Research article

Impact of high-standard basic farmland construction policies on agricultural eco-efficiency: Case of China

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Abstract: The impact of high-standard basic farmland construction policies on agricultural eco-efficiency has been extensively considered. Using the Chinese provincial panel data from 2007–2017, we first measure the level of agricultural eco-efficiency in China by employing data envelopment analysis. Then, using difference-in-difference models, we analyze the impact of high-standard basic farmland construction policies on agricultural eco-efficiency and test whether there is heterogeneity of this impact. Finally, we further explore the specific channels through which the polices of high-standard basic farmland construction affect agricultural eco-efficiency. The empirical results indicate that 1) the implementation of high-standard farmland construction policies can significantly improve agricultural eco-efficiency, 2) the heterogeneity of the impact of high-standard farmland construction policies on agricultural eco-efficiency is manifested in both regional and efficiency aspects and 3) high-standard farmland construction policies promote agricultural eco-efficiency through the interaction between the new land scale and the replanting index.

Keywords: high-standard basic farmland construction policies; agricultural eco-efficiency; difference-in-difference model; data envelopment analysis

JEL Codes: Q18

1. Introduction

Agricultural eco-efficiency is an essential indicator of the ecological and sustainable development of agriculture. "Eco-efficiency" is an expression of sustainable development, which refers to the promotional effects of resource utilization, investment, technological level, etc. on the production process toward the maximization of added economic value and the minimization of resource or energy consumption and environmental pollution. Although there are numerous definitions of eco-efficiency, its core is the evaluation of production levels in terms of economic and ecological effects. According to the idea of eco-efficiency, the evaluation of agricultural eco-efficiency should not only focus on the impact of maximizing eco-nomic benefits, but also on the impact of minimizing negative ecological effects. This can adequately reflect the economic strength and ecological level of a country or region, so countries have implemented various policies with the goal of improving agricultural eco-efficiency. The United States of America, for example, uses two different approaches to multi-stakeholder initiatives to achieve sustainable agriculture. One approach is to focus on resource adequacy for agricultural eco-efficiency, and the other is to maintain resilient agricultural and ecosystem functions (Konefal et al., 2019). In China, for example, grain production increased continuously to 621.4 million tons from 2004 to 2015, but the rapid development of the agricultural economy has come at the cost of a "reverse ecological" phenomenon. Agricultural production that is excessively reliant on primary energy-powered agricultural machinery and chemicals as raw materials exacerbates the greenhouse effect and contributes to severe soil pollution. Consequently, China has enacted a high-standard basic farmland construction policy to address these issues, as well as to improve agricultural eco-efficiency.

The high-standard basic farmland construction policy aims to solve the problems of fragmented farmland, a shortage of water facilities, a low quality of farmland and deterioration of farmland environment. Through the optimization of the structure and layout of fields, enhancement of the farmland water and road infrastructure, improvement of the quality of cultivated land, promotion of the agricultural mechanization and construction of an ecological protection system for farmland, the policy has led to increased resilience to agricultural disasters and higher comprehensive food production, which thus improved agricultural eco-efficiency and promoted sustainable agricultural development. The policy also plays a pivotal role in ensuring reasonable land development and appropriate land al-location (Feng et al., 2021; Tang et al., 2017). This is because the high-standard basic farmland construction policy is based on the China Land Improvement Plan (2011–2015). It is of paramount importance in optimizing the structure of land utilization, effectively realizing the protection of arable lands, promoting the integrated development of urban and rural areas and enhancing the level of economical and concentrated land use in both urban and rural areas (Li et al., 2021; Liu et al., 2014). And it also promoted the development of the Rural Revitalization Strategy. From production development to industrial prosperity, it emphasizes that rural revitalization must be supported by industries. From a clean and tidy appearance to ecological livability, it emphasizes that rural revitalization must be based on the harmonious coexistence between man and nature; from democratic management to effective governance, it emphasizes that rural revitalization must be guaranteed by good governance of rural societies; from poor life to affluent life, it emphasizes that rural revitalization must aim for a richer life for farmers.

Agricultural eco-efficiency refers to obtaining as much agricultural output as possible with as little resource consumption and environmental pollution as possible, and with a certain combination of agricultural input factors. And, the core idea of high-standard basic farmland is to obtain maximum

economic and social benefits on the basis of ecological considerations. The policy attaches importance to agricultural and rural development and accelerates the construction of high-standard farmland by refining farm cultivation efforts, increasing the efficiency of agricultural production, improving the traditional land production model and raising the income level of farmers. Moreover, there is an urgent need to overcome the prevailing situation in agriculture in order to meet realistic working requirements and promote sustainable agricultural development. China has built high-standard farmland with various new agricultural production techniques and facilities, which have improved the all levels of agricultural production, highlighted the technological content of agricultural production, achieved improved quality and efficiency of agricultural production and increased farmer production incomes. Therefore, the increase in the agricultural eco-efficiency of China depends to a large extent on the implementation of this policy.

