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Spatial and temporal variation and convergence in the efficiency of high-standard farmland construction: Evidence in China

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ABSTRACT

To assess the efficiency of high-standard farmland construction (HSFC), this study utilized data spanning from 1998 to 2020 obtained from 30 provinces, autonomous regions, and municipalities in China. This assessment was conducted using a three-stage super-efficient slack-based measure data envelopment analysis(SBM-DEA)model. Furthermore, we investigated the spatial and temporal variances and convergence of HSFC efficiency using the Dagum Gini coefficient and convergence analysis. The results firstly show that from 2007 to 2020, China's HSFC efficiency displayed fluctuations and declines, significantly influenced by environmental and stochastic factors. Secondly, it showed that the gap in China's HSFC efficiency has widened, with super-variable density being demonstrated as the primary source of spatial imbalance in HSFC efficiency. Thirdly, it showed that the deviation in the efficiency of HSFC in the central region of China from the average level has shown a gradually declining trend, while the deviation in the efficiency of HSFC in the national, western, eastern, and northeastern regions has not presented a downward trend. Fourthly, it demonstrated that over time, the efficiency of building high-standard agriculture throughout the nation and its four main areas will converge to the same level.

1. Introduction

Farmland protection is a major global concern, particularly relevant when considering China's proposition for high-standard farmland construction (HSFC). High-standard farmland refers to "farmland that is flat, concentrated, has perfect facilities, is water-saving and efficient, supports agriculture and electricity, is suitable for mechanical operation, has fertile soil, is ecologically friendly, has strong disaster resistance, and is compatible with modern agricultural production and operation mode."[1] High-standard farmland is high-quality farmland that is developed and worked in a way that saves water and land, produces high and stable yields, and is run in a manner that employs prudent ecological practices that involve taking specific measures such as land leveling and utilizing supporting facilities, thereby improving the fertility of cultivated land and enhancing the land's ability to resist natural risks. High-standard farmland not only plays a crucial role in ensuring food security (Halonen-Akatwijuka and Pafilis, 2014; Hao et al., 2024), but also promotes green ecological development of agriculture(Tang et al., 2023). Additionally, it is an important material guarantee for the comprehensive revitalization of rural areas as well as agricultural and rural modernization. Available data indicates that by the end of 2022, the country had built a cumulative total of 66.67 million hectares of high-standard farmland, stabilizing the guarantee of more than 1 trillion pounds of grain production capacity, more than half of the 127.87 million hectares of arable land is high-standard farmland.[2] However, limited to the public goods attributes of high-standard farmland, it is easy to "free-rider" behavior and fall into the "collective action dilemma" in the construction process, coupled with too many external administrative forces to interfere in the supervision and management, resulting in the overall construction of high-standard farmland is not ideal (Sun and Liu, 2017; Xu et al., 2020). As an important starting point and key measure to implement the strategy of "storing grain in the ground", the low efficiency of HSFC is probably not conducive to the improvement of farmland quality. Therefore, improving the efficiency of HSFC and realizing the improvement of cultivated land production level have become the key issues to be solved urgently to ensure food security.

Since the beginning of China's economic reformation and opening-up, the development of policies involving HSFC has been accelerated

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[1] Source: "the general principles of the construction of high standard farmland" (GB/T30600-2022), https://openstd.samr.gov.cn/bzgk/gb/newGbInfo?hcno=56806B705B9632406C71BA8E7CD7B8EFF.

[2] https://www.gov.cn/xinwen/2023-01/16/content_5737126.htm?eqid=808b812d0008036400000003645b13ff.

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to enhance support for agriculture. Since 2004, China's "No. 1 central document" has made clear requirements for HSFC tasks. A report from the 20th CPC National Congress emphasized the importance of safeguarding the 120 million hectares of arable land, while gradually transforming all permanent basic farmland into high-standard farmland. Additionally, in Central Document No. 1 from 2023, there is an explicit proposal to perform annual tasks involving the establishment of new construction and the renovation and upgrading of high-standard farmland. This proposal emphasizes the importance of addressing issues such as soil degradation and enhancing irrigation and drainage facilities on farmlands. Furthermore, the proposal focuses on the coordinated promotion of highly efficient, water-saving irrigation techniques and the refinement of long-term management and maintenance mechanisms. Furthermore, the 2023 Central Rural Work Conference further pointed out that "we will increase investment in the construction, management, and protection of high-standard farmland to ensure that the quantity of cultivated land is guaranteed and the quality is improved". Then, since the policy of developing high-standard farmland was implemented, how has China's HSFC efficiency changed? Are there significant differences in the overall level and growth trend of HSFC efficiency at different spatial scales? Does this difference mainly come from within or between regions? What kind of convergence mechanism exists in the construction of high-standard farmland? Answers to these questions enhance understanding of regional differences in HSFC efficiency, which is of great practical significance and value to the balanced development of HSFC and the reduction of regional disparities.

Existing theoretical studies on the effectiveness of HSFC mainly focus on the implementation effect and performance evaluation of HSFC. Conversely, from an empirical research perspective, scholars analyze the economic and ecological benefits of HSFC. They have found that the development of high-standard farmland significantly improves the quality of arable land, increases grain yield, promotes land transfer, advances agricultural mechanization, reduces the use of chemical fertilizers, and lowers carbon emissions in agriculture. HSFC—a crucial element of land consolidation—serves as an important way to protect both the quantity and quality of arable land (Song et al., 2019; Li et al., 2019). Specifically, HSFC not only significantly increases grain production by enhancing the multiple cropping index, reducing the impact of drought and flood disasters, and expanding the arable land area (Hao et al., 2024), but it also facilitates land leveling, environmental conservation in agriculture, and the improvement of agricultural infrastructure. Thus, HSFC promotes the scaling and mechanization of agriculture (Bradfield et al., 2021), enhances the quality of food products (Gong et al., 2023), and contributes to the growth of farmers' incomes (Chen et al., 2023). Additionally, some studies have explored the ecological benefits of HSFC. For example, Li et al. (2023) suggested that the policy of HSFC significantly reduces agricultural carbon emissions because it promotes green technology innovation and optimizes the structure of crop cultivation. Xiong et al. (2023) found that HSFC suppressed agricultural carbon emissions, mainly by reducing agricultural chemical input intensity and improving agricultural socialized services. Xu et al. (2022) investigated the quantitative impact of high-standard farmland development on the recycling behavior of agricultural film, based on survey data from rural areas of Sichuan Province. Their study found that the likelihood of recycling agricultural film increased by 16% among farmers participating in high-standard farmland projects. Some scholars also highlight the notable effect of HSFC in reducing chemical fertilizer usage, with this effect being particularly pronounced in major grain-producing regions and in the central and western parts of China (Liu et al., 2023).

