States, for example, the CRP program, implemented in 1985, promoted sustainable agricultural development by encouraging farmers to protect soil health and reduce soil erosion through economic incentives. This policy not only protects the ecological environment but also ensures the economic interests of farmers through financial subsidies and realizes the harmonious coexistence of environmental protection and agricultural development. Similarly, Pakistan in the 1950s, through government subsidies, improved farmland infrastructure, promoted agricultural scale management, effectively increased agricultural total factor productivity, and enhanced the competitiveness and sustainability of agriculture. These initiatives show that while innovation strategies differ from country to country, they are aimed at balancing environmental protection and farmer well-being while promoting agricultural development.

And for China, it has made progress in the overall efficiency of agriculture. In particular, from 2017 to 2023, China’s government implemented a series of major decisions aimed at transforming all permanent basic farmland into high-standard farmland and achieving high-quality transformation. These include dynamic balance systems, which

focus on protecting the quantity of cultivated land, and basic farmland planning, which focuses on protecting the quality of cultivated land. Through these policies, China has made progress in the overall efficiency of the agricultural economy, especially in upgrading the quality of farmland to support high-quality agricultural development.

In this study, we construct an AEE measurement system including input index, expected output, and non-expected output. Based on the empirical data of 30 provinces in China from 2005 to 2022, we systematically measure the time change trend of AEE in China and verify the positive impact of HFC on AEE through empirical analysis. This shows that HFC is one of the most effective ways to improve the sustainability of agricultural production. Theoretically and practically, optimizing the structure and quality of agricultural inputs enhances total factor productivity. HFC improves land quality, optimizes the allocation of resources like land, water, and energy, and promotes their efficient use. Additionally, it involves not only physical infrastructure like roads, water systems, and electricity but also adjustments to agricultural production structures and the promotion of green agricultural technologies, aligning with ecological requirements for sustainable development. Therefore, in terms of sustainable agricultural development, based on China's experience, HFC can be promoted in developing countries.

Heterogeneity analysis shows that this construction has a particularly significant positive impact on AEE in economically developed eastern China, while in the less developed western regions, the impact is negative (as shown in columns (1) and (3) of Table 7). This partly explains why developed countries have taken the lead in promoting farmland renovation policies. The transformation of high-standard farmland, the improvement of infrastructure, and the subsequent management and maintenance require a large amount of financial investment, which is closely related to regional economic development levels. Quantile regression results further confirm that the impact of HFC on AEE follows a “first increasing, then decreasing” trend (as shown in Table 8). This indicates that it has a significant positive impact on AEE in the initial stage of construction, but with the increase in input, the phenomenon of diminishing marginal benefit begins to appear. In China's practice, there is a phenomenon of “heavy construction, light management” in some areas, and some HFC “shut down” after a short period of operation and did not continue to create benefits. In essence, these are the lack of comprehensive management ability and the performance of inefficient fund management. This also reminds us that for developing countries, it is not appropriate to uniformly promote HFC in the whole region, and it is advisable to first experiment in regions with sufficient construction funds and high management and maintenance levels. Heterogeneity analysis also finds that the effect of HFC in areas with large geographic fluctuation is poor. Only centralized contiguous and large-scale is a basic principle in the scope design of HFC, but the mountainous and hilly areas are obviously different from the plain areas (as shown in columns (7) and (8) of Table 7). Therefore, this also reminds us that the appropriate scale of different regions, how to choose the content of facility construction, and how to construct the cost, etc. need to be based on extensive research, scientific calculation, and scientific planning to better lead the regional HFC.

The adjustment mechanisms find that the increase in agricultural technology innovation, capital accumulation, and land circulation strengthened the positive impact of HFC on AEE, and these factors jointly promote the efficiency and modernization of agricultural production (as shown in Table 9 and columns (4) of Table 10). However, labor mobility can weaken these positive effects (as shown in columns (1) to (3) of Table 10). According to new economic growth theory, technological progress boosts production efficiency, capital investment improves agricultural infrastructure, and enhanced comprehensive agricultural capacity increases farmers' willingness to engage in land circulation, leading to more efficient land use. Despite these benefits, challenges such as terrain barriers, infrastructure limitations, and insufficient technological supply can affect the success of HFC. To achieve factor substitution, it is necessary to adapt to local conditions according to the comparative advantage of resource endowment to achieve the expected effect.

