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The impact of land consolidation on farmer income: evidence from high-standard farmland construction in China

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Land consolidation has become an organized and widely implemented project in rural areas. However, research remains somewhat scarce on the contributing mechanism of land consolidation to farmer income in developing countries. Using provincial panel data from China, this study employs a fixed effects model to analyze the influence of high-standard farmland construction on farmer income and underlying mechanisms. Results suggest that the implementation of high-standard farmland construction can significantly augment farmer income. Reduction in agricultural production cost, improvement in agricultural management benefit and increase in non-farm income have led to the boost in income. The relationship between income and high-standard farmland construction exhibits regional disparities, with the most significant impacts concentrated in economically developed areas and low relief degree areas. Our findings suggest that it is imperative for the Chinese government to persistently promote the establishment of high-standard farmland, and further enhance its positive influence on advancing agricultural cost-effectiveness and expanding non-farm income channels for farmers.

KEYWORDS

land consolidation, high-standard farmland construction, farmer income, two-way fixed effects, China

1 Introduction

Rapid population growth and socioeconomic development have resulted in global losses of land and increased land fragmentation. Such fragmentation reduces land and labor productivity and affects sustainability regimes (Ženka et al., 2016; Lu et al., 2018; Penghui et al., 2021; Jiang et al., 2022). These problems are particularly pressing in developing countries, where poor water infrastructure and extreme land fragmentation raise the cost of agricultural production and limit potential farmland. Challenges like these make it difficult for farmers to live sustainably off the land, and make the diversification of family livelihoods even more difficult to achieve (Wang et al., 2022).

Land consolidation can help improve agricultural production efficiency and increase farmer income. Many studies have shown that land consolidation plays an important role in mitigating land fragmentation, improving agricultural infrastructure, and increasing agricultural profitability (Ying et al., 2020; Bizoza, 2021; Tran et al., 2022). Pašakarnis and Maliene (2010) studied the impact of land consolidation on sustainable rural development in Central and Eastern Europe and revealed that land consolidation can help minimize the issues associated with land fragmentation and improve agricultural production, employment infrastructure, and public facilities. Similarly, Hong et al. (2019) analyzed the impact of land consolidation on agricultural production in China using satellite data. They found that land consolidation improved local farmland productivity by improving agricultural production conditions and balancing production element distribution. Bahar and Kirmikil (2021) studied Kesik Village in Turkey to evaluate the production input of farmers before and after land consolidation, finding that land consolidation can reduce the degree of land fragmentation, which reduces transportation and time cost. Since 1960, many countries have carried out land consolidation projects in an attempt to reduce agricultural production cost and increase agricultural efficiency. In some developed countries, such as Germany, France, the Netherlands, and Belgium, large-scale land consolidation have promoted a high degree of scale and mechanization of agricultural production (Jiang et al., 2022). However, for some developing countries, they still face many difficulties in the process of land consolidation, resulting in little success.

China's per capita cultivated land area is less than half of the world's average, and land fragmentation is a significant problem (Hao et al., 2023). Relevant data shows that in 2018, the average cultivated land area of China's rural households was <7.5 mu[1], while a household's cultivated land area was distributed in 5.5 plots. The worst land fragmentation is generally in the southwest of China, for example in Chongqing and Sichuan, where the average number of plots was more than 9, respectively (Liu and Qian, 2023). In such fragmented farmland, farmers' unreasonable behavior such as excessive use of chemical fertilizer had been exacerbating the decline of farmland quality. Coupled with the lack of optimal irrigation facilities, smooth field roads, and advanced machinery equipment, China's agriculture faces many challenges (Liu et al., 2013; Han, 2014; Zou et al., 2023). To alleviate the negative impact of these factors on agricultural production and farmer livelihood, the Chinese government implemented a large-scale land consolidation project in rural areas beginning in 1988. This consolidation has focused on the construction of high-standard farmland. The project aims to improve farmland infrastructure using appropriate field management, irrigation and drainage techniques. In addition, focus is given to ecological protections, as well as to farmland power transmission and distribution. Farmland fertility is managed through soil improvement and fertilization.

In the early stages of this project, literature mainly focused on farmland regional demarcation and construction (Yang et al., 2013; Wang et al., 2014; Qiao et al., 2017; Song et al., 2019; Xu et al., 2020). With the Chinese government's increased investment in high-standard farmland construction, whether the construction of high-standard farmland meets the expected effect at the beginning of the policy design has attracted much attention from the scholars. Therefore, many scholars have quantitatively analyzed the implementation effect of high-standard farmland construction from the dimensions of yield, land use, efficiency and ecology. They found that high-standard farmland construction has a positive impact on increasing grain production capacity, promoting farmland transfer, improving production efficiency and reducing non-point source pollution (Chen and Hong, 2022; Zhu et al., 2022; Gong et al., 2023; Li et al., 2023; Ye et al., 2023). Such studies, however, tend to focus exclusively on agricultural impact, and less on the potential effects on farmer income. High-quality farmland can not only increase agricultural efficiency, but can also promote the vertical division of labor in agriculture, which can help broaden sources of income, so the construction of high-standard farmland is theoretically helpful to increase farmer income.