Certain studies have focused on the performance evaluation of HSFC. In terms of the evaluation system, some studies have used farmer satisfaction as an indicator to assess the performance of HSFC, considering the perspective of customer satisfaction (Guo and Wang, 2016). However, using farmer satisfaction as a performance evaluation outcome is prone to the influence of an individual's subjective feelings, making research outcomes highly subjective. Therefore, some researchers have selected three indicators of farmland productivity, farmland productivity stability, and farmland productivity uniformity to measure the effectiveness of HSFC (Pu et al., 2019). Because an increase in farmland productivity does not effectively reflect the comprehensive effect of HSFC, an increasing number of scholars have selected economic, social, ecological, efficiency, and equity performance indicators to measure the comprehensive performance of HSFC (Wang et al., 2018, 2022).

Regarding evaluation methods, the primary methodologies for measuring the performance of HSFC include the entropy weight TOPSIS method (Xiong et al., 2016) and the projection pursuit model (Ma and Shao, 2018). Some scholars have also utilized temporal and spatial data fusion technology based on MODIS and Landsat 8 OLI data to obtain time-series data and applied the vegetation photosynthesis model to estimate Net Primary Productivity in parts of Yongning County in Ningxia. The results indicate that using fused data for net primary productivity estimation can effectively detect the effects of HSFC (Niu et al., 2016). Additionally, researchers have used the analytic hierarchy process to determine the index weights for the evaluation system of HSFC, revealing that factors such as land slope, irrigation facilities, road network density, farmland location, land contiguity, and spatial patterns all impact the construction of high-standard farmland (Xu et al., 2020). Moreover, some scholars have used the data envelopment analysis (DEA) method to evaluate the performance of HSFC. For instance, Ma and He (2020) employed the DEA-SBM model to calculate the efficiency values of funds used in HSFC.

In general, the existing literature has achieved rich results in the implementation effect and performance evaluation of HSFC, which provides important inspiration for this paper. However, there are still many deficiencies. First, the existing literature has focused on analyzing the comprehensive evaluation of the benefits of HSFC, and few studies have systematically measured the efficiency of HSFC. Second, the existing research on the capital efficiency of HSFC mainly uses the DEA-SBM model for evaluation, but there are few studies on the use of the more accurate three-stage super-efficiency SBM-DEA model, which can eliminate the influence of external environmental and random factors to measure the efficiency of HSFC. Third, there is a scant in-depth analysis of HSFC efficiency from the perspective of inputs and outputs. Furthermore, there is a lack of targeted and systematic research on the regional differences and convergence mechanisms of HSFC efficiency.

Based on the limitations and gaps in existing research, this paper applies the three-stage super-efficiency SBM-DEA model to measure the efficiency of HSFC. This study captures the overall spatio-temporal pattern of HSFC efficiency, delves into the regional disparities of such efficiency, and deeply investigates the mechanisms behind the convergence towards high levels of efficiency in HSFC to supplement the existing literature from theoretical and practical perspectives effectively. The relevant research conclusions of this paper not only expand and enrich the theoretical research perspective of HSFC efficiency but also provide empirical evidence for improving the level of HSFC and promoting the regional coordinated development of HSFC.

This study provides unique contributions to the present body of knowledge when contrasted with current literature. First, this study introduces novel research ideas by focusing on high-standard farmland, analyzing the overall characteristics and regional variability of their construction efficiency. The objective of this study is to shed light on trends regarding high-standard farmland development across China and to furnish data-driven support for the enhancement of the quality of construction for high-quality farmland. Second, this investigation addresses issues in the research methods often employed alongside the traditional DEA model, which often produces inaccurate measurement results because it is difficult to resolve radial and angular biases. The super-efficient SBM model fails to address the impact of environmental factors as well as stochastic disturbances, making it difficult to determine the efficiency of relatively effective decision-making units

(Ramanathan and Sarkis, 2010). In comparison, the three-stage super-efficient SBM-DEA method not only considers both inputs and outputs, but also effectively neutralizes the influence of external environmental variables, including economic, societal, and policy aspects along with random influences, thus yielding a more accurate assessment of efficiency. Third, the convergence mechanism of HSFC efficiency in four major economic regions was empirically tested using two levels of σ convergence and β convergence.

2. Research methods

2.1. Three-stage super-efficiency SBM-DEA model

DEA is a common method for measuring efficiency. However, because traditional DEA models scale inputs and outputs in the same proportion, they tend to overestimate the efficiency value of DMU, thus affecting the accuracy of the measurement results (Ali and Seiford, 2020). The traditional DEA model also overlooks the impact of environmental factors and random disturbance terms, potentially skewing efficiency measurements. Thus, this study utilizes a three-stage super-efficient SBM-DEA method to evaluate the efficiency of the construction of high-standard farmlands while referencing extant studies (Li et al., 2020). The specific steps are as follows:

Stage 1: Using the super-efficient SBM model, the initial efficiency value and the input (or output) slack value of each decision unit are measured, and the mathematical expressions are as follows:

$$min\ \rho = 1 + \frac{1}{m}\sum_{i=1}^{m}\overline{s_i} \Big/ x_{ik} \tag{1}$$

$$\left\{ \begin{array}{c} \sum_{j=1,\neq k}^{n} x_{ij}\lambda_j - \overline{s_i} \leq x_{ik} \\ \sum_{j=1,\neq k}^{n} y_{rj}^{d}\lambda_j \geq y_{rk} \\ i = 1,\cdots,m; r = 1,\cdots,q \\ \lambda_j, s^-, s^+ \geq 0; j = 1,\cdots,n; j \neq 0; \end{array} \right\} \tag{2}$$

where ρ represents the efficiency evaluation value; x_{ik} and y_{rk} represent the elements of the input and output vectors, respectively; s^- and s^+ represent the slack variables of input and output; m is the number of input indicators; q is the amount of output indicators; λ denotes the weight of input or output elements; and n is the number of DMU.

