

Article

Transforming Rural Livelihoods Through Land Consolidation: Evidence from China's High-Standard Farmland Construction Policy

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Abstract

Rural livelihood transformation is increasingly vital for achieving agricultural modernization, reducing poverty, and promoting sustainable development in developing countries. Despite growing attention to land consolidation as a tool for improving agricultural resource allocation and productivity, its role in shaping rural livelihoods remains insufficiently understood. Addressing this gap, this study investigates the impacts of China's High-Standard Farmland Construction (HFC), the country's flagship land consolidation policy, on farmers' livelihoods, focusing on both income level and income structure. Using provincial panel data from 30 regions, we adopt a continuous difference-in-differences design and mediation effect model to identify the causal effects of HFC. The results indicate that HFC significantly promotes total household income. Specifically, HFC facilitates mechanized agricultural production by consolidating fragmented plots, reducing production costs, and improving crop yields, thereby increasing agricultural income. Simultaneously, mechanization substitutes for labor and releases surplus workers, who often move to off-farm employment, diversifying income sources and stabilizing household livelihoods. Heterogeneity analysis reveals that the benefits of HFC are unevenly distributed. Low-income households, central provinces, and major grain-producing areas experience the greatest gains, and moderate-scale implementation proves more effective than either small- or excessively large-scale projects. This study highlights mechanization as a key mechanism linking land consolidation to rural livelihood transformation. The findings demonstrate that well-planned and efficiently implemented HFC policies can not only enhance agricultural productivity but also foster diversified and inclusive rural livelihoods.



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1. Introduction

Rural households often face multiple challenges that limit their livelihoods, including small and fragmented landholdings, low agricultural productivity, overreliance on single crops, and limited access to non-farm employment opportunities. These constraints reduce income stability, restrict economic resilience, and hinder households from adapting to environmental and market shocks [1]. Consequently, promoting the transformation of rural livelihoods has become increasingly urgent, with the goal of improving both income levels and diversification. Land, as the fundamental productive asset, underpins agricultural

output and livelihood strategies. Land consolidation has been extensively adopted as a policy instrument aimed at optimizing land utilization and strengthening agricultural productivity. Empirical studies have shown that it not only improves land quality and availability [2,3], but also contributes to rural revitalization and sustainable regional development [4–6]. This approach has successfully mitigated the inefficiencies caused by land fragmentation and promoted more effective resource allocation in agriculture across many European countries [7–9].

In China, however, rapid urban expansion has encroached upon arable land, particularly in the southeastern coastal provinces, causing a decline in cultivable area [10,11]. Simultaneously, climate change and the increasing frequency of natural disasters have shifted the geographic center of agricultural production northward [12], exposing the spatial mismatch between water and soil resources [13,14]. Moreover, while the household contract responsibility system once boosted agricultural output, it has also resulted in excessive land fragmentation, raising production costs and limiting the scalability of mechanized operations [15,16]. These structural inefficiencies have undermined land-use efficiency and rural poverty and inequality [17].

Since 2008, China's land consolidation policy has centered on farmland amalgamation, the protection of permanent basic farmland, and the construction of high-standard agricultural land [18]. The launch of the National Land Improvement Plan (2011–2015) established technical guidelines for high-standard farmland implementation, which has since become the dominant mode of land consolidation in China. The primary goal of HFC is to transform fragmented, low-productivity plots into consolidated and fertile farmland while upgrading agricultural infrastructure to boost both economic productivity and ecological sustainability [19,20]. China has invested heavily in this program, namely, 15.02 billion USD, resulting in 66.67 million hectares of high-standard farmland in 2022. The National High-standard Farmland Construction Plan (2021–2030) targets 80 million hectares by 2030. Evaluating the policy impact of HFC is thus essential for guiding future policy implementation.

Following the implementation of HFC, scholars have examined its effects from various perspectives. Wang et al. (2022) [21] constructed an evaluation framework using the entropy weight method to quantitatively assess the economic, ecological, and social benefits of HFC. Empirical evidence shows that HFC improves farmland infrastructure and soil quality, alleviates land fragmentation, and enhances agricultural production efficiency [22–25]. Beyond economic outcomes, it also strengthens agricultural resilience to climate shocks, supporting national food security objectives [26]. From an ecological standpoint, HFC has improved water resource management, reduced energy inputs, and enhanced the efficiency of agricultural chemical use [27]. Moreover, it helps to mitigate greenhouse gas emissions [28]. Socially, HFC contributes to poverty alleviation by increasing yields and facilitating the adoption of modern technologies, thereby improving rural living standards [5].

Despite this growing body of evidence, relatively little attention has been paid to how HFC influences farmers' livelihood transformation. The sustainable livelihoods framework proposed by the UK Department for International Development offers a valuable lens for understanding how rural households allocate and utilize their resources to maintain and enhance their livelihoods. As land systems evolve, households adjust their livelihood strategies in response to changing human–land relationships [29]. Within this framework, HFC can reshape the composition, quality, and accessibility of land-based livelihood capital [19], influencing both agricultural and non-agricultural income sources. However, the specific pathways through which HFC affects farmers' livelihood transformation remain insufficiently studied. This gap limits understanding of how land consolidation fosters rural development household resilience.

Therefore, this study analyzes the impacts of HFC on farmers' livelihood transformation using the continuous difference-in-differences (DID) method and provincial panel data from China spanning 2004 to 2017. It further explores the mediating role of mechanized production and investigates heterogeneity. This study makes three main contributions. First, by drawing on the sustainable livelihood framework, it develops a theoretical model of "HFC–farmers' mechanized production strategy–livelihoods transformation" to reveal the mechanisms linking land consolidation to income diversification. Second, treating the HFC policy as a quasi-natural experiment and employing DID strategy allows for the identification of the net causal effects of HFC implementation while controlling for time-invariant unobservable heterogeneity across provinces, thereby enhancing the robustness and credibility of the findings. Finally, it conducts heterogeneity analysis across different land endowments, providing nuanced insights for designing more inclusive and diversified rural development policies.