Despite significant advances, research on land consolidation does not often cover developing countries, and few studies place land consolidation and farmer income in the same framework. Moreover, due to the difficulties of large-scale research and data acquisition, existing quantitative studies mostly focus on the local scale (Yin et al., 2022). To improve the relevant research on land consolidation, this paper focuses on the construction of high-standard farmland in China, and is committed to discussing two questions: First, can land consolidation increase farmer income? Second, how does land consolidation affect farmer income?

This paper constructs a theoretical analysis framework on the impact of high-standard farmland construction on farmer income. Based on the provincial panel data of China from 2006 to 2017, the two-way fixed effects model is used to identify the impact of high-standard farmland construction on farmer income and its mechanism. We also analyze the heterogeneity of farmer income from the dimensions of economic development and topography. In this way, we can more fully grasp the effect of China's high-standard farmland construction and provide a foundational understanding for follow-up policy improvements and land consolidation in other countries.

The structure of the remainder of this paper is as follows. Section 2 reviews the Institutional background of high-standard farmland construction in China and presents the analytical framework. Section 3 explains the research methodology. Section 4 shows the results of the empirical analysis, examining the mechanism of the impact of high-standard farmland construction on farmer income. Section 5 contains the conclusions and policy implications.

2 Institutional background and theoretical analysis framework

2.1 Policy evolution of high-standard farmland construction

Although it is widely believed that land consolidation can improve agricultural infrastructure and land quality, the history of China's high-standard farmland construction is not long, and can be divided into three stages. The evolution process and characteristics of each stage of the high-standard farmland construction policy is shown in Figure 1.

(1) 1988–2004: The embryonic stage.

In 1988, the National Land Development and Construction Fund Management Leading Group promulgated the Trial Measures for the Management of the National Land Development and Construction Fund, and began to implement land development and consolidation projects, which included the transformation

1 1 mu = 1/15 ha.

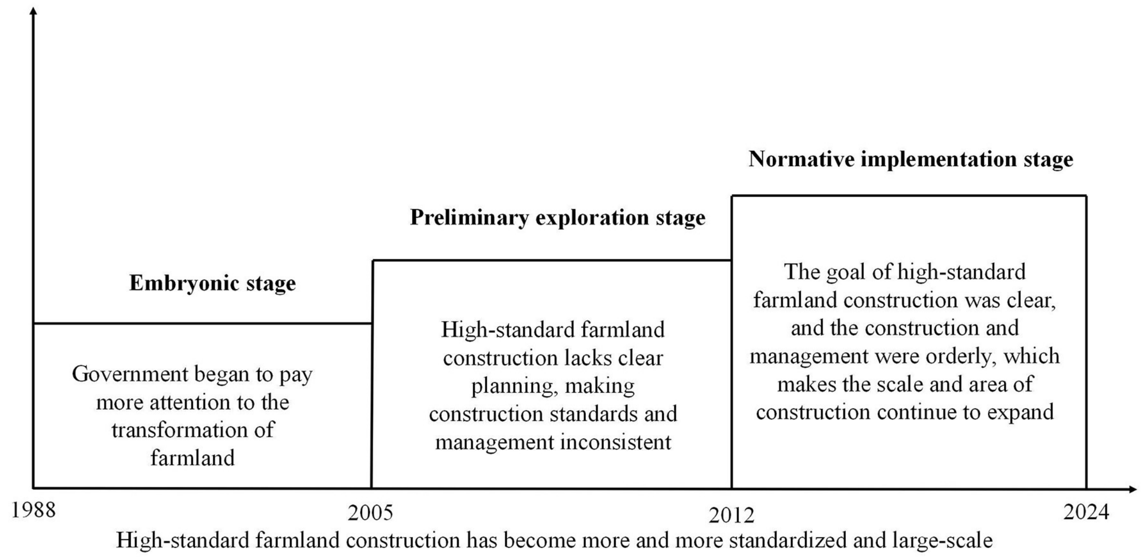

FIGURE 1
POLICY evolution of high-standard farmland construction.

of low-and-medium yield fields. The Central Committee of the Communist Party of China and the State Council issued the Notice on Further Strengthening Land Management and Effectively Protecting Cultivated Land in 1997, highlighting the need to actively promote land consolidation and land construction. In 2003, the Ministry of Land and Resources compiled the National Land Development and Consolidation Plan (2001–2010), which planned to develop and replenish 2.74 million hectares of cultivated land nationwide by 2010. At this stage, the government expanded its focus to the transformation of farmland.

(2) 2005–2011: The preliminary exploration stage.

In 2005, The Central Documents No. 1 proposed to strengthen the construction of shelterbelt system and farmland forest networks to create a good ecological barrier for the construction of high-standard farmland, which proposed the concept of "high-standard farmland" for the first time. By carrying out the 5-year demonstration zones construction, it would provide valuable experience for the country to explore effective mechanisms for the protection of basic farmland. In 2006, the central government designated 116 counties as national demonstration zones for basic farmland protection. Since then, although many documents had emphasized to speed up the construction of high-standard farmland, they were not normative guidance documents. This lack of central planning resulted in unclear objectives and irregular management.