Phase 2: Input–output adjustment based on the stochastic frontier analysis (SFA) model: Given that management inefficiency, environmental factors, and random disturbance terms lead to slack inefficiency, this stage applies the SFA model to adjust inputs and outputs by placing all decision units in the same environment. The SFA regression expression is shown below.

$$S_{rk} = f_r(Z_k\ ;\ \beta_r) + V_{rk} + U_{rk} \tag{3}$$

where Z_k represents the environmental variable and β_r denotes the environmental variable coefficient, $i = 1,2,3,\cdots I, r = 1,2,3,\cdots R$, V_{rk} denotes the random disturbance of the k decision unit on the r output slack, U_{rk} denotes the managerial inefficiency of the k decision unit on the r output slack.

Further, the SFA model is regressed to obtain its regression result estimates. To eliminate the effects of environmental variables and stochastic disturbance factors on efficiency, the output variables or input variables need to be adjusted, which is achieved using the following method:

$$X_{rk}^{*} = X_{rk} + [max(Z_k\beta_r) - Z_k\beta_r] + [max(V_{rk}) - V_{rk}] \tag{4}$$

where X_{rk} and X_{rk}^{*} denote the input values before and after adjustment, respectively, $[max(Z_k\beta_r) - Z_k\beta_r]$ adjusts each decision unit to the same environmental level, and $[max(V_{rk}) - V_{rk}]$ denotes the adjustment of the random perturbation terms of each decision unit to the same level.

Stage 3: The computed input values are incorporated into the super-efficient SBM method. This incorporation recalibrates the efficiency evaluation of HSFC, yielding adjusted efficiency figures that factor out environmental and stochastic influences.

2.2. Intertemporal dynamic change and decomposition method of HSFC efficiency

Since the super-efficient SBM model depends on the cross-sectional measurement of static HSFC efficiency in a single year, it falls short of capturing the dynamic evolution of HSFC efficiency in an extensive and authentic manner. Therefore, this study measures the fluctuations of HSFC efficiency in every province of China from 2007 to 2020 based on the global reference using the Malmquist index (Cullinane et al., 2002), as shown in equation (5):

$$M_k^G\left(x^{t+1}, y^{t+1}, b^{t+1}, x^t, y^t, b^t\right) = \frac{\rho_k^G\left(x^{t+1}, y^{t+1}, b^{t+1}\right)}{\rho_k^G(x^t, y^t, b^t)} \tag{5}$$

In equation (5), M_k^G denotes the Malmquist index under global covariance, which can be used to measure the change in the efficiency of HSFC. The Malmquist index can be broken down into efficiency change (EC) and technological change (TC). EC is the change in technical efficiency, with an EC > 1 indicating an increase in technical efficiency. TC is the change in technical progress, which indicates the extent to which the movement of the production frontier contributes to a change in productivity. A TC > 1 indicates technical progress.

2.3. Daugm Gini coefficient and its decomposition method

Utilizing the Daugm Gini coefficient and its decomposition method provides insights into the varying efficiencies of HSFC both nationwide and within distinct regions. The method dissects the overall Gini coefficient into constituent fragments: variations within regions, differences between regions and hypervariable density. Compared with the traditional Gini coefficient, the advantage of this method lies in the fact that it effectively addresses the issue of cross overlapping between the sample data, offering a clear delineation of the origins of regional disparities. The calculation method is shown in equations (6) and (7).

$$G = \frac{\sum_{j=1}^{k}\sum_{h=1}^{k}\sum_{i=1}^{n_j}\sum_{r=1}^{nh}\left|y_{ij} - y_{hr}\right.}{2n^2\mu} \tag{6}$$

$$G = G_w + G_{nb} + G_t \tag{7}$$

where G denotes the overall Gini coefficient, k denotes the number of regional divisions, n is the total number of provinces, and μ represents the average of all provinces. G_w, G_{nb}, and G_t denote the contribution of intra-regional variation, inter-regional variation, and hyperdensity, respectively.

2.4. Convergence test method

There are two main tests for convergence: σ convergence and β convergence. σ convergence refers to the gradually decreasing deviation from the average HSFC efficiency in different regions in the time series.

$$\sigma_t = \frac{\sqrt{\sum_i \frac{\left(Gover_{i,t} - \overline{Gover_{i,t}}\right)^2}{N}}}{\overline{Gover_{i,t}}} \tag{8}$$

where $Gover_{i,t}$ represents the efficiency at which high-standard farmland is being constructed within region i during the timeframe of t. N stands for the total count of provinces contained within each respective region.

β convergence can be categorized into two types: β absolute convergence and β conditional convergence. β absolute convergence suggests that, given equivalent external factors, the efficiency of constructing high-standard farmland across disparate regions will tend to equalize over time. This condition implies that regions with lower efficiency in building high-standard farmland have a faster growth rate when compared with regions with higher efficiency levels. The absolute convergence model is represented using equation (9).

$$\ln\left(\frac{Gover_{i,t+1}}{Gover_{i,t}}\right) = \alpha + \beta \ln\left(Gover_{i,t}\right) + \mu_{i,t} \tag{9}$$

where $ln\left(\frac{Gover_{i,t+1}}{Gover_{i,t}}\right)$ denotes the growth rate of HSFC efficiency in period t of region i. $Gover_{i,t+1}$ represents the efficiency of HSFC in region i for period t+1, $\mu_{i,t}$ represents the error term, and β represents the parameter to be estimated. The magnitude of β allows a determination of whether there is a β convergence trend in the efficiency of HSFC over time.