2. Theoretical Analyses and Research Hypotheses

Rural livelihood transformation entails not only increasing household total income but also diversifying income sources to strengthen resilience against environmental, market, and institutional shocks. Agricultural income is inherently volatile, being highly sensitive to weather conditions, pests, and market fluctuations [1]. In contrast, non-agricultural income, such as wage earnings from off-farm employment, tends to be more stable and less exposed to natural risks. Therefore, promoting both income growth and diversification is essential for improving rural welfare. It raises total income levels, stabilizes livelihood structures, enhances economic resilience, and reduces vulnerability to external disturbances. Against this backdrop, land consolidation policies, particularly HFC provide an institutional and infrastructural foundation for increasing agricultural productivity while facilitating labor reallocation, thereby supporting both income growth and livelihood stabilization.

HFC represents a form of direct public investment aimed at upgrading farmland quality and modernizing agricultural infrastructure. In practice, HFC involves not only the physical consolidation of fragmented plots and the construction of field roads, irrigation, and drainage systems, but also systematic improvements in soil fertility and ecological conditions. Measures such as deep plowing, soil loosening, straw return, and organic fertilizer application enhance soil structure and nutrient retention, while ecological facilities including shelterbelts, terraces, and water-conservation systems mitigate erosion, improve microclimatic conditions, and strengthen biodiversity. Together, these efforts enhance both the physical accessibility and ecological functionality of farmland. By integrating infrastructure upgrading with soil and ecological improvements, HFC enhances land productivity and ecological resilience, thus laying a stronger foundation for income growth and diversified livelihood strategies [5]. Specifically, HFC facilitates the formation of larger, contiguous plots that enable efficient, mechanized operations and reduce per-unit production costs [25]. Mechanization not only substitutes for increasingly scarce and costly rural labor but also improves standardization and precision in farming activities such as sowing, fertilization, and harvesting. These improvements lead to higher productivity and lower volatility in agricultural output. At the same time, upgraded infrastructure, such as field roads and irrigation and drainage systems, further enhances operational efficiency and reduces farmers' exposure to natural and market risks [27]. As a result, HFC enhances agricultural income while simultaneously freeing surplus labor for off-farm employment, thereby promoting both income diversification and livelihood stabilization [5,30].

The resulting improvements in land productivity and risk reduction alter farmers' land-use behavior and income strategies. Households with comparative advantages in agricultural may expand their operations through transferring in land, benefiting from

economies of scale and reduced per-unit production costs [31]. Conversely, those with better non-agricultural employment opportunities may transfer out their land to earn rental income while engaging in wage-based non-agricultural work [32]. This dual-pathway mechanism illustrates how HFC promotes agricultural intensification and land market participation, thereby contributing to higher and more diversified household income.

H1. *HFC increases farmers' total income.*

HFC significantly improves the structural and spatial conditions required for mechanized agricultural production. By consolidating fragmented and irregularly shaped small plots into larger, more contiguous land parcels, HFC reduces the operational complexity of using agricultural machinery and lowers associated production costs [33,34]. Larger and better-organized fields are more compatible with advanced machinery, thus encouraging the modern mechanization technologies [35,36]. Mechanization enhances production efficiency through several mechanisms. First, machinery replaces manual labor, reducing dependence on increasingly expensive rural labor, this is commonly referred to as the labor substitution effect [37,38]. Second, mechanized operations improve standardization and precision in sowing, fertilization, and harvesting, thereby optimizing the use of agricultural inputs and enhancing resource efficiency [39]. These improvements contribute to higher crop yields and more stable agricultural outputs, thus boosting agricultural income.

Beyond its direct benefits to agricultural production, the adoption of mechanization has indirect socioeconomic effects. By substituting labor in agricultural activities, it releases surplus rural labor, many of whom shift to off-farm employment in the secondary and tertiary sectors. The resulting income diversification allows households to combine higher agricultural earnings with relatively stable non-agricultural income, improving overall livelihood stability.

In summary, HFC increases household income through improvements in agricultural productivity but also facilitates labor reallocation that contributes to non-agricultural income growth. By simultaneously raising agricultural returns and promoting off-farm employment, HFC supports both income growth and livelihood transformation in rural areas.

H2. *HFC promotes mechanized production, thereby increasing farmers' agricultural income.*

H3. *HFC promotes mechanized production, thereby increasing farmers' non-agricultural income.*

3. Material and Methods

3.1. Model Setting

In 2011, the Chinese government officially introduced and implemented the National Land Improvement Plan (2011–2015), marking the beginning of the standardized implementation of HFC at both national and regional levels. The continuous variation in HFC area across provinces indicates that the treatment variable is not binary but continuous. Following existing research, a continuous DID model is adopted to objectively identify treatment intensity without imposing arbitrary group boundaries, thereby yielding more precise causal estimates.

3.1.1. Parallel Trend Test Model

Before estimating the DID model, it is necessary to verify the parallel trend assumption. To distinguish pre- and post-policy dynamics, the HFC implementation process is divided into the exploratory (2004–2010) and the standardized implementation phase (2011–2017), with 2004 as the reference year. The test model is formulated as follows:

$$\ln Income_{i,t} = \beta_0 + \sum_{2004}^{2017} \beta_i \ln High_i \times D(t = k) + \beta_2 X_{i,t} + \gamma_i + u_t + \varepsilon_{i,t} \quad (1)$$

where $\ln Income_{i,t}$ denotes the farmers' income in province i in year t (log-transformed); $\ln High_i$ denotes the HFC area (log-transformed); D denotes the dummy variable for the year; $X_{i,t}$ denotes the matrix of control variables; γ_i and u_t represent province and year fixed effect, respectively; and $\varepsilon_{i,t}$ is the random error term. If the coefficients of the pre-policy years are statistically insignificant, the parallel trend assumption holds.