According to the World Business Council for Sustainable Development, which first introduced the concept, eco-efficiency involves three main objectives: reducing resource consumption, reducing environmental impact and adding value to products (Li et al., 2020; Pastorok et al., 2003). The OECD defines eco-efficiency as "the efficiency with which ecological re-sources are used to meet human needs" (Picazo-Tadeo et al., 2011). This means that businesses, industries, etc., have a better capacity to produce goods and services while consuming fewer resources and preserving the environment. Thus, scholars have referred to it as an indicator of sustainability, linking the economic value of production activities to the environmental impact (Mueller et al., 2015; Zhang et al., 2008). Scholars have also extended it to the agricultural field, using agricultural eco-efficiency to reflect sustainable development and environmental variability in agriculture. The agricultural eco-efficiency states that agricultural production activities are carried out within the capacity of agricultural ecosystems. A high level of agricultural eco-efficiency can affect the synergies between agricultural production, economic development and ecological services. Research on agricultural eco-efficiency mainly includes aspects of measurement and the influential factors. Scholars have studied it from both micro and macro perspectives (Maxime et al., 2006).

Most of the studies on the measurement of agricultural eco-efficiency are based on data envelopment analysis (DEA). DEA is a non-parametric statistical method proposed based on the concept of relative efficiency, which ha beenpecifically designed to evaluate technical efficiency in different fields (Charnes et al., 1982). Coluccia used DEA to measure agricultural eco-efficiency in Italy (Coluccia et al., 2020) and Toma used DEA to analyze agricultural eco-efficiency in European Union countries (Toma et al., 2017). Reith and Guidry combined certain indicators related to composite eco-efficiency into a single ratio as agricultural eco-efficiency, which pro-vides a useful target for management and continuous improvement (Reith & Guidry, 2003). Regarding the factors influencing agricultural eco-efficiency, Zou et al. found that low agricultural eco-efficiency may be caused by economic and social factors, such as industrial structure, production technology and policies (Zou et al., 2020). Scholars also suggest that natural factors, like geographical and climatic conditions, may have a greater impact on agricultural eco-efficiency. Coderoni and Esposti found a tight connection between the greenhouse effect caused by agriculture and agricultural productivity in their study of agricultural eco-efficiency in Italy, i.e., climate change is associated with agricultural eco-efficiency (Coderoni & Esposti, 2014). Liu et al. found that China's compound fertilizer subsidy policy, as well as measures to increase farmer incomes, optimize farming structures and maintain stable prices for agricultural products, could also be effective in improving agricultural eco-efficiency (Liu et al., 2020b; Zhong & Li, 2020).

To guarantee food security and promote sustainable agricultural development, China has promulgated a high-standard basic farmland construction policy. As an important form of land governance in China, the policy is of great significance in promoting rural development and optimizing land management (Tang et al., 2017). Tang et al. considered that the objective of the high-standard basic farmland construction policy is to build basic farmland with centralized connection, supporting facilities, high yield, stability, good ecology, strong disaster prevention ability, and adaptability to modern agricultural production management (Tang et al., 2014). Song takes Hebei province in China as an example to evaluate the comprehensive land management in the region after the implementation of the high-standard basic farmland construction policy (Song et al., 2019). Qian et al. find that the high-standard basic farmland construction policy is the key measure for the current arable land conservation (Qian et al, 2016). Qiao et al. quantitatively evaluates the situation of each region in Huaihua city after the implementation of the high-standard basic farmland construction policy by applying the multi-factor comprehensive evaluation method and hierarchical analysis method (Li et al., 2021c; Qiao et al., 2017). The forementioned studies have provided an invaluable reference for this study.

What is the impact of the high standard basic farmland construction policy on agricultural ecological efficiency? In consideration of this problem, we drew lessons from the methods of scholars who have studied policy effect and found that most scholars have used the difference-in-difference (DID) approach to study policy effects. The DID model is effective in eliminating endogeneity problems, and it is more scientific when the dummy variable that indicates whether the policy is implemented is included. Wing et al. applied a DID model to focus on the policy effects of public health policies; they found that the DID approach can be a viable method for understanding contingent relationships (Khatun et al., 2021; Li et al., 2019a; Wing et al., 2018). Fresard evaluates the implementation of national cash policies using a the DID model. The result was that the implementation of national cash policies create a causal relationship between cash and product market performance (Fresard, 2010). Simon et al. studied the policy effects of the Affordable Care Act issued by the United States of America. They performed empirical analysis and constructed a DID model by utilizing the data from the Behavioral Risk Factor Surveillance System. The empirical results showed that among the low-income and childless adults, behaviors involving endangering their health were significantly reduced (Simon et al., 2017). Lin and Li discussed the impact of on the carbon dioxide emissions in five Nordic countries. They evaluated the effects of the policy about the carbon tax on carbon dioxide mitigation by using DID model; the results showed that the implementation of the policy about the carbon tax did not effectively alleviate the problem of large amounts of carbon dioxide emissions for some countries (Lin & Li, 2011; Zhu et al., 2021).

Based on the discussion above, we attempted to extend the previous studies in the following ways. First, we used an extension of the DID model, i.e., a continuous DID model, to econometrically analyze the impact of China's high-standard basic farmland construction policy on agricultural eco-efficiency, as based on the provincial panel data of China from 2007–2017. This approach can eliminate the confounding effects of unobservable factors that do not vary over time so as to improve the accuracy of research findings. Second, we tested the heterogeneity in regions and efficiency, which can better reflect the effects of the implementation of high-standard basic farmland construction policies under different circumstances. Third, we discuss the mediating effect of the impact of high-standard basic farmland construction policies on agricultural eco-efficiency. By constructing the combined indicator of land scales and replanting indexes, we explore the role of the new indicator in affecting the agricultural eco-efficiency of the high-standard basic farmland construction policy.