(3) 2012–2024: The normative implementation stage.

In 2012, the Ministry of Land and Resources created the National Land Consolidation Plan (2011–2015). The plan proposed to promote agricultural land consolidation by building 400 million mu of high-standard basic farmland by 2015. In the same year, the Ministry of Land and Resources also issued the High-standard Basic Farmland Construction Standards (TD/T1033-2012), which clearly stipulated the basic principles, objectives, and technical procedures of high-standard farmland construction. In 2013, the Ministry of Finance issued the National Comprehensive Agricultural Development High-standard Farmland Construction Plan, emphasizing that the construction of high-standard farmland was an important initiative to improve the agricultural production capacity and increase farmer income. The plan sought to build 800 million mu of high-standard farmland by 2020. In 2018, the Central Committee of the Communist Party of China and the State Council promulgated the Strategic Plan for Rural Revitalization (2018–2022), emphasizing the need to promote the construction of high-standard farmland on a large scale and ensure that 1 billion mu of high-standard farmland would be built by 2022. The National High-standard Farmland Construction Plan (2021–2030), implemented in 2021, called for the completion of 1.2 billion mu of high-standard farmland and the upgrading of 280 million mu of high-standard farmland by 2030.

Since 1988, the construction of high-standard farmland in China has gone through a process from pilot exploration to full promotion of standardization and standardization, with the construction scale and scope expanding continuously. Data from the Ministry of Agriculture and Rural Development show that, as of 2022, across 31 provinces, China has accumulated 1 billion mu of high-standard farmland, which accounts for 52% of the total area of cultivated land.

2.2 Theoretical analysis framework

Agricultural production and non-farm employment are the main sources of farmer income. As an important technological innovation for farmland, high-standard farmland construction optimizes land elements, labor elements, and machinery elements, promoting the rational allocation of agricultural production factors (Markussen et al., 2016; Liu et al., 2020; Nguyen and Warr, 2020). This style of land consolidation not only improves agricultural production and management, but also has an important impact on the non-farm production activities of farmers, which triggers a change in farmer income.

In terms of agricultural production, high-standard farmland construction helps to reduce the cost of agricultural production and increase the benefit of agricultural management, thereby raising farmer income. According to the theory of substitution, the quality improvement of certain factors will have a substitution effect on other factors. High-standard farmland construction includes the transformation of low-and-medium yield fields, deep plowing and deep polishing, the application of organic fertilizers, and the planting of green fertilizers (Sun et al., 2023). These measures improve soil fertility, water storage and moisture retention capacity and farmland irrigation efficiency, which can decrease the frequency of soil fertilization and irrigation, thereby reducing input cost (Tang et al., 2023). At the same time, high-standard farmland can help mitigate the adverse effects of natural disasters on food production. This promotes an increase in food production and quality, making more operational benefit for farmers.

High-standard farmland construction is conducive to large-scale operations, which enhance cost-saving and benefit-increasing of agricultural production. At present, there are two paths to achieve large-scale agricultural operation in China: one is the large-scale operation of farmland, and the other is service scale management (Hu, 2018). These two paths are interdependent and mutually reinforcing. The construction of high-standard farmland promotes the simultaneous expansion of plot size and farmland operation scale by "turning scattered pieces into whole pieces" and "turning small fields into large fields." It reduces the cost of conversion between plots and improves the management benefit of the unit area. Moreover, farmland spatial optimization can lead to the specialization of food production at the regional spatial scale, which promotes the horizontal division of agricultural production (Liang et al., 2021). Centralized and large-scale management can also reduce the operations cost associated with agricultural machinery, making it easier to realize the vertical division of agricultural production. Achieving both horizontal and vertical divisions of labor can enhance the development of the outsourcing of agricultural services (Luo, 2017). This helps give full play to the professional advantages of service scale management, promoting cost-saving and benefit-increasing of agricultural production (Sang et al., 2023).

From the perspective of non-farm production, the construction of high-standard farmland can improve farmers' non-farm income. First, the construction of high-standard farmland can induce the transfer of surplus rural labor to the non-farm sector and increase wage income (Nguyen and Warr, 2020). Under small-scale agricultural management, allocating too much labor to a limited amount of farmland reduces resource efficiency. According to the rational smallholder theory, farmers are rational economic actors who do not simply seek to maximize agricultural output, but also consider how to allocate household resources in order to maximize household welfare (Schultz, 1964). Considering that high-standard farmland construction has created good conditions for agricultural mechanization, logic suggests that rational farmers will choose to replace ordinary agricultural labor with agricultural machines or the outsourcing of agricultural services, transferring surplus labor to the non-farm sector to increase wage income.

Second, the construction of high-standard farmland can promote the farmland transfer and increase farmer property income. Enhancements in agricultural conditions can help farmers overcome the laborious, high-risk, low-return elements in farming (Bahar and Kirmikil, 2021). Stabilizing farmer return expectations expands the demand for transfers from farmers with comparative farming advantages. With a certain supply of farmland transfer, stronger demand for farmland transfer will drive up the price of farmland transfer. Considering the comparative returns from transferring farmland, small-scale farmers tend to transfer their farmland for higher land rental incomes.