According to the decomposition and regression results of AEE, the construction of HFC not only significantly improves the progress of agricultural technology but also promotes the efficiency of agricultural technology (as shown in Table 11). The two complement each other and jointly promote the overall improvement of AEE. Specifically, agricultural technological progress means that the introduction of new and more efficient production methods and technical means not only significantly improves the output efficiency per unit of resources but also reduces the emission of pollutants and waste and promotes the sustainability of agricultural production [71]. Improved technical efficiency in agriculture means better allocation of resources and less wastage in the production process, enabling higher yields and reduced environmental impact for the same inputs.

Although this study confirms the effectiveness of HFC in China on AEE, there are still two major limitations: the constraint of data granularity and the impact of policy evaluation. Future research can be expanded from the following two dimensions: First, the sample data needs to be further refined. Although the provincial sample data used in this study provide us with a macro-level analysis perspective, to more carefully explore the specific impact of HFC policies in different geographical regions, future studies should further refine the granularity of sample data and extend it to prefecture-level cities or even counties. This will help us to more precisely identify and understand the differentiated effects of policies in different geographical and economic contexts. Second, there is a lack of in-depth evaluation of policy effects. Although the relationship between HFC and AEE has been evaluated by the fixed effect model, the consideration of policy effects is still insufficient. Future studies should introduce more comprehensive assessment models to explore the long-term effects and potential impacts of high-standard farmland construction policies.

6. Conclusions and Policy Implications

Using empirical data from 30 provinces in China between 2005 and 2022, this study explores how HFC techniques can enhance AEE, considering factor endowment preferences and geographical characteristics. The research indicates that HFC significantly enhances AEE, particularly in the eastern region, the main grain-producing areas, and the regions with less geographical fluctuation. Additionally, agricultural innovations, capital accumulation, and land circulation reinforce the benefits of such construction, whereas labor mobility has a moderating effect. Quantile regression analyses show that the impact of high-standard farmland on AEE initially increases and then diminishes, potentially due to inadequate post-management and maintenance.

Based on the above discussions, the research policy implications are as follows:

First, strengthen policy support and implementation supervision for HFC. The government should not only strengthen the policy support for HFC but also refine the implementation rules and supervision mechanism to form a complete legal system. By providing incentives such as financial subsidies and tax incentives, farmers and agricultural enterprises will be stimulated to participate in the construction and transformation of high-standard farmland. At the same time, a set of strict supervision systems is established to ensure that the construction quality meets the standards, the progress meets the expectations, and the implementation efficiency and effect of the project are improved.

Second, promote the deep integration of agricultural technological innovation and capital accumulation. Technological innovation and capital accumulation are the key factors to improve the effect of HFC. It is suggested that the government increase investment in agricultural research and promote the innovation and application of green and efficient technologies such as precision agriculture and water-saving irrigation. At the same time, financial institutions are encouraged to develop financial products that meet the characteristics of agriculture and help agricultural enterprises and farmers increase capital investment and improve capital utilization to promote the process of agricultural modernization.

Third, optimize the allocation of human resources and guide the rational flow of labor. Faced with the problem that the outflow of rural labor affects the development of HFC, the government should rationally guide the flow of labor through policy optimization, such as

providing support for returning home to start businesses and improving rural education and medical conditions, to reduce the irrational loss of labor. In addition, it strengthens agricultural vocational education and skills training, improves farmers' ability to apply science and technology, enhances the attractiveness of agriculture to talents, and achieves an effective balance between human resources in agriculture and non-agricultural industries.

Fourth, deepen the reform of the land circulation system and innovate the land use model. The improvement of the land circulation system is the key to improving land use efficiency. The government should further optimize the land circulation policy, protect farmers' land rights and interests, encourage appropriate scale management, and promote the healthy development of the land circulation market. Explore the combination of land circulation and HFC, such as the implementation of land trusteeship, land share cooperation, and other models, to improve the ecological efficiency of agriculture. At the same time, when promoting the innovation of the land circulation system, it is necessary to fully consider the culture and market conditions of the country to ensure that the reform measures are both innovative and practical.