The remainder of the paper is structured as follows: Section 2 presents the specific research proposal, including the basic theoretical analysis, research hypothesis, empirical models, data sources and descriptive statistical analysis of the main variables; Section 3 contains the basic econometric analysis, including the empirical analysis of the continuous DID model, the parallel trend test and the placebo test; Section 4 provides further discussion, particularly on the heterogeneity test and the mediation effect study; Section 5 includes the conclusions and relevant policy recommendations.

2. Research design

2.1. Theoretical analysis and research hypotheses

The "Standard for the Construction of High-Standard Basic Farmland (TD/T1033-2012)" in China defines high-standard farmland as "the basic farmland that is concentrated and continuous, equipped with complementary facilities, highly and steadily productive, environmentally friendly, strongly disaster resistant and compatible with modern agricultural production and operation methods through rural land improvement within a certain period of time." Before the publication of the high-standard basic farmland construction policy, the main purpose of comprehensive land development was to effectively increase the arable land area lost through urbanization and industrial construction. However, the environmental and pollution problems affecting agricultural ecology are becoming more and more serious (Li & Liao, 2020; Li & Zhong, 2019). In order to relieve environmental pressure and improve agricultural eco-efficiency, China promulgated a high-standard basic farmland construction policy. It has changed the connotation of comprehensive land development from increasing the amount of arable land to steadily increasing the amount of arable land, improving its quality and ameliorating the ecological environment. In addition, one of the main elements of the high-standard basic farmland construction policy is the farmland project, which aims to solve China's long-standing problem of land fragmentation by "merging small fields into large ones" and "transforming zero into whole" measures of land improvement (Li et al., 2020a; Liu et al., 2020a). This can not only contribute to land level and concentrated and continuous management, but also promote the widespread application of advanced agricultural machinery technology, water-saving irrigation technology and other low-carbon and environmentally friendly technologies, thus significantly improving the agricultural eco-efficiency. Place et al. summarized the factors influencing agricultural eco-efficiency, and argued that expanding the degree of large-scale operations, reducing the degree of fragmentation of cultivated land, and promoting the degree of green agriculture development could effectively improve the agricultural eco-efficiency (Place et al., 2003). Based on the land remediation measures of the high-standard basic farmland construction policy in the above theoretical analysis, we argue that the high-standard basic farmland construction policy can increase the level of agricultural eco-efficiency via the improvement of the comprehensive land management level. Therefore, we hypothesize the following:

Hypothesis 1: The high-standard basic farmland construction policy can positively affect the agricultural eco-efficiency.

As the high-standard basic farmland construction policy has the characteristic of "focusing on the main food-producing areas and giving due consideration to non-food-producing areas", we decided to investigate whether the implementation of this policy is heterogeneous across regions. The following hypothesis is also proposed:

Hypothesis 2: There is heterogeneity in the impact of the high-standard basic farm-land construction policy on agricultural eco-efficiency in major food-producing and non-food-producing areas.

The agricultural eco-efficiency of a country or region depends to a large extent on the conditions of its resource endowment. China is a vast country with a complex and diverse terrain and various types of climates. This leads to a wide variation in the availability of agricultural resources across Chinese provinces, which results in a situation in which the agricultural eco-efficiency of some regions can be very prominent. Therefore, this study explores whether there is heterogeneity in the effects of China's high-standard basic farmland construction policies on different levels of agricultural eco-efficiency. Accordingly, we hypothesize the following:

Hypothesis 3: The magnitude of agricultural eco-efficiency will influence how it is affected by the high-standard basic farmland construction policy.

Increasing the land scale not only meets the requirements of the high-standard basic farmland construction policy, but also reduces the degree of land fragmentation. The replanting index reflects the average frequency of repeated cultivation of a block of land. The interaction between them can lead to increased land usage efficiency, thus contributing to the improvement of agricultural eco-efficiency under the high-standard basic farmland construction policy. Thus, we hypothesize the following:

Hypothesis 4: The interaction between a new land scale and the replanting index can in-fluence the effect of the high-standard basic farmland construction policy on agricultural eco-efficiency.

2.2. Model design

The high-standard basic farmland construction policy has been implemented normatively in China since 2011. As the policy has been implemented at different times, there are differences in the number of high-standard farmlands constructed in each province of China, and it varies continuously. Moreover, the policy objectives and implementation plan of each province in China also differ because the policy distinguishes between major grain-producing and non-grain-producing areas. This implies that, on one hand, there are differences in the construction of high-standard basic farmland before and after the implementation of the policy, and on the other hand, there are also differences in the construction of high-standard basic farmland in different provinces at the same time. To test whether hypothesis 1 is correct, we set up a DID model to investigate the effects of the policy on agricultural eco-efficiency, as based on previous assessments of the policy effects. In contrast to the conventional DID model, we used the continuous variable "percentage of land reclamation area" to distinguish the experimental group (samples with a high percentage of land reclamation area) from the control group (samples with a low percentage of land reclamation area), which can better capture the variability of the data. This avoids the artificial setting error arising from using the conventional DID model with dummy variables to distinguish the experimental and control groups. Therefore, Model 1 is

$$Ef_{it} = \alpha_0 + \beta_0 * area_i \times I_t + \gamma_0 * Control_{it} + \delta_t + \varepsilon_{it} \tag{1}$$

In Model 1, we use the fixed effect test empirically, and other models are based on this method. Ef_{it} denotes the agricultural eco-efficiency of a province i during a period t; $area_i$ denotes the percentage of land remediation area; I_t denotes the dummy variable for policy implementation; $Control_{it}$ denotes the control variable, which varies with time; δ_t is the time fixed effect; ε_{it} is the error term; α and β represent the effects of the constant terms and the high-standard farmland construction policy on agricultural eco-efficiency, respectively.