3 Methods, variables, and data

3.1 Model specification

To analyze the impact of land consolidation on farmer income, this paper uses a two-way fixed effects model, in which the intercepts capture the variation across provinces and time. This is shown in Equation (1).

$$Income_{it} = \alpha + \beta Hlamd_{it} + \delta X_{it} + \mu_i + \gamma_t + \varepsilon_{it} \quad (1)$$

where $Income_{it}$ represents the per capita disposable income of rural residents of province i in year t. $Hlamd_{it}$ represents the land consolidation input of province i in year t. X_{it} is a vector of baseline control variables. μ_i and γ_t represent the province and time fixed effect, respectively. The term ε_{it} is a random error term, which is assumed to be normally distributed. α is a constant term. β and δ are the vector of parameters to be estimated.

3.2 Variables

3.2.1 Explained variable

Farmer income is measured by the per capita disposable income of rural residents. It is the sum of rural residents' wage income, operating income, property income, and transfer income. To eliminate the impact of price changes on this metric, this paper uses the 2006 consumer price index of rural residents to normalize the data. Because consumption is closely related to income, and income has a certain volatility, while consumption is sticky and relatively stable (Carroll et al., 2011), this paper uses farmer consumption as an alternative explained variable to conduct a robustness test to verify the impact of high-standard farmland construction on farm economic conditions. This variable, measured by per capita consumption expenditure of rural residents, has also been exponentially deflated.

3.2.2 Key explanatory variables

The input of land consolidation is expressed by land management investment per unit of cultivated land area. The most important use of land management capital investment is land consolidation, which focuses on the transformation of low-and-medium yield fields and the construction of high-standard farmland demonstration projects. The investment degree of land management capital directly affects the scope and quality of land consolidation (Hu and Dai, 2022). Therefore, land consolidation input can measure the overall situation of land consolidation relatively completely. In order to test the robustness of the estimated results, this paper takes the area of land consolidation as the substitute variable of the input land consolidation and measures it by the proportion of transformed low-and-medium yield fields and high-standard farmland construction against the total cultivated land area.

3.2.3 Control variables

On the basis of ensuring the availability of data and referring to the existing document (Zhang et al., 2020; Qian et al., 2023), this paper focuses on three types of control variables: production factors, planting characteristics, and the external environment. Production factors are defined as follows. Rural human capital is expressed by the weighted average years of education of rural residents. We allocated five levels of education: illiteracy (0 years), elementary school (6 years), junior high school (9 years), senior high school (12 years), and college (16 years). We then calculated a weighted average to derive the number of people surveyed at each level as a proportion of the total number of people surveyed. Agricultural labor force is expressed by the number of employees in the primary industry. Land size is measured by the area of cultivated land per unit of rural population. The intensity of fertilizer use is measured by fertilizer use per unit of crop sown area. The intensity of agricultural machinery is expressed by the total power of agricultural machinery per unit of crop sown area. The second category is planting characteristics, which is expressed by the proportion of grain planting area to crop sown area. The third category is the external environment. Disaster rate is expressed by the proportion of crop sown area affected. Electricity consumption is measured by rural electricity consumption per unit of rural population and is used to characterize rural infrastructure. Industrial structure is expressed by the proportion of the gross output value of the primary industry to the total output value.

3.2.4 Mechanism variables

This paper selects three mechanism variables. First, the cost of agricultural production is measured by average production cost per acre for three staple grains: rice, wheat and maize. Since high-standard farmland is used almost entirely for grain production, and these three staple foods are the core of grain production. To more accurately measure the total average cost per mu of the three staple grains, this paper takes the proportion of the sown area of each grain in the total sown area as the weights, and then multiplies them by their respective production cost, eventually summing to get the final average production cost per mu. To eliminate the price factor, this paper converts the cost using the agricultural production material price index with 2006 as the base period. Second, the benefit of agricultural management is expressed by gross agricultural production per unit of sown area and is converted by using the gross agricultural product index with 2006 as the base period. Gross agricultural production can reflect the output of agricultural production and the market price of agricultural products, so it can better reflect the agricultural management benefit. Third, non-farm income is measured by the sum of per capita wage income and property income of rural residents. The definitions and descriptive statistical characteristics of the variables are shown in Table 1.

3.3 Data and descriptive analysis

3.3.1 Data

We selected the panel data of 30 provinces in China, excluding Hong Kong, Macao, Taiwan and Tibet, from 2006 to 2017 to verify the impact of high-standard farmland construction on farmer income. This sample interval is chosen for two main reasons: Firstly, data on the construction of high-standard farmland after 2017 is not available. Secondly, there are some missing data related to the period before 2006. Data within the chosen interval was taken from several sources. Farmer income, farmer consumption, agricultural management benefit, non-farm income, land size, fertilizer use, agricultural mechanization, planting structure, disaster rate, and electricity consumption were taken from the China Rural Statistical Yearbook. Land consolidation input and land consolidation area come from the China Financial Yearbook and the China Rural Management Statistics Annual Report. Agricultural production cost is taken from the Compilation of Cost-benefit Information on Agricultural Products. Rural human capital is from China Population and Employment Statistics Yearbook. Agricultural labor force is taken from the statistical yearbooks of each province. Industrial structure is taken from the China Statistical Yearbook.