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References

1. Thapa, B.; Chapagain, B.P.; Mcmurry, S.T.; Smith, L.M.; Joshi, O. Understanding landowner participation in the Conservation Reserve Program in the U.S. High Plains Region. *Land Use Policy* **2024**, *141*, 107163. [\[CrossRef\]](#)
2. Han, Y.; Chen, Y.; Chen, Y. Progress of high-standard farmland construction in China and Suggestions on Policy Improvement: Comparison of China's agricultural modernization Goals and lessons from the United States, Germany and Japan. *Rural Economics* **2022**, *5*, 20–29.
3. Wang, K.-C.; Buck, D. Relocating agrarian development in Asia: Food regimes, R&D programs, and the long twentieth century. *J. Peasant. Stud.* **2024**, *51*, 212–236.
4. Obwegger, A.; Mitter, H.; Schmid, E. Framing the CAP reform 2013 in Austria's agricultural media. *Agric. Hum. Values* **2024**, 1–23. [\[CrossRef\]](#)
5. Hao, S.; Wang, G.; Yang, Y.; Zhao, S.; Huang, S.; Liu, L.; Zhang, H. Promoting grain production through high-standard farmland construction: Evidence in China. *J. Integr. Agric.* **2024**, *23*, 324–335. [\[CrossRef\]](#)
6. Zhan, J.; Xu, Y. Environmental regulation, agricultural green productivity and food security. *China Popul. Resour. Environ.* **2019**, *29*, 167–176.
7. Qiao, M.; Wang, J.; Wang, B. High-standard farmland construction, agricultural socialization service and agricultural environmental technical efficiency. *Rural. Econ.* **2024**, *3*, 91–100.
8. Ren, J.; Chen, X.; Shi, L.; Liu, P.; Tan, Z. Digital Village Construction: A Multi-Level Governance Approach to Enhance Agroecological Efficiency. *Agriculture* **2024**, *14*, 478. [\[CrossRef\]](#)
9. Jiang, Z.; Liu, Y.; Zeng, Z.; Qin, G. Study on the impact of fiscal environmental protection expenditure on agroecological efficiency: Empirical evidence from the development strategy of the Yangtze River Economic Belt. *Econ. Probl.* **2022**, *6*, 113–122.
10. Cao, L.; Fan, L.; Lei, X. Fiscal decentralization, environmental regulation and agroecological efficiency. *Stat. Decis.* **2021**, *37*, 138–143.
11. Wu, F.; Gao, Q.; Liu, T. Agricultural science and technology innovation, spatial spillover and agroecological efficiency. *Stat. Decis.* **2020**, *36*, 82–85.
12. Kuang, Y.; Zhang, R. Effects of farmland transfer on ecological efficiency of grain production. *China Popul. Resour. Environ.* **2021**, *31*, 172–180.
13. Wang, Y.; Huang, Y. Effects of mismatching of agricultural resources on agroecological efficiency: Evidence from 13 major grain-producing areas in China. *Ecol. Econ.* **2022**, *38*, 129–137.