β conditional convergence represents the growth rate of efficiency that is influenced by other factors. Because there are differences in farmers' income and education levels, rural population sizes, GDP per capita, financial autonomy, and urbanization levels in different regions, this study draws on relevant studies to construct a conditional convergence test model that includes the above control variables as shown in equation (10).

$$\ln\left(\frac{Gover_{i,t+1}}{Gover_{i,t}}\right) = \alpha + \beta \ln\left(Gover_{i,t}\right) + \gamma control \tag{10}$$

In equation (10), γ denotes the regression coefficient of the control variable. If β is less than 0 and passes the significance test, it indicates that there is β conditional convergence in the efficiency of HSFC.

3. Data analysis

3.1. Index data selection

HSFC is strongly associated with the development of agricultural production, the improvement of farmers' income, and the improvement of the rural ecological environment. In this study, using approaches from extant studies (Guo et al., 2020), we combine the objectives of food quantity, quality, and ecological security, selecting input variables, output variables, and external environment variables based on the input-output relationship. We develop an index system for assessing the efficiency of HSFC as shown in Table 1.

Based on the characteristics of HSFC and combined with existing research, to represent the input of HSFC this study selects three types of input indicators: capital investment, labor input, and land input. Capital input refers to the amount of investment in HSFC. This study adopts the state financial expenditure on agriculture, forestry and water affairs to represent capital input. In this paper, planting employees are used to represent it. According to previous studies, this index can be measured by two indexes: cultivated land area or grain sown area, but the latter more accurately reflects the actual use of land. When measuring the output of HSFC, both the economic and ecological benefits should be considered. The economic benefit mainly refers to the grain increase brought by the construction of High-standard farmland, which is represented by the grain yield. Ecological benefits reflect the improvement of the farmland ecological environment, measured by effective irrigation area, farmland consolidation area, and soil erosion control area.

Because HSFC is a systematic project, including decision-making, construction, and management, its efficiency is not only affected by input and output factors but is also closely related to other factors such as the level of economic and social development and relevant policies

Table 1
High standard farmland construction efficiency evaluation index system.

Tier 1 Indicators	Secondary indicators	Variables and descriptions
Input Variables	Capital investment	the agricultural comprehensive development (billion yuan)
	Labor input	Planting industry employees (10,000 people)
	Land input	Grain sown area (thousand hectares)
Output Variables	Grain yield	Grain yield (Ten thousand tons)
	Effective irrigated area	Refers to the area of irrigated land used for agricultural production and effectively irrigated farmland cultivated (million hectares)
	Farmland Improvement Area	Built high standard farmland area (million hectares)
	Soil erosion control area	In the construction of high standard farmland, for the treatment area of soil and water conservation (thousand hectares)
External environment variables	Farmers' income level	Rural per capita disposable income (yuan)
	Educational attainment of farmers	Average years of schooling for rural population: $H = 6Y_1 + 9Y_2 + 12Y_3 + 15Y_4$[a]
	Rural population size	Rural population/arable land area
	GDP per capita	GDP per capita (yuan/person)
	Financial autonomy	Ratio of standardized provincial public finance revenue to standardized provincial public finance expenditure
	Urbanization level	Ratio of urban population to total population in each province at the end of the year

[a] Y_1, Y_2, Y_3, and Y_4 represent the proportion of rural population aged 6 and above with primary and secondary school education, the proportion of rural junior high school education, the proportion of senior high school education, and the proportion of junior college education or above, respectively.

and regulations. For instance, in 2022, the Ministry of Finance and the Ministry of Agriculture and Rural Affairs jointly issued the Measures for Farmland Construction Subsidy Fund Management, which explicitly stipulates that specific subsidies will be provided by central finance to local governments to facilitate HSFC and differentiated subsidies will be granted based on local conditions. Local governments are expected to support HSFC within their own regions through channels such as land leasing revenues from public budgets and government-managed fund budgets. This policy proposal provides financial assurance for HSFC, thereby enhancing its efficiency. Therefore, based on related research (Liu et al., 2018; Tang and Ni, 2018), this study investigates six environmental variables: level of economic development, fiscal autonomy, farmers' education level, farmers' per capita income level, population size, and urbanization level.

(1) Level of economic development: As the economic level improves and citizens' demands become increasingly diverse, the necessity and possibility of citizen participation in the management of social public affairs also increase. However, Baumol (1967) contended that regions with high levels of economic development may increase the provision costs of public infrastructure, leading to efficiency reduction. Consequently, additional analysis is required to validate the correlation between the level of economic advancement and the efficiency of HSFC. This paper plans to measure regional economic development level using per capita GDP.
(2) Fiscal autonomy: Previous studies have discovered that the larger the fiscal autonomy, the more notable the scale effect of rural infrastructure investment (Liu and Xia, 2018). Additionally, administrative coordination and fiscal input are institutional

factors that relate to the improvement of the efficiency of government expenditure. Therefore, fiscal autonomy impacts the quality and efficiency of HSFC to a certain extent. Following a study by Chen (2010), this research measures fiscal autonomy using the public's standardized provincial fiscal income and fiscal expenditure.

(3) Farmers' education level: Farmers with high education are keenly aware of the maintenance requirements of high-standard farmland after construction, which enables them to enhance farmland productivity. However, some research indicates that a household head's education negatively impacts the household's participation in farmland irrigation system governance (Qin et al., 2019). Other scholars found a household head's education level had no significant effect on the performance of village farmland irrigation system governance (Yang et al., 2020). Therefore, it is necessary to investigate the link between farmers' educational levels and the efficiency of developing high-standard farmland. Using the approaches adopted by extant studies, this research aims to measure farmers' education levels using the proportion of rural labor with at least middle school education to total rural labor.