3.3.2 Descriptive analysis

To preliminarily understand the relationship between high-standard farmland construction and farmer income, Figure 2 depicts the changing trend of HINPUT and per capita disposable income of rural residents. From 2006 to 2017, HINPUT and per capita disposable income of rural residents both showed an upward trend, with a generally consistent change rate. The statistical test shows that the Pearson correlation coefficient between two variables is 0.67. The above descriptive analysis provides preliminary evidence that high-standard farmland construction increases farmer income, but whether there is a causal relationship between the two still needs to be empirically tested.

4 Empirical results and analysis

4.1 Benchmark regression

The Hausman test shows that the two-way fixed effects panel model is more appropriate than the random effects model, so this paper uses this model to estimate the parameters of Equation (1). The estimation results of model (1) are showed in Table 2. Columns (1) to (4) show the influence of high-standard farmland construction on farmer income obtained without any control variables and by adding production factors, planting structure and external environment control variables in turn according to the

TABLE 1 Variable definitions and descriptive statistics.

Variable	Variable definition	Mean	Std. Dev
Income	Per capita disposable income of rural residents converted by CPI index with 2006 as the base period (1,000 yuan/capita)	6.746	3.481
Consumption	Per capita consumption expenditure of rural residents converted by CPI index with 2006 as the base period (1,000 yuan/capita)	5.232	2.625
Cost	Average production cost per mu for the three staple grains (1,000 yuan/mu[a])	0.625	0.190
Benefit	Gross agricultural production per unit of sown area (1,000 yuan/mu)	1.652	1.013
Non-farm	The sum of per capita wage income and property income of rural residents (1,000 yuan)	3.216	2.787
HINPUT	Land management investment per unit of cultivated land area (1,000 yuan/mu)	0.310	0.296
HRATE	The proportion of the area of transformed low-and-medium yield fields and high-standard farmland construction in the total cultivated land area (%)	51.670	31.873
Capital	Weighted average years of schooling of rural residents (years)	7.676	0.687
Labor	The number of employees in the primary industry (10,000 capita)	943.517	694.031
Land	The area of cultivated land per unit of rural population (capita/mu)	2.534	2.014
Fertilizer	Fertilizer use per unit of crop sown area (kg/mu)	24.136	7.961
Machine	Total power of agricultural machinery per unit of sown area (kw/mu)	0.398	0.170
Structure	The proportion of grain planting area to crop sown area (%)	65.382	13.294
Disaster	The proportion of the disaster area to crop sown area (%)	21.343	14.758
Electricity	Rural electricity consumption per unit of rural population (10,000 kwh/capita)	0.173	0.443
Industry	The proportion of the gross output value of the primary industry to the total output value (%)	10.809	5.613

[a] 1 mu = 1/15 ha.

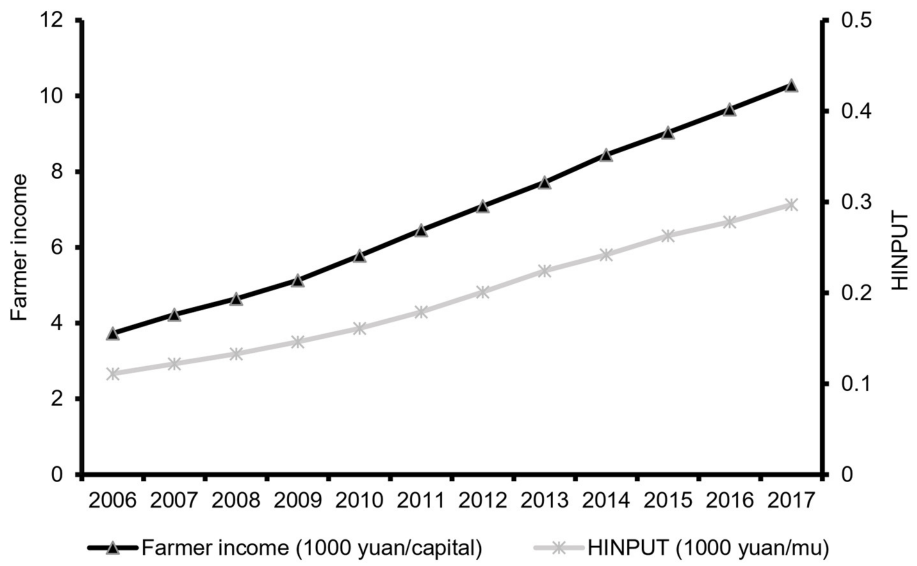

FIGURE 2
HINPUT and farmer income.

stepwise regression method. The results show that no matter how the control variables change, the estimation coefficients of HINPUT are significantly positive at the level of 1%, indicating that the construction of high-standard farmland can significantly improve the income level of farmers, and the estimated results of the model are relatively robust. Taking column (4) as an example, each 1,000 yuan/mu increase in the input of land consolidation can increase farmer income by 3,000 yuan, indicating that the income increasing effect of high-standard farmland construction is significant.