14. Hou, M.; Yao, S. Spatial spillover effect and threshold characteristics of rural labor transfer on agroecological efficiency in China. *Resour. Sci.* **2018**, *40*, 2475–2486.
15. Asante, B.O.; Temoso, O.; Addai, K.N.; Villano, R.A. Evaluating productivity gaps in maize production across different agroecological zones in Ghana. *Agric. Syst.* **2019**, *176*, 102650. [[CrossRef](#)]
16. Hou, M.; Deng, Y.; Yao, S. Rural labor transfer, fertilizer application intensity and agroecological efficiency: Interaction and spatial spillover. *Agric. Tech. Econ.* **2021**, *10*, 79–94.
17. Rahman, S.; Anik, A.R. Productivity and efficiency impact of climate change and agroecology on Bangladesh agriculture. *Land Use Policy* **2020**, *94*, 104507. [[CrossRef](#)]
18. Li, X.; Li, G.; Gao, Y. Research on Promoting agricultural green Total factor Productivity by high-standard farmland construction: An empirical test based on Continuous Differential. *Chin. J. Agric. Resour. Reg. Plan.* **2024**, *45*, 32–43.
19. Pu, L.; Zhang, S.; Yang, J.; Yan, F.; Chang, L. Assessment of High-standard Farmland Construction Effectiveness in Liaoning Province During 2011–2015. *Chin. Geogr. Sci.* **2019**, *29*, 667–678. [[CrossRef](#)]
20. Qu, Y.; Lyu, X.; Peng, W.; Xin, Z. How to evaluate the green utilization efficiency of cultivated land in a farming household? A case study of shandong province, China. *Land* **2021**, *10*, 789. [[CrossRef](#)]
21. Zhao, Y.; Sun, X. Whether high-standard farmland construction can promote the cultivation of new professional farmers: Evidence from villages. *Rural. Econ.* **2022**, *4*, 135–144.
22. Liu, H.; Zhang, W. Spatial and temporal variation and convergence in the efficiency of high-standard farmland construction: Evidence in China. *J. Clean. Prod.* **2024**, *452*, 142200. [[CrossRef](#)]
23. Liang, Z.; Zhang, L.; Zhang, J. Land regulation and fertilizer reduction: Quasi-natural experimental evidence from China's high-standard basic farmland construction policy. *Chin. Rural. Econ.* **2021**, *4*, 123–144.
24. Palladino, P. Science for whom? Agricultural development and the theory of induced innovation. *Agric. Hum. Values* **1987**, *4*, 53–64. [[CrossRef](#)]
25. Lin, J.Y.; Tan, G. Policy burdens, accountability, and the soft budget constraint. *Am. Econ. Rev.* **1999**, *89*, 426–431. [[CrossRef](#)]
26. Song, W.; Zhang, H.; Zhao, R.; Wu, K.; Li, X.; Niu, B.; Li, J. Study on cultivated land quality evaluation from the perspective of farmland ecosystems. *Ecol. Indic.* **2022**, *139*, 108959. [[CrossRef](#)]
27. Yu, F.; Sun, H.; Liu, Y. High-standard farmland construction: Connotation, characteristics, problem diagnosis and promotion path. *Econ. Rev.* **2024**, *1*, 61–68.
28. Chen, L.; Peng, J. Impact of high-standard farmland construction policy on grain production capacity and its mechanism in China. *Resour. Sci.* **2024**, *46*, 145–159.