3.1.2. DID Model

To identify average treatment effect of HFC after the standardized implementation, the DID model is constructed as follows:

$$\ln Income_{i,t} = \beta_0 + \beta_1 \ln High_i \times I_t^{post} + \beta_2 X_{i,t} + \gamma_i + \mu_t + \varepsilon_{i,t} \quad (2)$$

where I_t^{post} represents the dummy variable indicating the timing of the standardized implementation of HFC, equal to 1 for years ≥ 2011 , and 0 otherwise. The definitions of other variables and coefficient settings are consistent with those in Equation (1). The estimated parameter β_1 represents the net impact of HFC on farmers' income, controlling for time-invariant unobservable heterogeneity across provinces. A significantly positive β_1 indicates that HFC effectively enhances rural income.

3.1.3. Mediation Effect Model

To identify the channels linking HFC to farmers' income, the study adopts the following mediation analysis framework:

$$Medi_{i,t} = \alpha_0 + \alpha_1 \ln High_i \times I_t^{post} + \alpha_2 X'_{i,t} + \gamma_i + \mu_t + \varepsilon_{i,t} \quad (3)$$

$$\ln Income_{i,t} = \varphi_0 + \varphi_1 \ln High_i \times I_t^{post} + \varphi_2 Medi_{i,t} + \varphi_3 X_{i,t} + \varphi_i + \mu_t + \varepsilon_{i,t} \quad (4)$$

where Med_i is the mediator variable. If α_1 is significantly positive, it suggests that HFC enhance the level of agricultural mechanization. Then incorporates the mediator variable into the baseline model. If the coefficient φ_1 in Equation (4) is significantly positive and less than β_1 , it can be concluded that the HFC positively influences both agricultural and non-agricultural income through improvements in agricultural mechanization.

3.2. Variable Selection

To capture rural livelihoods transformation, this study focuses on both the income levels and composition, reflecting households' capacity to diversify and stabilize their livelihoods. The dependent variable is farmers' income, which includes total income, agricultural income, and non-agricultural income. Farmers' total income is measured by per capita disposable income, while agricultural income refers to operating agricultural income. All income variables are log-transformed and deflated using the 2004 rural consumer price index to account for inflation.

The key explanatory variable is the interaction between HFC area and the policy dummy. Consistent with prior research [26,40,41], the HFC area includes both renovated low- and medium-yield farmland and high-standard farmland. As a robustness check, the model alternatively measures HFC intensity using central government investment in integrated agricultural development, which supports farmland improvement, irrigation infrastructure, and water-saving facilities.

The mediator variable is agricultural mechanization, measured by the total agricultural machinery power (log-transformed). This indicator, widely used in prior studies [6,42], effectively reflects the mechanization level in agricultural production.

Following previous studies [28,36], control variables include infrastructure, economic development, urbanization, human capital, financial support, agricultural investment, industrial structure, and natural capital. All capital-related variables are deflated to ensure comparability. Detailed descriptive statistics are provided in Table 1.

Table 1. Variable definitions and descriptive statistics.

Variables	Definition	Mean	Std.	Min	Max
Total income	ln per capita disposable income	8.573	0.519	7.532	9.765
Agricultural income	ln agricultural operating income	7.734	0.402	6.574	8.532
Non-agricultural income	ln sum of wage, property and transfer income	7.884	0.777	6.223	9.644
HFC area	ln sum of renovated low- and medium-yield farmland and high-standard farmland	7.216	0.816	5.105	8.443
Mechanized production	ln total power of agricultural machinery	7.551	1.068	4.607	9.401
Economic development	ln GDP	6.888	5.396	0.466	26.100
Urbanization	Percentage of urban resident population (%)	0.518	0.144	0.260	0.896
Industrial structure	Proportion of non-agricultural industries (%)	0.887	0.060	0.631	0.997
Infrastructure	Total road mileage per 100 km ²	0.701	0.471	0.030	2.110
Financial support	Percentage of local general government expenditure in GDP (%)	0.135	0.058	0.006	0.327
Agricultural investment	ln rural economic activities for the construction and acquisition of fixed assets	4.855	1.124	0.827	6.574
Human capital	Weighted average years of rural education (years)	7.468	0.685	5.149	9.797
Natural capital	Total sown area of crops (million ha)	0.549	0.490	0.012	7.290

Source: Authors' estimates from balanced panel data, 2004–2017.

3.3. Data Sources

Since the HFC data are unavailable after 2017, this study uses balanced panel data from 30 provinces in China, excluding Hong Kong, Macao, Taiwan, and Tibet, covering 2004–2017. Data on income, rural investment, mechanization, and sown area, all derived from the China Rural Statistical Yearbook. Data on HFC area and fiscal expenditures are obtained from the China Financial Statistical Yearbook. Education and urbanization data are sourced from the Statistical Yearbook of Population and Employment in China. Regional GDP and industrial structure data are obtained from the China Statistical Yearbook, while road mileage data are taken from the China Transportation Yearbook.

4. Results and Discussion

4.1. Parallel Trend Test

Ensuring the validity of the DID estimator requires that the parallel trend assumption holds. If this assumption holds, the effect of the HFC policy on farmers' income w should emerge only after the policy's implementation, while the dynamic impacts prior

to policy should remain statistically insignificant and fluctuate around zero. To verify this, we estimate the interaction coefficients between HFC area and year dummies based on Equation (1), separately for the pre-policy period (2004–2010) and post-policy period (2011–2017). Figure 1a,b plot coefficients of the dynamic effects graph, with and without control variables, within a 90% confidence interval.