In addition, the agricultural labor force, disaster rate and electricity consumption are also important factors affecting farmer income. The agricultural labor force significantly reduces the income level of farmers. This indicates that excessive labor allocation to agricultural production reduces the efficiency of labor

TABLE 2 Impact of high-standard farmland construction on farmer income.

	(1)	(2)	(3)	(4)
HINPUT	2.895*** (0.842)	3.191*** (0.847)	3.382*** (0.837)	3.001*** (0.532)
Capital		−0.163 (0.227)	−0.092 (0.224)	−0.012 (0.235)
Labor		−0.002* (1.221)	−0.002 (0.001)	−0.002** (0.001)
Machine		−1.994 (1.789)	−1.468 (1.566)	−1.776 (1.571)
Structure			0.037* (0.019)	0.025 (0.017)
Disaster				−0.005** (0.002)
Electricity				0.980*** (0.189)
Industry				0.034 (0.043)
Province fixed effect	Control	Control	Control	Control
Year fixed effect	Control	Control	Control	Control
Constant	3.450*** (0.241)	7.423*** (1.951)	3.994 (2.476)	4.617** (2.233)
R^2	0.932	0.936	0.940	0.950
N	360	360	360	360

***, **, and * indicate the significance level of 1%, 5% and 10% respectively. Numbers in brackets are robust standard errors.

force allocation and affects the diversification of family livelihood, which limits the growth of family income (Asfaw et al., 2019). Natural disaster rate also has a significant negative effect on farmer income. Natural disasters damage agricultural profits by reducing the production and quality of agricultural products. Therefore, it is urgent to strengthen agricultural disaster prevention and reduction to reduce farmers' losses. The influence coefficient of electricity consumption on farmer income is significantly positive, mainly because robust rural economic infrastructure can promote agricultural production efficiency and labor transaction efficiency (Renkow et al., 2004; Teruel and Kuroda, 2005), driving agricultural production and broadening farmers' income channels.

4.2 Robustness test

To verify the robustness of the estimation result and avoid the impact of improper indicator selection, interference from other factors, and endogeneity problems on the regression results, this paper uses alternative variables, an adjusted sample period, and the instrumental variable method to enhance the reliability of the benchmark regression results.

4.2.1 Replace variables

Farmer consumption is used to reflect the income level of farmers, and land consolidation area is used to measure the construction of high-standard farmland. The results in columns (1) and (2) of Table 3 show that the impact of high-standard farmland construction on farmer income is significantly positive regardless of variable replacement, indicating that the results of benchmark regression is robust. Specifically, the result in column (1) shows that each 1,000 yuan/mu increase in the input of land consolidation can increase the consumption of rural residents by 2,484 yuan, which is close to the result of benchmark regression. The result in column (2) shows that if the area of land consolidation increases by 1 unit, the income of rural residents can increase by 32 yuan.

4.2.2 Adjust the sample period

The sample time span is adjusted to 2006–2011 in this paper. As noted in the policy evolution section, during 2006 to 2011, the construction of high-standard farmland was still in a preliminary phase. In general, the construction of high-standard farmland during this period lacked standardization and the scope and area of construction were small. If the construction in this period can also produce a significant income increasing effect, it suggests that the result of benchmark regression is robust. The result in column (3) of Table 3 shows that the impact coefficient of HINPUT is positive at the level of 1%, indicating that the construction of high-standard farmland has a significant effect on farmer income, which is consistent with the results of benchmark regression. More importantly, by comparing the estimated results of column (4) in Table 2 and column (3) in Table 3, we found that compared with the period from 2006 to 2011, the income increasing effect of high-standard farmland construction is greater in the period from 2006 to 2017. This suggests that enhanced standardization and scale will improve the positive impact on farmer income.

TABLE 3 Robustness test.

	(1) Replace the explained variable	(2) Replace the core explanatory variable	(3) Adjusted sample period	(4) Instrumental variable method
HINPUT	2.484*** (0.497)		2.421*** (0.593)	3.093*** (0.372)
HRATE		0.032* (0.016)		
Capital	−0.243 (0.188)	0.227 (0.283)	−0.135 (0.271)	0.041 (0.168)
Labor	−0.001 (0.001)	−0.002* (0.001)	−0.000 (0.001)	−0.003*** (0.001)
Machine	−2.104 (2.042)	−1.319 (1.489)	−4.335* (2.459)	−1.416* (0.726)
Structure	0.015 (0.020)	0.008 (0.019)	0.027 (0.027)	0.019 (0.013)
Disaster	−0.003** (0.002)	−0.003 (0.002)	−0.003* (0.002)	−0.006** (0.003)
Electricity	−0.022 (0.163)	1.103*** (0.200)	4.703*** (1.602)	0.931*** (0.173)
Industry	0.026 (0.043)	0.057 (0.053)	0.010 (0.047)	0.042 (0.026)
Province fixed effect	Control	Control	Control	Control
Year fixed effect	Control	Control	Control	Control
Constant	5.233** (2.097)	2.257 (2.518)	4.023 (3.099)	
R^2	0.940	0.940	0.921	0.949
N	360	360	180	330

***, **, and * indicate the significance level of 1%, 5% and 10% respectively. Numbers in brackets are robust standard errors. To simplify the presentation of results, the results of the first stage of instrumental variable estimation are not reported in this paper, and can be obtained from the authors on request.