The validity of the DID model estimation relies on the verification of the parallel trend hypothesis, i.e., the trend of agricultural eco-efficiency in the experimental and control groups is consistent in time before the implementation of the high-standard basic farmland construction policy. Referring to Nunn & Qian, we set the following Model 2:

$$Ef_{it} = \alpha_1 + \sum_{t=2007}^{2017} \beta_1 * area_i \times D_t + \gamma_1 * Control_{it} + \delta_t + \varepsilon'_{it} \tag{2}$$

In Model 2, D_t is denoted as a dummy variable for the year, and all other variables and coefficients are consistent with Model 1. If the implementation of the high-standard basic farmland construction policy can significantly improve the agricultural eco-efficiency, then the variation of the coefficient β_1 of the interaction term for the land remediation area percentage, as well as the year dummy variable on agricultural eco-efficiency, should tend to be smooth before the implementation of the policy; also, the variation of β_1 is significantly increased after the implementation of the policy.

To test hypothesis 3, we constructed new indicators (i.e., the interaction terms for the new land scale and replanting index) and employed a two-stage approach to examine the underlying mechanism of the impact of high-standard basic farmland construction policies on agricultural eco-efficiency. The first stage is verifying the impact of the high-standard basic farmland construction policy on the new indicator through regression of the policy on the new indicator. The second stage is verifying whether the coefficient of the high-standard basic farmland construction policy changes after adding the new indicators to the regression Equation. Therefore, we respectively Model 3 and Model 4 as follows:

$$M_{it} = \alpha_2 + \beta_2 * area_i \times I_t + \gamma_2 * Control_{it} + \delta_t + \varepsilon''_{it} \tag{3}$$

$$Ef_{it} = \alpha_3 + \beta_3 * area_i \times I_t + \gamma_3 * Control_{it} + \theta * M_{it} + \delta_t + \varepsilon'''_{it} \tag{4}$$

In Model 3, M_{it} is the new indicator, θ is the coefficient for the effect of the new indicator on agricultural eco-efficiency and the remaining parameters are consistent with Model 1.

2.3. Variable selection and data sources

2.3.1. Explained variables

Referencing to Liao, we calculated the agricultural eco-efficiency through the super-efficiency SBM Model (Liao et al., 2021). The super-efficiency SBM Model is a super efficiency DEA Model with the main feature being the consideration of relaxation variables (Andersen & Petersen, 1993; Li & Ma, 2021; Tone, 2001). We measured the agricultural eco-efficiency (Ef_{it}) of 31 provinces in China with input and output indicator data from 2007–2017. The elementary input indicators were land input, labor input, machinery and equipment inputs, water resources inputs, fertilizer inputs, pesticide inputs, agricultural film input, and energy input; the expected output indicators was the agricultural product output; the agricultural carbon emissions and the combined index of agricultural non-point source pollution were used as indicators of unexpected output (Li et al., 2019b; Liu et al., 2020b; Pan & Ying, 2013; D. Pan, 2013). Detailed descriptions of the indicators are shown in Table 1.

Table 1. Indicators for measuring agricultural eco-efficiency.

First-level indicators	Second-level indicators	Third-level indicators	Indicator description
Input indicators	Elemental inputs	Land input	Total crop planting area/1000 hectares
		Labor input	(Total agricultural outputs/Total agricultural & forestry & fishery outputs) × (Number of primary industry employees/10,000)
		Machinery and equipment input	Total agricultural machinery power/10,000 kW
		Water resource input	Effective irrigated area/1000 hectares
		Fertilizer input	Agricultural fertilizer purity/10,000 tons
		Pesticide input	Amount of pesticide usage /10,000 tons
		Agricultural film input	Amount of agricultural plastic film / tons
		Energy input	Amount of agricultural diesel/10,000 tons
Output indicators	Expected outputs	Agricultural output	Total agricultural outputs / billion yuan
	Unexpected outputs	Agricultural carbon emission	The sum of the quantities of the six categories of carbon emission sources: fertilizers, pesticides, agricultural films, agricultural diesel, agricultural irrigation and tillage loss multiplied by the corresponding emission factors; the corresponding emission factors were 0.8956, 4.9341, 5.18, 0.5927, 20.476 and 312.6.
		The combined index of agricultural non-point source pollution	The entropy value method is used to combine four types of indicators: nitrogen loss, phosphorus loss, pesticide residues and agricultural film residues. Nitrogen (phosphorus) loss is equal to the sum of the amount of nitrogen (phosphorus) fertilizer applied and the amount of nitrogen (phosphorus) contained in compound fertilizer multiplied by the fertilizer loss coefficient; pesticide and agricultural film residues are equal to their usage multiplied by the corresponding residue coefficients; the fertilizer loss coefficient, pesticide residue coefficient and agricultural film residue coefficient were 0.65, 0.5 and 0.1 respectively.

2.3.2. Explained variables

In this study, the interaction term ($\text{area}_i \times I_t$) for land remediation area proportion (area_i) and the dummy variable (I_t) in the high-standard farmland construction policy was used to characterize the high-standard basic farmland construction policy; the specific variable descriptions are shown in Table 2.

Table 2. Description of the explanatory variables.