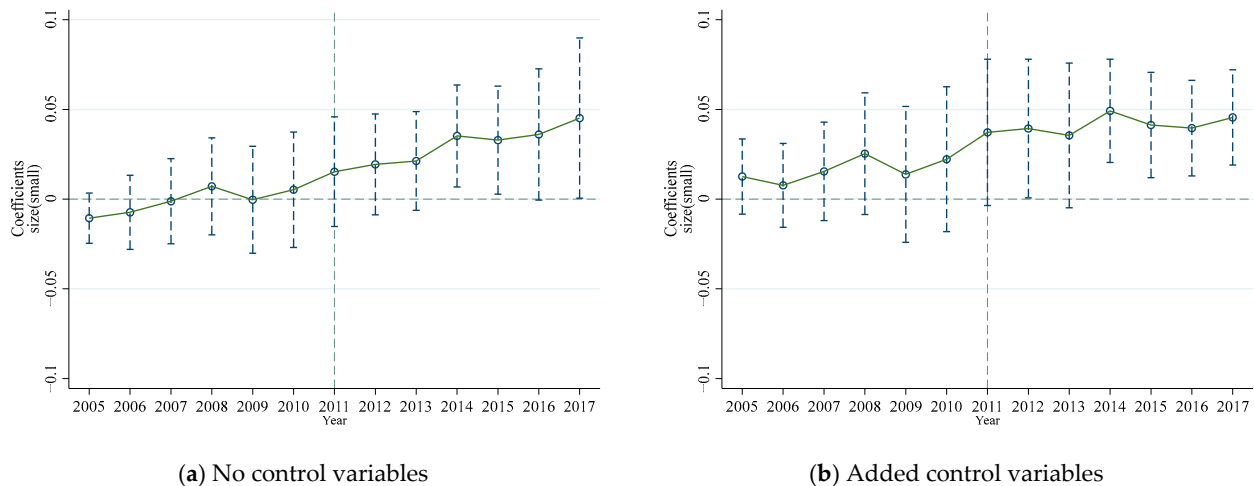


Figure 1. Parallel trend test.

As shown in Figure 1, the 90% confidence intervals for the estimated coefficient β_t prior to policy implementation consistently include zero, indicating no statistically significant differences in β_t related to the HFC policy. In contrast, during the two-year period following policy implementation, the 90% confidence interval for β_t excludes zero, signifying significant differences in β_t during these years as a result of the HFC policy. Moreover, the coefficients display a clear upward trend in the years following implementation, indicating that the policy's influence on farmers' income has gradually strengthened over time. In addition, to ensure robustness against potential bias from staggered policy implementation, we re-estimated the dynamic effects using the heterogeneity-robust event-study estimator following previous study [43]. The results were highly consistent with the baseline findings, confirming the absence of pre-trends and the sustained positive impact of the HFC policy over time.

The results of the dynamic policy effects are presented in Table 2. Before HFC policy implementation, the coefficient β_t remains statistically insignificant, confirming the absence of pre-existing differences. Starting from 2011, however, the coefficient β_t turns positive and increases steadily from 0.039 in 2012 to 0.045 in 2017. These findings validate the parallel trend assumption and indicate that the impact of the HFC policy becomes evident after a one-year lag.

Table 2. Results of dynamic policy effects.

Variable	(1)	(2)
lnHFC2005	−0.009 (0.008)	0.012 (0.012)
lnHFC2006	−0.006 (0.012)	0.008 (0.014)
lnHFC2007	0.000 (0.014)	0.015 (0.016)

Table 2. *Cont.*

Variable	(1)	(2)
lnHFC2008	0.008 (0.016)	0.025 (0.020)
lnHFC2009	0.001 (0.017)	0.014 (0.022)
lnHFC2010	0.006 (0.019)	0.022 (0.023)
lnHFC2011	0.017 (0.018)	0.037 (0.023)
lnHFC2012	0.021 (0.016)	0.039 * (0.022)
lnHFC2013	0.023 (0.016)	0.035 (0.023)
lnHFC2014	0.036 ** (0.017)	0.049 *** (0.017)
lnhiHFC2015	0.034 * (0.018)	0.041 ** (0.017)
lnHFC2016	0.037 * (0.022)	0.040 ** (0.016)
lnHFC2017	0.047 * (0.027)	0.045 *** (0.016)
Control variables	No	Yes
Province-fixed effect	Yes	Yes
Time-fixed effect	Yes	Yes
Constant	8.003 *** (0.010)	7.274 *** (0.247)
Sample size	420	420
R ²	0.986	0.990

Note: ***, **, * denote statistical significance at the 1%, 5%, and 10% levels, respectively (applies throughout the text).

4.2. The Result of DID Model

The results of the DID estimation assessing the effect of HFC on total household income are presented in Table 3. Models (1) to (4) display the outcomes of stepwise regression analyses. Across all specifications, the coefficient on HFC remains significantly positive, indicating that HFC implementation leads to a statistically meaningful increase in farmers' income. This provides strong empirical support for H1, suggesting that land consolidation under HFC enhances household income levels, which is a key dimension of livelihood transformation.

Table 3. The result of the DID model.

Variables	(1)	(2)	(3)	(4)
Interaction term (area)	0.031 * (0.016)	0.022 ** (0.009)	0.023 ** (0.008)	0.024 *** (0.008)
Economic development		−0.016 ** (0.007)	−0.025 *** (0.008)	−0.025 *** (0.008)

Table 3. Cont.