4.2.3 Consider endogeneity

Considering that areas with high agricultural income may pay more attention to agricultural production, the investment in the construction of high-standard farmland may be greater, which means that farmer income may affect the construction of high-standard farmland. Therefore, there may be reverse causality between high-standard farmland construction and farmer income. To weaken the estimation bias caused by endogeneity, this paper follows the method of Alfaro et al. (2004) and Li et al. (2021) and introduces the one-stage lag of the explanatory variable as an instrumental variable to conduct a robustness test. The parameter estimation result of the instrumental variable is 0.937, which is significant at 1%. The model passes the unidentifiable test of the instrumental variable and the weak instrumental variable test, indicating that the selection of HINPUT with a lag of one period as the instrumental variable is effective. In the estimation results of the instrumental variable method, the impact coefficient of HINPUT is significantly positive at the 1%, indicating that the construction of high-standard farmland can increase farmer income.

4.3 Mechanism test

The above benchmark regression results show that high-standard farmland construction can significantly increase farmer income. Theoretical analysis points out that the construction of high-standard farmland has the transmission mechanism to promote farmer income by reducing the cost of agricultural production, improving the benefit of agricultural management and non-farm income. Since the impact of production cost, management benefit and non-farm income on farmer income is obvious, this paper directly examines the impact of high-standard farmland construction on the above three mechanism variables to determine whether the three are important channels for high-standard farmland construction to affect farmer income.

Table 4 reports the estimated results of the model. As shown in column (1), the estimation coefficient of HINPUT is significantly negative, and an increase of 1,000 yuan/mu of the input of land consolidation can reduce the average cost of agricultural production per mu by 361 yuan. This is consistent with the conclusion of Do et al. (2023) that land consolidation can significantly reduce the corresponding agricultural production cost

TABLE 4 Impact mechanism test.

	(1) Cost	(2) Benefit	(3) Non-farm
HINPUT	−0.361* (0.212)	2.324*** (0.132)	4.135*** (0.449)
Control variables	Control	Control	Control
Province fixed effect	Control	Control	Control
Year fixed effect	Control	Control	Control
Constant	0.775 (0.520)	−0.672 (1.022)	0.078 (2.037)
R^2	0.852	0.860	0.848
N	320	360	360

*** and * indicate the significance level of 1% and 10% respectively. Numbers in brackets are robust standard errors. The control variables in column (1) (2) include not only the control variables in Table 2, but also the land size and the intensity of fertilizer use, which are closely related to agricultural input and output. Due to the absence of some years of agricultural production cost data in Beijing and Tianjin, the sample size is slightly smaller.

of rice-growing households in Vietnam. The result of column (2) shows that land consolidation improves the benefit of agricultural management at the significance level of 1%, and each 1,000 yuan/mu increase in the input of land consolidation can result in 2,324 yuan of benefit improvement. These results indicate that the construction of high-standard farmland reduces cost and improves agricultural benefit. Column (3) of Table 4 shows that the estimation coefficient of HINPUT is 4.135 and passes the significance test at the 1% level, indicating that the construction of high-standard farmland can effectively increase the non-farm income of farmers. These estimation results verify that the construction of high-standard farmland has the mechanism of reducing the cost of agricultural production, improving the benefit of agricultural management and increasing non-farm income to promote farmer income.

4.4 Heterogeneity analysis

This paper focuses on exploring the differential impacts of high-standard farmland construction from two dimensions: differences in economic and social development, and differences in topography and landscape. Table 5 reports the impact of the construction of high-standard farmland on farmer income as related to these variables.

4.4.1 Economic development dimension

This paper divides the study sample into more economically developed areas and less economically developed areas based on whether the sample per capita GDP is greater than the sample median. Columns (1) and (2) of Table 5 report the impact of the construction of high standard farmland on farmer income in these two areas. Results show that in more economically developed areas, the impact coefficient of HINPUT is significantly positive. In less economically developed areas, the impact coefficient is positive but not significant, indicating that the income-increasing effect of high-standard farmland construction is more obvious in more economically developed areas. We consider two possible reasons for this observation. The first is that the construction of high-standard farmland is a government-led engineering and construction project, relying mainly on local financial funds, which are directly affected by regional economic development. Therefore, more economically developed areas invest more heavily in the construction of high-standard farmland, which enhances any potential effects. Secondly, the marketization level in more economically developed areas is higher. These areas can not only absorb more agricultural labor released by the construction of high-standard farmland nearby, but can also bring more value-added income, which increases the wage income and property income of farmers.