(4) Farmers' per capita income level: After the 1990s, farmers' incomes changed, with many of them ceasing their reliance on household operating income growth and instead mainly relying on remunerative income growth (Zhong, 2007). According to the National Bureau of Statistics, from 2004 to 2023, the proportion of farmers' wage income increased from 32.37% to 42.24% while the proportion of farmers' operating income decreased from 60.13% to 34.26%, indicating that wage income has gradually become the main component of farmers' income. With the continuous increase in farmers' incomes, the proportion of household operating income gradually decreases and the dependence on agricultural production decreases, weakening farmers' willingness to participate in HSFC. Consequently, this study utilizes regional per capita income of farmers to examine the influence of rising farmer incomes on the efficiency of constructing high-standard farmland.

(5) Population size: In counties with large population sizes, the demand for rural public goods is great. This demand compels local governments to supply rural public goods, forming a "scale economy" in the supply and improving efficiency (Huang and Yao, 2021). Therefore, the proportion of a rural population to arable land area is employed to represent the rural population size, functioning as an indicator of the influence of population size on the efficiency of the construction of high-standard farmland.

(6) Level of urbanization: If a region has a high level of urbanization, it is likely to have well-developed infrastructure (Lu and Du, 2012). This infrastructure not only has a strong radiating driving effect but also improve the level of rural infrastructure construction. Additionally, as urbanization progresses, the surplus rural labor force gradually migrates to cities. This migration leads to a change in the regional pattern of food production and intensifies the non-grain use of cultivated land (Wei et al., 2023), which may impact HSFC. This study measures urbanization levels using the proportion of the urban population to the total population for each province.

3.2. Data source

Based on the index system constructed above, considering the condition of HSFC on the ground, data availability, and other factors, this study utilizes available panel data from 2007 to 2020 for analysis. Due to an absence of data on soil erosion control areas in Shanghai, the variable is not a part of the analysis; therefore, only 30 provinces, autonomous regions, and municipalities in China are included in the research. In the analysis, the data on labor input, land input, grain output value, farmers' income level, effective irrigation area, soil erosion control area, and rural population size were obtained from the China Rural Statistical Yearbook.[3] Data on the GDP per capita, fiscal autonomy and urbanization levels were drawn from the China Statistical Yearbook.[4] Data on investments in the total agricultural development and farmland renovation area were acquired from the China Financial Yearbook.[5] Data on farmers' educational levels were drawn from Lastly, individual indicators and data were acquired as follows: In the calculation of grain output value, the data were adjusted to the 2007 constant price output value to eliminate the influence of prices. To enhance the reliability and continuity of the data, the farmland renovation area data from 2018 to 2020 were obtained from the HSFC tasks issued annually by the Ministry of Agriculture and Rural Affairs. Individual missing data were supplemented according to the trend of time-series data and the linear interpolation method. Based on the geographical location and economic development level of a region, the 30 provinces are divided into four regions: the northeast, eastern, central, and western regions.[6] Descriptive statistics for each of the input-output variables and environmental variables are shown in Table 2.

4. Results and analysis

4.1. Measurement and decomposition of high standard farmland construction efficiency

4.1.1. Measurement and decomposition of the efficiency of traditional HSFC in the first stage

This study utilizes MAXDEA software to evaluate the efficiency of developing high-standard farmland across 30 provinces, autonomous regions, and municipalities from 2007 to 2020, as detailed in Table 3.

Analysis from Table 2 reveals the following:

(1) The mean efficiency of HSFC in China between 2007 and 2020 stands at 0.695, indicating a moderate to high level of efficiency. The trend during the period displays a U-shaped pattern, initially declining, then stabilizing, and eventually increasing, with regional efficiency disparities widening.

(2) HSFC efficiency in the eastern region has experienced a change characterized by a decrease first and then an increase, and the average value of construction efficiency from 2007 to 2020 is 0.689, which is slightly lower than the national average.

(3) Both central and western areas display a U-shaped efficiency change for high-standard farmland development, with a decline followed by a steady increase. Simultaneously, the construction efficiency in the central and western regions is lower than the national average.

(4) The average efficiency value for HSFC in the northeastern region from 2007 to 2020 is 0.906, surpassing the national average by a broad margin. This result suggests that the efficiency of HSFC in China varies by region, particularly in the northeast and west.

[3] Department of Rural Social and Economic Survey, National Bureau of Statistics (Ed.): China Rural Statistical Yearbook (2006–2021, calendar years), Beijing: China Statistics Press.

[4] National Bureau of Statistics (Ed.): China Statistical Yearbook (2006–2021, calendar years), Beijing: China Statistics Press.

[5] Editorial Committee of China Finance Yearbook (Ed.): China Finance Yearbook (2006–2018, calendar years), Beijing: China Finance Magazine.

[6] The eastern region includes nine provinces, including Beijing, Tianjin, Hebei, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong and Hainan; The central region comprises six provinces, namely Shanxi, Anhui, Jiangxi, Henan, Hubei and Hunan; The western region includes 12 provinces, including Inner Mongolia, Guangxi, Sichuan, Guizhou, Yunnan, Tibet, Shaanxi, Gansu, Ningxia, Xinjiang, Chongqing and Qinghai; The northeast region includes three provinces: Heilongjiang, Jilin and Liaoning.

Table 2
Descriptive statistical results of each variable.

Category of indicators	Specific indicators	Average value	Standard deviation	Minimum value	Maximum value
Input Variables	Capital investment	855.37	2636.43	22.96	23948.46
	Labor input	157973.6	994790.9	15.39	7986534
	Land input	7152.93	19550.58	46.52	119230.1
Output Variables	Food production value	3831.13	10520.69	28.76	66949.15
	Effective irrigated area	3989.8	10899.95	109.2	69160.52
	Farmland Improvement Area	230.84	762.2	0.03	8000
	Soil erosion control area	14250.46	42878.47	15.59	302169
External environment variables	Farmers' income level	10437.6	5757.21	2328.9	34911.3
	Educational attainment of farmers	7.56	0.81	3.80	9.74
	Rural population size	1.1	1.81	0.04	9.38
	GDP per capita	48024.41	27110.33	8824	164220
	Financial autonomy	24.69	29.07	0.1	95.09
	Urbanization level	54.96	13.92	21.5	89.6

Table 3
National and east-west-northeast regions HSFC efficiency from 2007 to 2020 in statg1.