29. Qian, L.; Yang, G.; Zhong, Y. Have land and Grain: Does high-standard farmland construction increase grain yield per unit area? *J. Nanjing Agric. Univ. (Soc. Sci. Ed.)* **2024**, *24*, 132–143.
30. Liu, C.; Liu, L.; He, R. Study on ecosystem service response of high-standard farmland construction in Loess Hilly region: A case study of high-standard farmland construction project in Yuzhong County. *China Popul. Resour. Environ.* **2018**, *28*, 124–130.
31. Peng, J.; Liu, Y.; Chen, L. Effects and mechanisms of high-standard farmland construction on farmland disaster reduction. *Acta Ecol. Sin.* **2024**, *17*, 1–15.
32. Chen, Y.; Sun, Z.; Wang, Y.; Han, Y. Impact of high-standard farmland construction on farmers' income growth—Quasi-natural experiments from China. *Front. Sustain. Food Syst.* **2023**, *7*, 1303642.
33. Habyarimana, J.-B.; Opoku, E.E.O. Technological progress, worker efficiency, and growth in Africa: Does China's economy matter? *China Econ. Rev.* **2018**, *52*, 151–164. [[CrossRef](#)]
34. Gong, B.; Zhang, S.; Wang, S.; Yuan, L. Review on agricultural technology progress in the 70 years since the founding of New China. *Issues Agric. Econ.* **2020**, *6*, 11–29.
35. Cai, F. Promoting agricultural and rural modernization with labor productivity as the starting point. *China Rural. Econ.* **2024**, *7*, 2–15.
36. Jin, P.; Mangla, S.K.; Song, M. The power of innovation diffusion: How patent transfer affects urban innovation quality. *J. Bus. Res.* **2022**, *145*, 414–425. [[CrossRef](#)]
37. Wang, W.; Zhang, S. An empirical test on the modernization of agricultural industry chain driven by digital economy. *Stat. Decis.* **2024**, *40*, 22–27.
38. Li, G.; Fan, L.; Feng, Z. Capital accumulation, Institutional Change and Agricultural Growth: Empirical Estimation of agricultural growth and capital stock in China from 1978 to 2011. *Manag. World* **2014**, *67*–79+92. [[CrossRef](#)]
39. Zhang, Q. "Horizontal Concentration" and "Vertical concentration" of agricultural capitalization: A new understanding of Marx and Chayanov. *J. China Agric. Univ. (Soc. Sci. Ed.)* **2024**, *41*, 34–55.
40. Lin, B.; Fei, R. Analyzing inter-factor substitution and technical progress in the Chinese agricultural sector. *Eur. J. Agron.* **2015**, *66*, 54–61. [[CrossRef](#)]
41. Li, L.; Khan, S.U.; Guo, C.; Huang, Y.; Xia, X. Non-agricultural labor transfer, factor allocation and farmland yield: Evidence from the part-time peasants in Loess Plateau region of Northwest China. *Land Use Policy* **2022**, *120*, 106289. [[CrossRef](#)]
42. Zou, X.Q.; Xie, M.H.; Yu, S.K.; Li, Z.Y. Spatial spillover effect of rural labor transfer on ecological efficiency of cultivated land use. *China Land Sci.* **2023**, *37*, 59–69.
43. Zhang, Y.; Zhang, Y. Impact of migrant work and gender Difference on farmland abandonment. *J. Hunan Agric. Univ. (Soc. Sci. Ed.)* **2023**, *24*, 19–28.