4.4.2 Topographic and geomorphic dimension

Using the relief degree of land surface dataset of China measured by You et al. (2018)[2], we divided our sample area into low relief degree areas and high relief degree areas based on whether the relief degree of land surface is >1. Columns (3) and (4) of Table 5 report the impact of the construction of high-standard farmland on farmer income in these two types of areas. The results show that the estimation coefficient of HINPUT is significantly positive in low relief degree areas and not significant in high relief degree areas. This suggests that the construction of high-standard farmland is better able to promote the income of farmers in low relief degree area. Zhang and Yang (2021) also found that the income-increasing effect of farmland remediation in the plains was more pronounced than farmland remediation in mountainous areas. A possible reason for this is that areas with low topographical relief are more conducive to large-scale high-standard farmland construction, which further highlights the advantages of regional agricultural development and demonstrates the dual role of high-standard farmland construction in agricultural and non-farm production. In areas with high topographic relief, however, the construction of high-standard farmland is difficult and costly. Additionally, most of these areas have a comparatively poor economic development level, so the local government lacks enthusiasm in implementing high-standard farmland construction. This results in small-scale and poor-quality construction, making it more difficulty effectively playing the role of high-standard farmland construction.

5 Conclusions and implications

5.1 Conclusions

In most developing countries, land fragmentation is still an important factor hindering agricultural development and farmer incomes. Therefore, reducing the degree of land fragmentation is crucial to developing modern agriculture and raising farmer income levels in these areas. Globally, land consolidation has long been used as a powerful tool for dealing with land fragmentation.

2 Relief degree is measured by variations in terrain at the average altitude in a certain area, and it is an important indicator for classifying landform types.

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TABLE 5 Heterogeneity analysis: regional differences.

	(1) More economically developed areas	(2) Less economically developed areas	(3) High relief degree areas	(4) Low relief degree areas
HINPUT	2.520*** (0.754)	1.208 (1.088)	−1.032 (1.336)	2.112*** (0.610)
Control variables	Control	Control	Control	Control
Province fixed effect	Control	Control	Control	Control
Year fixed effect	Control	Control	Control	Control
Constant	2.798 (2.202)	−0.477 (1.354)	6.336** (2.319)	2.523 (2.721)
R^2	0.959	0.973	0.981	0.964
N	180	180	132	228

*** and ** indicate the significance level of 1% and 5% respectively. Numbers in brackets are robust standard errors. Control variables are same as Table 2.

China has long been committed to addressing the issue of land fragmentation to guarantee food security and transform agricultural development. At present, the nation is using high-standard farmland construction as a starting point to promote land consolidation. This paper constructs a theoretical framework to analyze the impact of high-standard farmland construction on farmer income. Based on the panel data from 30 provinces in China from 2006 to 2017, we use the two-way fixed effects model to quantitatively examine whether high-standard farmland construction can promote farmer income and the mechanisms behind it.

The major findings of this paper are three-fold. (1) High-standard farmland construction can significantly increase farmer income. (2) This increase occurs in three main ways: reducing agricultural production cost, improving agricultural management benefit and expanding non-farm income. (3) The income-increasing effect of high-standard farmland construction presents obvious regional imbalances. This manifests in the fact that high-standard farmland construction has a more significant income-increasing effect on farmers in more economically developed and low relief degree areas, while it has no significant effect on farmers in less economically developed and high relief degree areas. China's achievements in the construction of high-standard farmland show that land consolidation in developing countries has good economic benefits, and this project also provides practical experience for developing countries to carry out land consolidation.

5.2 Policy implications

We recommend three relevant policy suggestions based on our findings. First, local governments should strictly implement a new round of high-standard farmland construction policies and continue to promote the improvement of agricultural production conditions. It is necessary for government at all levels to increase investment in the construction of high-standard farmland and improve standards and implementation rules. To ensure the long-term benefits of high-standard farmland construction, local governments should use digital platforms to store and manage high-standard farmland construction information.

Second, governments should aim to the scale of farmland and services. In the process of promoting high-standard farmland construction, land leveling and consolidation should be closely integrated with the adjustment of land ownership and the transfer of farmland to promote the concentration and contiguity of farmland. The agricultural socialized service system should be improved to deepen the vertical division of agricultural labor and promote the transfer of agricultural labor force to the secondary and tertiary industries.

Third, we need to account for variations in construction shortcomings to maximize benefits to the greatest number of farmers as possible. In its early stages, the construction of high-standard farmland focused on areas with more robust economies and better natural conditions. In the future, while consolidating the results of the previous period, we should increase investment in the construction of high-standard farmland in less economically developed regions with poorer natural conditions through multiple channels, gradually improving cost-sharing mechanisms. At the same time, we should strengthen the efficiency of the use of funds and give priority to areas where local agricultural production conditions are weak.

5.3 Limitations

The study still has some limitations that need to be further explored. First of all, due to the availability of data, it is difficult to obtain the latest annual information on the high-standard farmland construction, making it difficult to discuss the latest and continuous impact of high-standard farmland construction. Secondly, the information on high-standard farmland construction only remains at the provincial macro level, so it is impossible to further explore the impact and mechanism of high-standard farmland construction on individual farmers. In the future, we will be committed to the implementation of micro-level research on high-standard farmland construction, and understand the latest progress of high-standard farmland construction and explore its impact on individual farmers through field research and other means.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

XC: Conceptualization, Formal analysis, Investigation, Writing – original draft. ZX: Funding acquisition, Project administration, Writing – review & editing. GH: Data curation, Visualization, Writing – review & editing. QG: Supervision, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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