Time	Eastern Region	Central Region	Western Region	Northeast Region	National overall
2007	0.914	0.798	0.742	0.987	0.860
2008	0.754	0.714	0.682	0.977	0.782
2009	0.677	0.605	0.585	0.764	0.658
2010	0.657	0.557	0.562	0.763	0.635
2011	0.655	0.551	0.536	0.864	0.652
2012	0.680	0.558	0.521	0.869	0.657
2013	0.604	0.546	0.523	0.907	0.645
2014	0.634	0.554	0.520	0.867	0.644
2015	0.633	0.565	0.516	0.861	0.644
2016	0.633	0.559	0.503	0.871	0.642
2017	0.636	0.629	0.518	0.904	0.672
2018	0.646	0.610	0.561	1.195	0.753
2019	0.707	0.655	0.578	0.901	0.710
2020	0.810	0.762	0.594	0.958	0.781
Average value	0.689	0.619	0.567	0.906	0.695

Malmquist index is a common indicator for measuring the dynamic change of HSFC efficiency. This paper calculates and breaks down the yearly average M index for each Chinese province from 2007 to 2020, as shown in Table 4. The findings suggest that the average efficiency of HSFC during this period stands at 0.993, signifying that the efficiency of China's HSFC has largely remained consistent. Eleven out of thirty provinces in China have an M value greater than 1. The ranking from highest to lowest is Beijing, Jilin, Tibet, Jiangxi, Fujian, Anhui, Zhejiang, Heilongjiang, Jiangsu, Tianjin, and Inner Mongolia. In general, the efficiency of HSFC has grown fast in the eastern region, whereas the western region is experiencing a decline. This condition indicates poor construction of high-standard farmlands in the western region that has not yet met the actual production and living needs of farmers. From the viewpoint of provinces, the EC and TC indices of 12 provinces, namely Beijing, Tianjin, Inner Mongolia, Jilin, Jiangsu, Anhui, Fujian, Jiangxi, Shandong, Hainan, Tibet, and Ningxia, are all greater than 1. Across different regions, the Eastern, Central, and Northeastern regions have EC and TC indices greater than 1. Notably, the EC index surpasses the TC index in all regions. This result implies that the enhanced efficiency in constructing high-standard farmland in the Eastern, Central, and Northeastern areas is largely driven by the combination of technological progress and technical efficiency improvement, with the latter playing a more dominant role.

4.1.2. Analysis of SFA regression results in the second stage

In the second stage of DEA analysis, slack variables from initial inputs served as independent variables and the environmental factors were used as the explanatory variables for SFA analysis, and the results are shown in Table 5. The analysis reveals the following findings:

(1) Farmers' income level. The evaluation reveals that farmers' earnings inversely influence the labor input and capital input slack variables significantly. This finding suggests that the higher the income level of farmers, the lower the redundancy of capital and labor input, and the higher the efficiency of HSFC, which is inconsistent with the expected results. A potential cause of the result is that the higher the income level of farmers, the more they engaged in non-agricultural work (Zhu, 2002), tending to transfer land to obtain rental income. This is conducive to the large-scale

Table 4
Efficiency index of HSFC and its decomposition by provinces and municipalities in the first stage from 2007 to 2020.

Region	M-index	EC Index	TC Index	Region	M-index	EC Index	TC Index
Beijing	1.048	1.028	1.019	Guangdong	0.987	0.999	0.992
Tianjin	1.001	1.007	1.005	Guangxi	0.965	0.985	0.985
Hebei	0.961	0.982	0.991	Hainan	0.970	1.132	1.038
Shanxi	0.996	1.002	0.993	Chongqing	0.985	0.999	0.991
Inner Mongolia	1.000	1.015	1.011	Sichuan	0.989	0.995	0.999
Liaoning	0.998	0.985	1.040	Guizhou	0.980	0.991	0.992
Jilin	1.037	1.059	1.020	Yunnan	0.995	1.009	0.989
Heilongjiang	1.005	1.017	0.995	Tibet	1.034	1.113	1.013
Jiangsu	1.003	1.000	1.015	Shanxi	0.967	0.989	0.983
Zhejiang	1.011	0.995	1.053	Gansu	0.991	1.007	0.986
Anhui	1.015	1.021	1.055	Qinghai	0.961	0.988	0.982
Fujian	1.018	1.222	1.123	Ningxia	0.990	1.018	1.004
Jiangxi	1.032	1.080	1.002	Xinjiang	0.990	0.986	1.009
Shandong	0.998	1.000	1.003	East	1.000	1.041	1.027
Henan	0.994	0.996	1.011	Middle	1.005	1.015	1.013
Hubei	0.994	1.001	0.997	West	0.987	1.008	0.995
Hunan	0.996	0.990	1.019	Northeast	1.013	1.020	1.018
				National	0.993	0.985	1.021

Table 5
SFA regression results of national HSFC from 2007 to 2020.

Variables	Financial input (slack variable)	Labor input (slack variable)	Land input (slack variable)
Farmers' income level	−392.565*** (61.378)	−0.475** (0.220)	27.140 (129.231)
Educational attainment of farmers	−32.194 (21.567)	−0.514*** (0.072)	−71.208 (45.201)
Rural population size	−20.276 (22.218)	4.650*** (0.071)	−19.451 (46.664)
GDP per capita	89.364* (79.596)	−0.315 (0.280)	363.748** (168.096)
Financial autonomy	103.217 (58.336)	1.758*** (0.190)	54.258 (122.819)
Urbanization level	9.759*** (2.189)	−0.086*** (0.007)	4.499 (4.586)
Constant term	2127.343*** (451.699)	−0.452 (1.679)	−4050.114*** (949.376)
Sigma-squared	3230000000	1.649	45300000
gamma	0.999	0.622	0.994
LR	43.82***	12.04**	42.00***

and mechanized operation of cultivated land, convenient for HSFC, and is associated with the reduction of the redundant investment of capital and labor, and improved construction efficiency. In addition, the income level of farmers has a positive impact on the land input slack variable, but it is not significant.