Indicator description	Measurement indicators
The interaction term of land remediation area share and the dummy variable for implementation of the high-standard farmland construction policy（$\text{area}_i \times I_t$）	The proportion of land rehabilitation area is the percentage of the total area of transformed low and medium yielding land and high-standard farmland to the total arable land area; I_t is the dummy variable for the implementation of the high-standard farmland construction policy, After 2011, I_t was designed to take the value of 1 and 0 vice versa.

2.3.3. Control variable

We selected the following control variables that may affect agricultural eco-efficiency based on the indicators for measuring agricultural eco-efficiency in Table 1. The specific control variables are described as shown in Table 3.

Table 3. Description of control variables.

Indicator name	Indicator description	Reason for selection
Agricultural disaster rate (DI)	Crop disaster area/Total crop planting area (%)	Floods, droughts, typhoons, hailstorms and other severe weather may damage the agricultural production environment and cause abnormal fluctuations in outputs.
Density of agricultural machinery (In)	Total agricultural machinery power/total crop planting area (kW/ha)	Reflect the level of agricultural mechanization.
Level of financial support to agriculture (Fi)	Local finance expenditures on agriculture & forestry & water affairs/Local finance general budget expenditures (%)	Financial subsidies to agriculture can influence agricultural inputs such as fertilizers, pesticides and farm machinery services which reflect the impact of administrative interventions on agricultural eco-efficiency.
Cropping structure (St)	The proportion of the sown area for food crops to that for cash crops (%)	The ratio of the area sown for food crops to the area sown for cash crops determines the structure of local agricultural products. Different ratios meet the needs of the local agricultural market to varying degrees and thus create different economic values.
Replanting index (MCI)	The proportion of total sown crop area/Cultivated land area (%)	The replanting index refers to the average number of crops planted on the same plot of arable land in a given period (usually one year), which reflects the impact of increasing land abandonment on agricultural eco-efficiency.

2.3.4.   Intermediate variables

According to the theory and hypothesis above, the interaction term for the land scale and replanting index ($M_{it} = lnadd_{it} \times MCI_{it}$) was selected as the intermediate variable in this study. Due to the difficulty of data collection, we adopted additional arable land area from comprehensive land development as the proxy variable for land scale. The reasons are as follows. First, the increase in arable land area from land remediation mainly originates from field leveling and consolidation, which will be directly reflected in the expansion of land scale. Second, the increased land scale from land remediation does not necessarily lead to an increase in total arable land area since the increase or decrease in total arable land area is also influenced by ecological fallback, agricultural industry restructuring and construction land. Indicators related to the total arable land area cannot accurately reflect the impact of the implementation of the high-standard farmland construction policy on plot size. Therefore, we employed the new arable land area (add) for comprehensive land development, which is closely related to the construction of high-standard farmland, to characterize the land scale. The replanting index illustrates the effect of increasing land abandonment on agricultural eco-efficiency. The effect of the interaction between them is the average number of crops planted on the arable land added under the high-standard basic farmland construction policy, which can reflect the results of the arable land constructed by the policy.

All data in this study were sourced from the provincial database of the National Bureau of Statistics of China, the China Macroeconomic Database, the China Rural Statistical Yearbook, the China Finance Yearbook and the China Statistical Yearbook. Missing data were filled in by using linear interpolation. In order to avoid experimental bias caused by different data units, we made a logarithm of the new arable land area (add) for land comprehensive development. The descriptive statistics of the variables are shown in Table 4.

Table 4. Descriptive statistics.

Variable	observation	Mean	Standard deviation	Min	Median	Max
Ef	341	0.717	0.322	0.250	0.582	1.277
area	341	0.018	0.020	0.002	0.014	0.213
St	341	3.066	3.593	0.639	2.042	27.010
DI	341	0.209	0.149	0.000	0.174	0.696
In	341	6.684	3.700	2.270	5.624	26.979
Fi	341	0.115	0.035	0.030	0.114	0.218
MCI	341	1.287	0.462	0.514	1.201	3.982
lnadd	341	8.563	1.254	3.834	8.940	10.791

3.   Empirical analysis

3.1. Impact of high standard basic farmland construction policy on agricultural ecological efficiency

We examined Model 1 using the continuous DID approach; the results are shown in Table 5.

Table 5. Baseline regression results.

Variable	Agricultural eco-efficiency	Agricultural eco-efficiency
High-standard basic farmland construction policy	4.294**	5.688*
	(2.46)	(1.70)
Cropping structure	−0.0207***	
	(−4.76)	
Agricultural disaster rate	−0.602***	
	(−5.04)	
Density of agricultural machinery	0.00301	
	(0.64)	
Level of financial support to agriculture	−2.911***	
	(−5.80)	
Replanting index	−0.212***	
	(−4.70)	
Time effect	YES	
_cons	1.541***	0.705***
	(14.26)	(11.32)
N	341	341

Note: *, ** and *** represent passing the significance test at 10%,5% and 1%, respectively.