Variables	(1)	(2)	(3)	(4)
Urbanization		0.825 *** (0.261)	0.743 *** (0.252)	0.740 *** (0.253)
Industrial structure		0.599 * (0.312)	0.440 (0.320)	0.432 (0.317)
Infrastructure			0.102 ** (0.037)	0.106 *** (0.037)
Financial support			−0.089 (0.187)	−0.090 (0.187)
Agricultural investment			0.014 (0.017)	0.013 (0.017)
Human capital				0.013 (0.019)
Natural capital				0.009 ** (0.003)
Time fixation effect	Yes	Yes	Yes	Yes
Province fixed effect	Yes	Yes	Yes	Yes
Constant	8.003 *** (0.010)	7.225 *** (0.214)	7.350 *** (0.215)	7.268 *** (0.247)
Sample size	420	420	420	420
F-statistic	827.30	2325.69	1676.05	2794.17
R ²	0.986	0.989	0.990	0.990

Note: ***, **, * denote statistical significance at the 1%, 5%, and 10% levels, respectively (applies throughout the text). Source: Authors' own results obtained using Stata17.

The positive effect of HFC on total income underscores its function as a public investment that improves land productivity and creates favorable conditions for rural development. These findings are consistent with international experiences. For instance, investments in Iran's water sector and agricultural research and development (R&D) in the United States have been shown to substantially boost agricultural incomes and stimulate rural economic development [44,45]. Nevertheless, the effectiveness of such investments in poverty reduction has been found to vary considerably across sectors and regions, depending on implementation efficiency and institutional context [46].

Aligned with these insights, the results indicate that HFC, as a state-driven agricultural infrastructure initiative, significantly enhances total household income. Moreover, the income gains associated with HFC contribute to broader goals of rural poverty reduction. Although the analytical framework employed in this study differs from that of Peng et al. (2022) [5], the consistency in empirical results reinforce the credibility and generalizability of our conclusions.

4.3. Robustness Tests

4.3.1. Placebo Test

A placebo test is employed to verify whether the observed impact on farmers' income arises from other policy changes or random factors. In this study, the placebo test is conducted by randomly generating an experimental group 500 times by re-generating the interaction term. The kernel density distributions of the resulting coefficients and *p*-values are presented in Figures 2 and 3. As shown in Figure 2, all the regression coefficients are less than 0.024 and follow a normal distribution centered around zero. This suggests

that no significant influencing factors have been omitted from Equation (2), and that the income effect is attributable to the HFC. Similarly, Figure 3 demonstrates that the majority of p -values exceed 0.1, indicating that the estimation results are unlikely to arise from random noise.

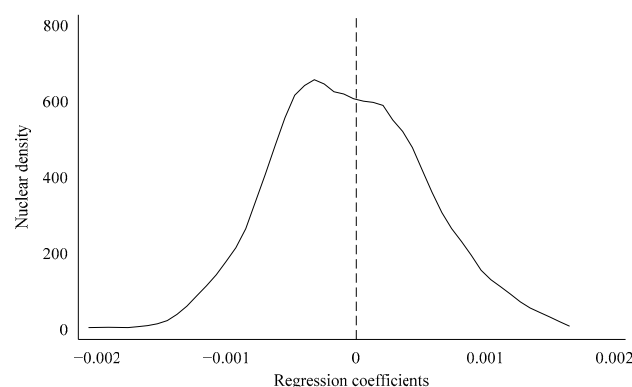


Figure 2. Coefficient kernel density plot.

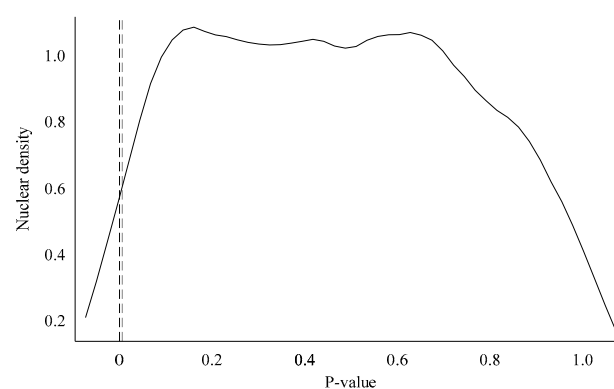


Figure 3. p -value kernel density plot.

4.3.2. Goodman–Bacon Decomposition

To examine the robustness of the DID estimates under staggered policy implementation, we applied the Goodman–Bacon decomposition. The comparison between treated and never-treated provinces accounts for 89.4% of the total weight, with an estimated effect of 0.044 as shown in Table 4. The comparisons between early- and late-treated groups contribute only 10.6% in total, with small estimates (-0.018 and 0.046). The overall weighted DID estimate (0.040) is highly consistent with the main results, indicating that the policy effect is mainly driven by valid treated–control comparisons. Hence, heterogeneous treatment timing does not introduce substantial bias, confirming the robustness of the TWFE estimates.

Table 4. Goodman–Bacon Decomposition Results.

Type of Comparison	Weight	ATE
Early-treated group vs. Late-treated group	0.068	-0.018
Late-treated group vs. Early-treated group	0.038	0.046
Treated group vs. Never-treated group	0.894	0.044
Weighted DID estimate		0.040

Source: Authors' own elaboration.

4.3.3. Alternative Specifications

Considering that the effects of HFC on farmers' income may not occur instantaneously but rather manifest gradually, potential time-lag effects are examined. To mitigate endogeneity concerns, a one-period lag of both the dependent and control variables is incorporated into Equation (2). The results, reported as (1) in Table 5, show a significantly positive coefficient, aligning with the benchmark regression. Furthermore, the coefficient exceeds that of the baseline model, implying that the income effect of HFC emerges with a temporal lag.

Table 5. Robustness test for replacing variables.