(2) Farmers' education level. As shown in Table 5, farmers' education level negatively affects the slack variables of financial input, labor input, and land input, but only labor input passes the significance test. This finding indicates that as education level increases, the redundancy values of these inputs will decrease inversely, thus leading to the efficient allocation of resources.

(3) Village population size. As can be seen from Table 5, rural population size has a negative but not significant effect on the financial input and land input slack variables. Although an increase in village population size can reduce the financial input and land input redundancy to some extent, this effect is relatively small.

(4) GDP per capita. As can be seen from Table 5, GDP per capita has a positive effect on financial input and land input slack variables, and both pass the significance test. This outcome indicates that an increase in GDP per capita leads to an increase in capital input and land input. The reason behind this situation may be that rapid economic growth prompts the government to increase capital investment in the construction of high-standard farmland and motivates farmers to expand the area under grain cultivation, which leads to a redundant increase in capital input and land input.

(5) Fiscal autonomy. As shown in Table 5, financial autonomy has a positive effect on the slack variables of financial input, labor input and land input, but only the slack variable of labor input passed the significance test. This outcome indicates that increasing fiscal autonomy will significantly increase the number of plantation workers, causing resources to become inefficiently allocated and leading to low efficiency of HSFC. The reason for this outcome may be that the level of government fiscal autonomy represents the degree of government domination over financial resources. When local governments enjoy a certain degree of fiscal autonomy, they can optimize the allocation of public resources to a large extent.

(6) Level of urbanization. As shown in Table 5, the level of urbanization has a significant negative effect on the labor input slack variable. This outcome indicates that the increase in urbanization level will promote the outflow of rural labor, thus significantly reducing the number of employees in the plantation industry and optimizing the efficiency of resource allocation. The regression coefficients of the slack variables of urbanization level and capital input and land input are positive, and the regression coefficient of capital input passes the significance test. The reason may be that the improvement of urbanization level has intensified the population outflow (Jia and Zhong, 2022), and the problem of aging in rural areas is serious. To solve the problem of shortage of rural labor force, reduce the further outflow of labor force, and retain the surplus rural labor force, the government will increase financial support, protect the interests of farmers in grain farming, and promote the increase of rural income.

4.1.3. Calculation and decomposition of the adjusted HSFC efficiency in the third stage

According to the analysis in Table 6, in general, the efficiency of HSFC in China from 2007 to 2020 shows a fluctuating and decreasing trend of middle to upper-level efficiency. The national average efficiency level is 0.765, which is an improvement compared to the first stage, indicating that the efficiency of HSFC in China is underestimated before excluding the influence of environmental error factors.

The average efficiency values of HSFC in the four major regions, from high to low, are 0.875, 0.765, 0.743, and 0.731 for the northeast, east, west, and central regions, respectively. The values may be attributable to the fact that the northeast region is dominated by plains: due to its better natural conditions, the difficulty and cost of HSFC are lower, making it easier to improve HSFC efficiency. The eastern region has a relatively developed economy, and the dividend marginal effect associated with the development and application of digital technology is higher, making it more conducive to HSFC. In contrast, the central and western regions are dominated by hills and mountains that are not suitable for mechanized operations; consequently, HSFC in the regions is relatively poor. In addition, from 2007 to 2020, the efficiency of HSFC in the northeast region increased significantly and was higher than the national average; the efficiency of HSFC in the central and western regions was lower than the national average and showed a U-shaped change characteristic of first declining - then stable - then rising, in which the efficiency difference between the northeast and central regions was larger, and the efficiency difference between the northeast and eastern regions was relatively small. The efficiency values of the whole country and the four major regions show a fluctuating trend. Compared with the efficiency values of the first stage, the fluctuations range of the efficiency values in the third stage in the whole country and the eastern, central and western regions has a decreasing trend, i.e., the efficiency values are more concentrated among the provinces and show a gradual convergence.

In terms of phases, the development of the entire sample period can be divided into three stages: the first stage is the rapid decline period

Table 6
National and east, west and northeast high standard farmland construction efficiency from 2007 to 2020 in stage 3.

Time	Eastern Region	Central Region	Western Region	Northeast Region	National overall
2007	0.885	0.822	0.807	0.917	0.858
2008	0.835	0.786	0.790	0.920	0.833
2009	0.811	0.731	0.765	0.814	0.780
2010	0.808	0.737	0.761	0.830	0.784
2011	0.785	0.728	0.751	0.842	0.777
2012	0.768	0.727	0.750	0.833	0.770
2013	0.734	0.718	0.745	0.828	0.756
2014	0.734	0.724	0.738	0.839	0.759
2015	0.713	0.717	0.729	0.830	0.747
2016	0.719	0.714	0.724	0.813	0.743
2017	0.727	0.704	0.723	0.839	0.748
2018	0.726	0.706	0.723	1.236	0.848
2019	0.7264	0.706	0.703	0.819	0.739
2020	0.735	0.719	0.699	0.892	0.761
Average value	0.765	0.731	0.743	0.875	0.765