According to the regression results in Table 5, the high-standard farmland construction policy can significantly improve agricultural eco-efficiency. With the inclusion of control variables, the coefficient for the impact of the high-standard basic farmland construction policy on agricultural eco-efficiency was 4.294. This reflects that the implementation of the high-standard basic farmland construction policy significantly increased agricultural eco-efficiency by 4.294% with other conditions held constant. It indicates that the high-standard basic farmland construction policy has a significant incremental effect on agricultural eco-efficiency. And, the effect of the high-standard basic farmland construction policy on agricultural eco-efficiency was also significantly positive without the inclusion of control variables. Therefore, Hypothesis 1 is proven. This conclusion may be due to the fact that the policy of high-standard basic farmland construction has transformed the traditional model of land governance in China. This policy improves the ecological environment by improving the utilization of land resources, increasing the available land area and stimulating land usage potential. In the early years, China pursued the traditional smallholder decentralized land management model, and the performance evaluation of land management focused only on the remediation results. This resulted in some unavoidable problems at that time. For example, some regions pursued agricultural production excessively, thus exacerbating serious soil pollution, damaging the ecological environment and causing the decline of agricultural eco-efficiency. Following the promulgation of high-standard basic farm-land construction policies, China has shifted from a predominantly economic benefit evaluation to emphasizing economic, social and ecological benefits simultaneously. This has accelerated the transformation of the agricultural development pattern and vigorously promoted the modernization of agriculture. Thereafter, the comprehensive production capacity of arable land has improved, the agricultural production conditions have been refined and the national food security has been ensured. The implementation of this policy combines agricultural production and resource support with environmental protection and provides strong support for agricultural eco-efficiency while improving the general agricultural level.

3.2. Parallel trend test and placebo test

To ensure the accuracy of the above findings, we first conducted the parallel trend test for Model 2. Second, to test whether the sample satisfies the "common trend" constraint of the DID model, referencing Cai et al., we conducted the placebo test for Model 1 by selecting data before the implementation of the policy (2007–2010) and taking 2009 as the implementation point of the policy (Cai et al., 2016). The results are shown in Table 6.

Table 6. Parallel trend test and placebo test.

Variable	Parallel trend test	Placebo test
Time dummy variable	−0.174**	
	(−2.15)	
Percentage of land remediation area	1.947	
	(0.73)	
$\text{area}_i \times I_t$		−0.419
		(−0.35)
$\text{area}_i \times I_t$ (year-3)	−0.0155	
	(−0.40)	
$\text{area}_i \times I_t$ (year-2)	−0.0274	
	(−0.71)	
$\text{area}_i \times I_t$ (year-1)	−0.0353	
	(−0.70)	
$\text{area}_i \times I_t$ (year+1)	0.0519	
	(1.32)	
$\text{area}_i \times I_t$ (year+2)	0.0955**	
	(2.47)	
$\text{area}_i \times I_t$ (year+3)	0.0788**	
	(2.56)	
Cropping structure	−0.0215**	−0.0243***
	(−2.40)	(−2.63)
Agricultural disaster rate	−0.633**	−0.566***
	(−2.61)	(−3.27)
Density of agricultural machinery	0.00368	−0.00706
	(0.25)	(−0.61)
Level of financial support to agriculture	−2.988***	−2.967***
	(−3.01)	(−3.18)
Replanting index	−0.228*	−0.281***
	(−1.82)	(−3.25)
Time effect	YES	YES
_cons	1.573***	1.668***
	(7.13)	(9.62)
N	341	124

Note: *, ** and *** represent passing the significance test at 10%,5% and 1%, respectively.

According to the results in Table 6, we conclude that the empirical results in Table 5 are robust. From the parallel trend test results in Table 6, it can be concluded that the empirical results in Table 5 do not violate the parallel trend hypothesis. As shown in Table 6, the impact coefficient β for the high-standard basic farmland construction policy were insignificant during the first three years of its implementation. This indicates that there is no significant difference in the impact coefficients before the implementation of the policy. In the last three years of policy implementation, the impact coefficient β for the policy was significantly positive during the last two years, except for the first year. This is possible due to the lagged effect of the policy. This made the effect of the policy on agricultural eco-efficiency insignificant during the first year of its release. From 2013 and beyond, the policy has significantly contributed to the increase in agricultural eco-efficiency. From this, it can be verified that the results of this study follow the parallel trend hypothesis. The results of the placebo test (Table 6) show that, if the high-standard basic farmland construction policy was implemented in 2009, it would have no effect on agricultural eco-efficiency. As can be seen in Table 6, the estimated coefficient for the DID regression results was −0.419; this is insignificant assuming that China enacted the high-standard basic farm-land construction policy in 2009. This indicates that there was no policy effect before the implementation of the high-standard basic farmland construction policy, i.e., the empirical results of DID can be evaluated by using the placebo test.

4. Further discussion

4.1. Heterogeneous impact of high-standard basic farmland construction policy on agricultural ecological efficiency

4.1.1. From the perspective of agricultural functional area orientation

The high-standard basic farmland construction policy promulgated in China is focused on the main grain-producing regions, with due consideration given to the non-grain-producing regions. The main grain-producing regions are the thirteen regions in China that account for 75.4% of China's total grain production; about 95% of the country's increased grain production is from these regions. These thirteen regions are Hebei Province, Inner Mongolia Autonomous Region, Liaoning Province, Jilin Province, Heilongjiang Province, Jiangsu Province, Anhui Province, Jiangxi Province, Shandong Province, Henan Province, Hubei Province, Hunan Province, and Sichuan Province; the non-grain-producing regions are the remaining provinces. We investigated whether there was a difference in the impact of the high-standard basic farmland construction policy on agricultural eco-efficiency between these two types of regions by applying a heterogeneity test. The empirical results are shown in Table 7.