44. Shi, Z.; Zhang, Y. Land ownership and rural labor migration: Evidence from provincial panel data. *Resour. Sci.* **2022**, *44*, 647–659.
45. Fang, Z.; Li, G.; Li, X.; Liao, W. Agricultural land transfer and fertilizer reduction: A quasi-natural experiment from agricultural land transfer policy. *Chin. J. Agric. Resour. Reg.* **2023**, *44*, 123–134.
46. Chen, J.; Xue, Y.; Qian, L. Does high-standard farmland construction promote the enthusiasm of farmers to grow grain?—Investigation on double-cropping rice planting. *J. Nanjing Agric. Univ. (Soc. Sci. Ed.)* **2024**, *24*, 98–109.
47. De Roest, K.; Ferrari, P.; Knickel, K. Specialisation and economies of scale or diversification and economies of scope? Assessing different agricultural development pathways. *J. Rural Stud.* **2018**, *59*, 222–231. [[CrossRef](#)]
48. Sun, X.; Zhang, L. Influence of high-standard farmland construction on the bias of agricultural technology progress. *J. Nanjing Agric. Univ. (Soc. Sci. Ed.)* **2024**, *24*, 148–159.
49. Song, Y.; Liu, W.; Xie, Z. Model evaluation of effects of high-standard farmland construction policy on planting structure. *Trans. Chin. Soc. Agric. Eng.* **2023**, *39*, 227–235.
50. Zhang, K.; Zhang, G.; Han, Y.; Zhang, J.; Wu, L. Effects of agricultural machinery operation services on agroecological efficiency: Local effects and spatial spillovers. *J. China Agric. Univ.* **2023**, *28*, 223–237.
51. Fang, Y.; Zeng, X. Evaluation and improvement path of agroecological efficiency in China. *J. Agric. Resour. Environ.* **2021**, *38*, 135–142.
52. Ding, B.; Zhao, Y.; Deng, J. Measurement, decoupling characteristics and driving factors of planting carbon emissions in China. *China Agric. Resour. Reg. Plan.* **2022**, *43*, 1–11.
53. Deng, Y.-J.; Chao, B. Agroecological efficiency and its influencing factors in China from the perspective of grey water footprint. *Sci. Agric. Sin.* **2022**, *55*, 4879–4894.
54. Davis, D.R. Intra-industry trade: A Heckscher-Ohlin-Ricardo approach. *J. Int. Econ.* **1995**, *39*, 201–226. [[CrossRef](#)]
55. Cao, J.; Wang, Y. Digital countryside, technological innovation and high-quality agricultural development. *Manag. J.* **2024**, *37*, 128–142.
56. Li, L.; Hu, X.; Wang, D.; Liu, J. Organic composition of agricultural capital and agricultural economic growth. *Economist* **2023**, *6*, 88–99.
57. Yuan, X.; Sun, W. Research on the mechanism of digital Economy affecting rural industrial integration: An Empirical Study based on provincial panel data in China. *Manag. J.* **2024**, *37*, 143–158.
58. Li, K.; Shi, L. Effect of rural industry Integration on agricultural carbon emission: Mechanism path and spatial spillover effect analysis. *Chin. J. Agric. Resour. Reg.* **2024**, *45*, 1–14.
59. Li, X.; Zhang, Y. Digital economy, rural labor migration and common prosperity of rural farmers. *Stat. Decis.* **2024**, *40*, 5–10.
60. Zhang, L.; Leng, L.; Yang, S.; Lin, X.; Chen, S.; Li, G. Empirical analysis of the impact of land circulation and socialized service on agricultural total factor productivity. *Econ. Geogr.* **2024**, *44*, 181–189+240. [[CrossRef](#)]
61. Wang, B.; Wang, L.; Li, X. Can high-standard basic farmland construction policies curb agricultural non-point source pollution? *Resour. Environ. Yangtze Basin* **2023**, *32*, 1736–1747.
62. Yang, L.-N.; Zhang, X.-Y. Does agricultural trade promote green agricultural development in China? — Based on the perspective of agricultural green total factor productivity. *Financ. Trade Res.* **2024**, *35*, 31–41.
63. Yuan, H.; Zhu, C. Digital economy, transaction costs and regional innovation and entrepreneurship in China. *Sci. Res. Manag.* **2023**, *44*, 19–28.
64. Nunn, N.; Qian, N. The potato's contribution to population and urbanization: Evidence from a historical experiment. *Q. J. Econ.* **2011**, *126*, 593–650. [[CrossRef](#)] [[PubMed](#)]
65. Chen, F.; Jiang, G.; Dong, K. Spatial spillover effect of digital economy on green transformation of manufacturing industry. *China Popul. Resour. Environ.* **2024**, *5*, 114–125.
66. Gong, Y.; Zhang, Y. “Toward grain” or “away from grain”: Policy effects of high-standard farmland construction. *J. Jiangxi Univ. Financ. Econ.* **2023**, *6*, 68–83.
67. Bai, P.; Zhang, Y. Digital economy, declining demographic dividend and rights and interests of middle and low skilled workers. *Econ. Res.* **2021**, *56*, 91–108.
68. Hao, L.; Naiman, D.Q. *Quantile Regression*; Sage Publications, Inc.: Thousand Oaks, CA, USA, 2007.
69. Long, H.; Tu, S.; Ge, D.; Li, T.; Liu, Y. The allocation and management of critical resources in rural China under restructuring: Problems and prospects. *J. Rural Stud.* **2016**, *47*, 392–412. [[CrossRef](#)]
70. Liu, J.; Yuan, Y.; Lin, C.; Chen, L. Do agricultural technical efficiency and technical progress drive agricultural carbon productivity? based on spatial spillovers and threshold effects. *Environ. Dev. Sustain.* **2023**, 1–25. [[CrossRef](#)]
71. Färe, R.; Grosskopf, S.; Lindgren, B.; Roos, P. Productivity changes in Swedish pharmacies 1980–1989: A non-parametric Malmquist approach. *J. Product. Anal.* **1992**, *3*, 85–101. [[CrossRef](#)]

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