Robustness Test Method	Variables	(1)	(2)
Consider the time lag in the effect	Interaction term (area)	0.028 *** (0.008)	
Replace the core explanatory variable	Interaction item (investment)		0.030 *** (0.010)
Control variables		Yes	Yes
Province fixed effect		Yes	Yes
Time fixation effect		Yes	Yes
Constant		7.128 *** (0.232)	7.206 *** (0.240)
Sample size		390	420
R ²		0.990	0.990

Note: ***, **, * denote statistical significance at the 1%, 5%, and 10% levels, respectively (applies throughout the text). Source: Authors' own elaboration. Source: Authors' own elaboration.

Additionally, to further ensure robustness, the measurement of the HFC is replaced with the level of integrated agricultural development investment. The results, presented as (2) in Table 4, remain significant and consistent with the benchmark regression. Overall, these robustness checks confirm that the HFC policy exerts a positive and reliable impact on farmers' income, thereby confirming hypothesis H1.

4.4. Mechanism Analysis

The mediation analysis results are summarized in Table 6. Model (1) reveals that HFC significantly promotes the adoption of mechanized agricultural production, with a coefficient of 0.128. This indicates that HFC enhances both the structural and operational conditions required for mechanization, including larger and more contiguous plots, improved field infrastructure, and reduced operational complexity.

Furthermore, (3), (5), and (7) indicate that mechanized production partially mediates the effect of HFC on total household income, agricultural income, and non-agricultural income, with estimated coefficients of 0.016, 0.070, and 0.042, respectively. To mitigate potential endogeneity, we re-estimated the mediation model using the one-period lag of mechanization as an instrumental variable (Table A1). The results remain consistent with those in Table 6. These results confirm that mechanization serves as a critical transmission channel linking land consolidation policies to rural livelihood transformation. Specifically, mechanized production increases agricultural productivity by reducing labor intensity, improving input efficiency, and stabilizing crop yields, thereby boosting agricultural income. Simultaneously, mechanization releases surplus labor, which can be reallocated to non-agricultural activities, expanding income diversification and enhancing household economic resilience.

Table 6. The result of mediation effect model.

Variables	Mechanization	Total Income		Agricultural Income		Non-Agricultural Income	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Interaction item	0.128 ** (0.047)	0.024 *** (0.008)	0.016 * (0.009)	0.110 ** (0.043)	0.070 ** (0.031)	0.058 ** (0.023)	0.042 * (0.024)
Mechanization			0.060 ** (0.027)		0.309 *** (0.074)		0.127 ** (0.058)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Province fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time fixation effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	6.236 *** (1.353)	7.268 *** (0.247)	6.890 *** (0.347)	6.387 *** (0.593)	4.460 *** (0.812)	5.424 *** (0.649)	4.631 *** (0.659)
R ²	0.643	0.990	0.991	0.852	0.883	0.978	0.979

Note: ***, **, * denote statistical significance at the 1%, 5%, and 10% levels, respectively (applies throughout the text). Source: Authors' own elaboration.

These conclusions are in line with prior studies emphasizing the role of HFC in boosting agricultural yields and production efficiency [47]. Prior research has shown that land consolidation initiatives reduce labor demand in agricultural production, and enable surplus rural labor to shift into non-agricultural sectors, thereby raising household non-farm income [48]. From a broader livelihood transformation perspective, these results indicate that HFC not only raises income levels but also improves the sustainability, rationality, and diversity of livelihood strategies. Farmers become better equipped to balance agricultural and non-agricultural activities, adapt to environmental and market shocks, and pursue more resilient livelihood pathways [49].

Overall, the results demonstrate that the HFC contributes to enhancing the sustainable development capabilities of farmers' household livelihoods. These results not only enrich the evaluation of high-standard farmland policy but also provide important implications for poverty alleviation and rural revitalization policymaking.

4.5. Heterogeneity Analysis

4.5.1. Income Heterogeneity

This study explores how the income effects of HFC vary across different income groups. The results, presented in Table 7 (1) and (2), reveal that HFC exerts a statistically significant positive effect on the income of low-income households at the 1% significance level, while the effect on high-income households is statistically insignificant. These findings suggest that low-income farmers are more responsive to land consolidation policies, exhibiting higher income elasticity. By improving access to productive land resources and enhancing the efficiency of input allocation, HFC disproportionately benefits lower-income groups, thereby contributing to fostering inclusive income growth.

The disparity underscores that HFC not only raises average household income but also helps reduce income inequality, a critical consideration for sustainable rural development. Inclusive growth ensures that both productivity enhancement and equitable distribution are achieved simultaneously. In this sense, HFC plays a dual role: stimulating agricultural productivity and household income on one hand, and enhancing social equity by delivering more substantial benefits to disadvantaged groups. These results hold important policy implications, highlighting that land consolidation programs such as HFC can serve as effective instruments not only for rural economic revitalization but also for promoting balanced regional development and social inclusion [50].

Table 7. Income and regional heterogeneities.

Variables	(1) Low	(2) High	(3) Major	(4) Non-Major	(5) Eastern	(6) Central	(7) Western
Interaction item	0.040 *** (0.014)	0.006 (0.010)	0.104 *** (0.024)	0.027 ** (0.013)	0.017 * (0.010)	0.056 *** (0.020)	0.026 ** (0.011)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Province fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time fixation effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	7.362 *** (0.262)	6.819 *** (0.371)	6.869 *** (0.169)	7.104 *** (0.277)	8.451 *** (0.358)	6.679 *** (0.335)	6.874 *** (0.214)
R ²	0.985	0.988	0.996	0.991	0.992	0.997	0.994

Note: ***, **, * denote statistical significance at the 1%, 5%, and 10% levels, respectively (applies throughout the text). Source: Authors' own elaboration.