Table 7 shows that the effect of the high-standard basic farmland construction policy on agricultural eco-efficiency was different between the main grain-producing areas and the non-main grain-producing areas. The effect of the policy on agricultural eco-efficiency was not significant in non-grain-producing regions; however, the effect of the policy was 29.049 in grain-producing regions, and thus significantly positive. This shows that under the impact of the high standard basic farmland construction policy in the main grain producing areas, the agricultural ecological efficiency in these areas has increased significantly by 29.049%. Therefore, Hypothesis 2 is confirmed. The results in Table 7 suggest that the heterogeneity is probably due to the different positioning of agricultural functional areas. Due to the different positioning of agricultural functional areas, the land inputs, labor

inputs, machinery and equipment as well as agricultural resources in the main grain-producing areas can be much greater than those in the non-main grain-producing areas. This led to a high level of internal specialization and scale operation in the main grain-producing areas. After the release of the high-standard basic farmland construction policy, its policy effects overlapped with those of the main grain-producing areas to provide support for the increase in agricultural eco-efficiency. It may also be that the key implementation targets of the policy are the main grain-producing regions. Therefore, these thirteen regions will obtain more policy support and achieve better policy implementation results.

Table 7. Results of heterogeneity test for different regions.

Variable	Non-grain-producing areas	Major grain-producing areas
High-standard basic farmland construction policy	1.230	29.049***
	(0.572)	(4.651)
Cropping structure	−0.075***	0.008
	(−3.264)	(0.994)
Agricultural disaster rate	−0.622**	−0.255
	(−2.214)	(−0.900)
Density of agricultural machinery	0.017	−0.012
	(1.634)	(−1.035)
Level of financial support to agriculture	−3.985***	−2.320
	(−4.255)	(−1.464)
Replanting index	−0.277***	0.155
	(−6.865)	(1.047)
Time effect	YES	YES
_cons	1.839***	0.791**
	(13.236)	(2.350)
N	198	143

Note: *, ** and *** represent passing the significance test at 10%,5% and 1%, respectively.

4.1.2. From the perspective of agricultural functional area orientation

Before the promulgation of the high-standard basic farmland construction policy, there was a certain degree of variation in the agricultural eco-efficiency of each region. Moreover, with the implementation of the policy, the magnitude of agricultural eco-efficiency was shown to vary from region to region. We investigated whether there is heterogeneity in the effects of the high-standard basic farmland construction policy on different levels of agricultural eco-efficiency by evaluating the distribution of agricultural eco-efficiency. The results are shown in Table 8.

The results in Table 8 show that, for different levels of agricultural eco-efficiency, there is heterogeneity among the impacts generated by the high-standard basic farmland construction policies. As agricultural eco-efficiency increased, the impact of the high-standard basic farmland construction policy became more and more significant. However, agricultural eco-efficiency at the 5th and 95th percentiles was not as significantly affected by the policy as it was at the other levels. On this basis, Hypothesis 3 is supported. The results in Table 8 show that, for areas with high or low agricultural eco-

efficiency, the high-standard basic farmland construction policy is no longer the most dominant influential factor for agricultural eco-efficiency. The lower significance at the 5th percentile of agricultural eco-efficiency may be attributed to the poor ecological environment and low resource endowment in the region; thus, the high-standard basic farmland construction policy only plays a role to a certain extent. The lower significance at the 95th percentile of agricultural eco-efficiency may be due to the fact that the ecological environment and resource endowment of the region have reached the optimum level and there is no more space for improvement in agricultural eco-efficiency. At the 25th, 50th and 75th percentiles of agricultural eco-efficiency, the policy effect increased significantly with the increase of agricultural eco-efficiency. This indicates that the improvement of agricultural eco-efficiency is relatively dependent on the high-standard basic farmland construction policy.

Table 8. Results of heterogeneity test for eco-efficiency.

Variable	5th percentile	25th percentile	50th percentile	75th percentile	95th percentile
High-standard basic farmland construction policy	17.315*	23.712***	32.636***	44.080***	71.893*
	(1.95)	(5.69)	(5.18)	(2.79)	(1.77)
Control variables	YES	YES	YES	YES	YES
_cons	0.079	0.204***	0.379***	0.602***	1.146***
	(1.09)	(3.74)	(10.37)	(11.15)	(11.52)
N	341	341	341	341	341

Note: t statistics in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

4.2. Mechanism analysis for the impact of the high-standard basic farmland construction policy on agricultural ecological efficiency

We constructed a new indicator to be a mediating variable (i.e., land scale × replanting index) to investigate how this indicator affects the improvement of agricultural eco-efficiency by the high-standard basic farmland construction policy. The empirical results are shown in Table 9.

According to Table 9, it is clear that there is a mediating effect of the new indicator we constructed on the effect of the high-standard basic farmland construction policy on agricultural eco-efficiency. The coefficient for the effect of the high-standard basic farmland construction policy on the new indicator was 8.287 and significant at the 5% level, indicating that the interaction between the land scale and replanting index is promoted by the high-standard basic farmland construction policy. In addition, the coefficient for the new indicator on agricultural eco-efficiency was 0.051 and significant at the 1%. This suggests that the interaction between the land scale and replanting index also contributes, to a certain degree, to agricultural eco-efficiency. This suggests that the interaction between the land scale and replanting index also contributes, to a certain degree, to agricultural eco-efficiency, and that it can affect the effect of the high-standard basic farmland construction policy on agricultural eco-efficiency. Therefore, Hypothesis 4 is proven. The results in Table 9 indicate that the mediating effect is probably due to the fact that the high-standard basic farmland construction policy leads to an increase in land scale, optimizes the land usage structure and enables the effective management of integrated rural land management. Moreover, it was found to have a significant effect on the improvement of crop cultivation and arable land conservation capacity. These aspects interact with each other so that the high-standard basic farmland

construction policy can improve agricultural eco-efficiency significantly by promoting the land leveling project and increasing the land usage efficiency.

Table 9. Regression results for intermediary effects.

Variable	Land scale growth rate × replanting index	Agricultural eco-efficiency
The high-standard basic farmland construction policy	8.287**	3.783*
	(2.372)	(1.786)
Cropping structure	−0.021***	−0.019***
	(−3.087)	(−5.296)
Agricultural disaster rate	−0.744***	−0.671***
	(−2.634)	(−3.611)
Density of agricultural machinery	−0.012	0.006
	(−0.753)	(1.290)
Level of financial support to agriculture	−4.256***	−2.590***
	(−3.421)	(−4.620)
Replanting index	7.639***	−0.593***
	(37.695)	(−3.019)
Land scale growth rate	1.319***	−0.084**
	(27.222)	(−2.045)
Land scale growth rate × Replanting index		0.051*
		(1.806)
Time effect	YES	YES
_cons	−9.515***	2.170***
	(−18.952)	(7.911)
N	279	279

Note: *, ** and *** represent passing the significance test at 10%,5% and 1%, respectively.

5. Conclusions

Using the dynamic panel data of 31 provinces in China from 2007 to 2017, this study focused on the impact of the high-standard basic farmland construction policies on agricultural eco-efficiency, while controlling for the impact of multiple factors on agricultural eco-efficiency. We first employed a continuous DID model to preliminarily study the relationship between the high-standard basic farmland construction policy and agricultural eco-efficiency. Second, we discussed whether there are differences in the impact of high-standard basic farmland construction policies on agricultural eco-efficiency in terms of region and efficiency by conducting a heterogeneity test. Finally, we investigated whether the interaction between the new land scale and the replanting index has a mediating effect on the impact of the high-standard basic farmland construction policy on agricultural eco-efficiency by performing mechanism analysis.

Our empirical results indicate the following: i) The implementation of the high-standard basic farmland construction policy in China can significantly improve agricultural eco-efficiency. The implementation of the high-standard basic farmland construction policy in China can significantly

improve agricultural eco-efficiency. On average, the policy can increase agricultural eco-efficiency by 4.294%, and this result was shown to be robust through the parallel trend and placebo tests (Li et al., 2021b). ii) There is significant heterogeneity in the impact of the high-standard basic farmland construction policy on agricultural eco-efficiency in terms of the region and efficiency. Regarding the regions, according to the positioning of the agricultural functional areas, the policy significantly contributes to agricultural eco-efficiency in the main food-producing regions, while it is not a major factor in agricultural eco-efficiency in non-food-producing regions. Regarding efficiency, according to the different distribution dimensions of agricultural eco-efficiency, the impact of the policy on the higher and lower levels of agricultural eco-efficiency is different from that on other levels of agricultural eco-efficiency. iii) The high-standard farmland construction policy can promote agricultural eco-efficiency through the interaction between the new land scale and replanting index. We constructed the new indicators (the interaction between the new land scale and replanting index) to test empirically. The results showed that the new indicators have a mediating effect on the impact of the high-standard basic farmland construction policy on agricultural eco-efficiency, and the new indicators can promote agricultural eco-efficiency.

These conclusions reveal that China's high-standard basic farmland construction policy facilitates the improvement of agricultural eco-efficiency. Therefore, China should accelerate the high-standard basic farmland construction policy to improve the comprehensive capability of agriculture and expedite the construction of the agricultural eco-efficiency system. The high-standard basic farmland construction policy can ensure the stability of grain, increase income and ensure farming, which is the basic guarantee for the implementation of the Rural Revitalization Strategy. The government should tap the new potential of grain production, improve farmers' enthusiasm for growing grain and maximize the development of agricultural ecological efficiency. Specifically, China should first focus on implementing the high-standard basic farmland construction policy in non-grain-producing areas in particular. The policy has already yielded a significant effect in the main grain-producing areas, i.e., a significant improvement in agricultural eco-efficiency. In the future, China should strengthen the construction of the high-standard basic farmland in non-grain-producing regions to expand the positive influence of the policy on agricultural eco-efficiency. Second, other countries should learn the high-standard basic farmland construction policy in accordance with their economic and regional characteristics. For countries with higher economic levels and superior geographic locations, the construction of the high-standard basic farmland should improve the promotion and application of technological innovation in agriculture to increase the upper bound of agricultural eco-efficiency. For countries with poor economic levels and complex geographical locations, the construction of high-standard basic farmland can emphasize the improvement of the arable environment and the increase of total agricultural output to improve the lower bound of agricultural eco-efficiency. Moreover, other countries should also strengthen inter-regional agricultural technology cooperation and policy coordination so as to share the experience of the highly agricultural eco-efficient regions to the less eco-efficient regions and thus achieve the overall enhancement of agricultural eco-efficiency. Third, the expansion of land scale, as well as the improvement of the replanting index, should be the key components of future policies for the construction of high-standard basic farmland in all countries. China should continue to adopt land reclamation measures and increase the frequency of crop planting on this basis so as to improve more expeditiously. And, others can use this practice to improve the agricultural eco-efficiency for reference.

Conflict of interest

All authors declare no conflicts of interest in this paper.

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