Moreover, from the perspective of farmers' perceptions, most households are generally supportive of converting their land into high-standard farmland, as it brings notable gains in productivity and income. Nevertheless, challenges emerge in the post-construction phase. Although farmers are the main beneficiaries, shared infrastructure, such as rural roads, irrigation systems, and power facilities often suffers from a "free-rider" problem, resulting in weak incentives for long-term maintenance and management [51]. The current implementation of HFC remains largely construction-oriented, with insufficient emphasis on sustained management, which may compromise the durability of its benefits [52].

4.5.2. Regional Heterogeneity

Given China's vast geographical diversity and pronounced disparities in regional resource endowments, industrial structures, and stages of economic development, this study further investigates the regional heterogeneity in the income effects of HFC. Provinces are first classified into major grain-producing areas and non-major grain-producing areas based on their functional roles in national grain production. The empirical results, reported in Table 7 (3) and (4), demonstrate that HFC increases farmers' income in both groups significantly. Notably, the estimated effect is substantially larger in major grain-producing regions, which aligns with the HFC policy's strategic emphasis on ensuring national food security and its preferential resource allocation toward key grain-producing zones.

To further examine spatial variation, provinces are also categorized into eastern, central, and western regions, reflecting differences in geographic location and levels of socio-economic development. The grouped regression results in Table 7 (5)–(7) show that HFC has a statistically significant positive impact on farmers' income across all three regions. However, the magnitude differs: the effect is strongest in the central region, followed by the western region, and weakest in the eastern region.

Several underlying factors may explain this variation. Many central provinces, especially those located in the Huang-Huai-Hai Plain, serve as core agricultural production areas and are thus primary targets of HFC investment and policy support. The region's strong institutional and infrastructural focus on agricultural modernization amplifies the income effect. Although the western provinces also benefit from HFC, their relatively underdeveloped agricultural infrastructure and harsher natural conditions limit the policy's immediate impact. Nevertheless, as agriculture remains a primary income source of income in the west and with some provinces specializing in animal husbandry, the HFC still plays a vital role in supporting rural livelihoods. On the other hand, the eastern region, despite its economic advancement and superior infrastructure, shows a relatively smaller marginal income gain from HFC, likely due to diminishing returns, as the baseline income level of

farmers is already high and much of the low-hanging fruit in productivity improvements has been realized.

In summary, these findings highlight the necessity of considering regional characteristics when evaluating the effectiveness of land consolidation policies. Tailoring implementation strategies to regional needs may enhance the efficiency and equity of policy outcomes across China's diverse rural landscape.

4.5.3. Scale Heterogeneity

Moderate-scale land management serves as a critical foundation for enhancing the efficiency of mechanized operations. To explore the heterogeneity of the HFC's income effect across different land management scales, a triple interaction term is constructed based on Equation (2), incorporating the proportion of farmers within each land management scales. The results, presented in Models (1) to (6) in Table 8, show that the HFC positively and significantly effects on income for management scales of 2–3.33 ha, 3.33–6.67 ha, and 6.67–13.33 ha. Moreover, the coefficients increase with expanding management scale.

Table 8. Scale heterogeneity.

Variable	(1)	(2)	(3)	(4)	(5)	(6)
$\ln \text{HFC} \times I_{2011} \times \text{scale}_{0-10}$	−0.008 (0.005)					
$\ln \text{HFC} \times I_{2011} \times \text{scale}_{10-30}$		0.012 (0.010)				
$\ln \text{HFC} \times I_{2011} \times \text{scale}_{30-50}$			0.031 * (0.017)			
$\ln \text{HFC} \times I_{2011} \times \text{scale}_{50-100}$				0.066 ** (0.032)		
$\ln \text{HFC} \times I_{2011} \times \text{scale}_{100-200}$					0.338 *** (0.140)	
$\ln \text{HFC} \times I_{2011} \times \text{scale}_{>200}$						0.272 (0.333)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Province fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Time fixation effect	Yes	Yes	Yes	Yes	Yes	Yes
Constant	6.978 *** (0.282)	6.987 *** (0.240)	6.938 *** (0.251)	6.870 *** (0.256)	6.938 *** (0.301)	6.965 *** (0.262)
R ²	0.988	0.988	0.988	0.988	0.988	0.988

Note: ***, **, * denote statistical significance at the 1%, 5%, and 10% levels, respectively (applies throughout the text). The models all added the single item of the interaction item, and the estimated result are omitted.

These findings indicate a non-linear relationship between landholding size and policy effectiveness. Moderate-scale land management provides the optimal structural environment for mechanization and efficient production, maximizing the benefits of HFC. This suggests that land consolidation efforts should be complemented by institutional support mechanisms, such as land transfer systems, cooperative farming, or service outsourcing to fully leverage the potential of high-standard farmland and support both agricultural intensification and livelihood diversification.

Moreover, the scale effect also reflects variations in farming organization. Smallholders typically depend on cooperative or service-based production models, while medium- and large-scale farms adopt fully integrated mechanized operations. HFC enhances the efficiency of each type in distinct ways: it improves land-use coordination and collective efficiency among smallholders, while facilitating technological upgrading and cost reduction

in larger operations. Recognizing and addressing these differentiated effects is essential for designing land consolidation policies that align with the diversity and structural evolution of rural production systems.

5. Conclusions

The HFC is a vital agricultural investment within China's food security strategy. This study investigates the impact of HFC on farmers' livelihood transformation, focusing on changes in both income levels and income structure, and explores the underlying mechanisms through theoretical and empirical analyses. The key findings are as follows: First, the HFC has a significant positive effect on household income, a finding that remains consistent across multiple robustness tests. By improving the quality of land-based livelihood capital through direct government investment, HFC effectively reduces production costs and increases household economic capacity. Second, the mechanism analysis indicates that the HFC raises both agricultural and non-agricultural income by the promotion of mechanization. By improving agricultural infrastructure, soil quality, and land fragmentation, HFC enhances agricultural productivity and profitability. Simultaneously, mechanization substitutes for manual labor, releasing surplus labor into non-farm employment. This labor reallocation fosters income diversification, strengthens household resilience, and contributes to sustainable livelihood transformation. Third, the effects of HFC vary across income groups, regions, and management scales. The HFC yields particularly strong benefits for low-income households, central regions, and major grain-producing areas. Additionally, significant improvements are observed when farmland management scales are within the ranges of 2–3.33 ha, 3.33–6.67 ha, and 6.67–13.33 ha.

This study contributes to the existing literature by developing a theoretical framework linking HFC, farmers' mechanized production strategies, and income outcomes. The findings reveal that HFC not only directly improves farmland quality and agricultural productivity but also indirectly enhances farmers' income by facilitating the substitution of labor with mechanized operations. This dual pathway enriches the theoretical understanding of how land system reforms affect rural livelihoods, highlighting the interaction relationship between land consolidation policies and farmers' adaptive livelihood strategies. Furthermore, the finding that low-income farmers benefit more substantially underscores HFC's potential to reduce income disparities and foster inclusive rural development. Globally, these findings offer valuable insights for developing countries seeking to achieve sustainable agricultural transformation and rural revitalization. Integrating land consolidation with mechanization and labor mobility can help policymakers boost productivity, alleviate rural poverty, and foster inclusive, resilient rural development amid evolving socioeconomic and environmental challenges.

Despite offering valuable insights, several limitations warrant attention. The use of provincial-level panel data constrains the exploration of micro-level heterogeneity. Future research could incorporate finer-scale data at county or household levels to better capture behavioral and structural variations. While mechanization is identified as a key mediating factor, other potential mechanisms, such as land transfer, technology adoption, and financial support remain unexplored and warrant further investigation. The data period ending in 2017 also limits the evaluation of long-term policy impacts and recent policy effects. Future studies should employ updated datasets to assess the sustainability and dynamic impacts of HFC. Finally, incorporating ecological and environmental dimensions would enable a more comprehensive assessment of HFC's contributions to sustainable rural development.

Based on the empirical findings, the following policy recommendations are proposed to enhance the effectiveness of HFC and promote rural livelihood transformation.

Strengthen agricultural mechanization and service accessibility. Mechanized production has been identified as a key channel through which HFC enhances income. The government should provide subsidies, low-interest loans, and tax incentives for machinery purchases, while reinforcing the socialized service system to ensure that smallholders can access affordable and efficient mechanization services. Promoting smart farming technologies, such as precision planting, automated irrigation, and soil monitoring systems, can further enhance productivity and reduce labor constraints. Agricultural cooperatives can serve as key intermediaries by pooling resources, providing shared machinery, and lowering individual investment costs. Promote moderate-scale operations through multi-agent cooperation. The income benefits of HFC are maximized when farmland is consolidated into moderately sized plots suitable for mechanized production. Policymakers should improve the land transfer market to reduce entry barriers, streamline registration procedures, and secure tenure rights for leasing arrangements. Rural collective organizations, cooperatives, and farmer associations should play a leading role in consolidating fragmented plots, coordinating cooperative farming, and managing shared resources, thereby enhancing efficiency and economies of scale.

Implement regionally differentiated HFC policies tailored to local conditions. Since HFC outcomes vary by region, policy design should reflect local resource endowments and development stages. In the western region, where natural conditions and infrastructure are less favorable, policy focus should prioritize long-term sustainability, ensuring that land improvement translates into tangible livelihood benefits. In non-major grain-producing areas, policies should emphasize improving farmland quality, adjusting the local agricultural industry structure, and expanding the scope of HFC projects to enhance both income stability and diversification. For central and key grain-producing regions, ongoing support should emphasize upgrading infrastructure, improving mechanization, and optimizing resource utilization to sustain productivity growth.

Enhance farmer engagement and promote awareness of HFC benefits. Effective implementation requires not only capital investment but also active participation from local households. Governments should promote awareness through information campaigns, technical training, and demonstration projects, encouraging adoption of modern machinery, sustainable practices, and diversified income activities. Mechanisms should be established to involve farmers in the maintenance and management of high-standard farmland, fostering long-term ownership, participation, and livelihood resilience.

Integrate HFC with broader rural development initiatives. HFC should be embedded within a comprehensive rural modernization framework that links infrastructure construction with training, credit access, market integration, and climate-resilient agricultural practices. Such integration can amplify policy synergies, promote income diversification, and strengthen the overall resilience and inclusiveness of rural development.

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

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

Appendix A

Table A1. Robustness check for the mediation effect.

Variables	Mechanization (1)	Total Farmers' Income (2)	Total Farmers' Income (3)	Agricultural Income (4)	Agricultural Income (5)	Non-Agricultural Income (6)	Non-Agricultural Income (7)
Interaction item	0.125 *** (0.045)	0.028 *** (0.008)	0.017 * (0.009)	0.079 ** (0.037)	0.036 (0.025)	0.070 *** (0.024)	0.051 * (0.026)
Mechanization			0.088 *** (0.028)		0.344 *** (0.090)		0.149 ** (0.064)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Province fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time fixation effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	6.213 *** (1.221)	7.124 *** (0.232)	6.578 *** (0.322)	6.514 *** (0.669)	4.379 *** (0.815)	5.597 *** (0.691)	4.669 *** (0.702)
R ²	0.696	0.990	0.991	0.837	0.871	0.976	0.977

Note: ***, **, * denote statistical significance at the 1%, 5%, and 10% levels, respectively (applies throughout the text).

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