from 2007 to 2009, the second stage is the slow decline period from 2009 to 2017, and the third stage is the stable change period from 2017 to 2020. Specifically, during the period from 2007 to 2009, the overall efficiency of HSFC in the nation and in the 4 major regions has a substantial declining trend. The efficiency decreases by 10% nationally, 9.12% in the eastern region, 12.45% in the central region, 5.49% in the western region, and 12.65% in the northeastern region. From 2009 to 2017, the efficiency of HSFC in the nation and in the four major regions generally maintains a consistent trend with minimal fluctuations. During the period from 2017 to 2020, despite significant fluctuations observed at the national level and in the northeastern region, other regions experience only mild fluctuations. It is worth noting that China's HSFC efficiency grew rapidly in 2018, with a year-on-year growth of 4.41%. Accordingly, this paper speculates that the reason for the rise in HSFC efficiency since 2017 may lie in the fact that with the promotion of HSFC policies, arable land protection became a policy hotspot at that time, which in turn led to a rapid increase in HSFC efficiency in 2017–2020. Before 2018, China had initiated policies for the construction of high-standard farmland, issuing the "National Overall Planning for HSFC (2011–2020)" in 2013, setting forth the short-term task of completing 26.67 million hectares of high-standard farmland by 2015 and striving to establish 53.33 million hectares by 2020. However, there were no clearly defined annual construction targets and tasks for each province, leading to a lack of enthusiasm for HSFC among the provinces. Additionally, the construction process involved multiple government departments such as land and resources, finance, development and reform, water resources, and agriculture, leading to functional conflicts and overlaps in practice. This resulted in multiple construction plans within many provinces, with areas failing to unify efforts, which impacted construction efficiency. After major state institutional reforms in 2018 led to farmland construction project management responsibilities being integrated into the Ministry of Agriculture and Rural Affairs, fragmented management issues were eliminated. The planners focused on the construction of high-standard farmland, implementing the strategy of "Tibetan food in the land, Tibetan food in technology". In the same period, the Ministry of Agriculture and Rural Affairs issued HSFC tasks annually. In 2019, the ministry issued "Implementation Measures for Evaluation and Incentives of HSFC (Trial)", which formulated evaluation criteria for HSFC, allocating 100–200 million yuan of HSFC funds to each incentive province. It effectively ensures the completion of construction tasks and improves the efficiency of HSFC in China.

Table 7 presents the M, EC, and TC indexes of the efficiency of HSFC in each province and region of China in the third stage (2007–2020). In the four major regions, except for the M index in the northeast, which is greater than 1, the M index in all other regions is less than 1. This condition indicates that the efficiency of HSFC in China has not improved greatly, and the majority of provinces maintain the same or even show a decreasing trend in the construction efficiency. The EC and TC and EC indices in the eastern, central, and northeastern regions are greater than 1, while the TC indices in the eastern, central, western, and northeastern regions are less than 1. This outcome indicates that the decrease in the efficiency of HSFC in the eastern, central, and western regions is mainly caused by technological progress. Specifically, in the eastern region, only Beijing, Tianjin, Jiangsu, and Zhejiang have M indexes greater than 1, revealing a positive growth in the efficiency of HSFC, while the rest of the provinces regress, with the average annual decline rate from high to low found in Hebei, Shandong, Hainan, Guangdong, and Fujian, in that order (see Table 8).

Regarding the breakdown of the results of the M index in eastern provinces and regions, except for Hebei and Guangdong provinces, the technical efficiency index of the remaining provinces is greater than 1, which is the main driving force behind the growth of HSFC efficiency. Four of these provinces, Beijing, Hebei, Guangdong, and Hainan, have a technical progress index of less than 1, offsetting some of the benefits of technical efficiency. For the central provinces, the efficiency of HSFC declines in all 6 provinces from 2007 to 2020. The average annual decline rates from high to low are Henan (1.8%), Hubei (1.0%), Hunan (0.8%), Anhui (0.7%), Jiangxi (0.6%), and Shanxi (0.4%).

Concerning the decomposition of the M index in central provinces, the technical progress index of all 6 provinces is less than 1, which is the main cause behind the restriction of growth of HSFC efficiency. In western provinces, except for Tibet and Inner Mongolia, which have a slight increase in the efficiency of HSFC, the index of HSFC in all other provinces is less than 1. The average annual decline rates in descending order are Guangxi (3.2%), Gansu (1.1%), Qinghai (0.6%), Sichuan (0.24%), Shanxi (0.23%), Ningxia (0.2%), Yunnan (0.19%), Guizhou (0.16%), Xinjiang (0.1%), and Chongqing (0.1%).

The breakdown of the efficiency index of HSFC in the western region, except for Tibet and Inner Mongolia, where technical progress appears to rise, is as follows: the index of technical progress in all other provinces is less than 1, which is the main reason inhibiting the improvement of HSFC.

In the northeast region, all 3 provinces with an M index greater than 1 from 2007 to 2020 realize an improvement in the construction level of high-standard farmland, with the following average annual growth rates: Jilin – 5.7%, Liaoning – 1.7%, and Heilongjiang – 1.6%, in that order. Regarding the M index decomposition, the technical efficiency index is greater than 1 in all 3 provinces, which is the main driver of the growth in efficiency of HSFC. However, the technical progress indices of Jilin and Heilongjiang provinces are less than 1, which partially offset the effect of technical efficiency.

Table 7
National and provincial and municipal high standard farmland construction efficiency index and its decomposition in the third stage from 2007 to 2020.

Region	M-index	EC Index	TC Index	Region	M-index	EC Index	TC Index
Beijing	1.001	1.023	0.979	Guangdong	0.983	0.993	0.992
Tianjin	1.004	1.003	1.007	Guangxi	0.968	0.981	0.987
Hebei	0.965	0.984	0.992	Hainan	0.982	1.001	0.981
Shanxi	0.996	1.001	0.997	Chongqing	0.999	1.020	0.986
Inner Mongolia	1.002	1.003	1.008	Sichuan	0.976	0.989	0.996
Liaoning	1.017	1.008	1.009	Guizhou	0.984	0.992	0.993
Jilin	1.057	1.092	0.996	Yunnan	0.981	0.998	0.987
Heilongjiang	1.016	1.024	0.994	Tibet	1.013	1.013	1.000
Jiangsu	1.018	1.009	1.009	Shanxi	0.977	0.988	0.992
Zhejiang	1.009	1.013	1.006	Gansu	0.989	0.999	0.992
Anhui	0.993	1.020	0.976	Qinghai	0.994	1.001	0.994
Fujian	0.995	1.047	1.008	Ningxia	0.998	1.005	0.996
Jiangxi	0.994	1.028	0.988	Xinjiang	0.999	0.988	1.012
Shandong	0.980	1.006	0.989	East	0.987	1.009	0.996
Henan	0.982	1.002	0.989	Middle	0.991	1.016	0.988
Hubei	0.990	1.017	0.986	West	0.988	0.998	0.995
Hunan	0.992	1.030	0.993	Northeast	1.022	1.041	0.999
				National	0.992	1.009	0.994

Table 8
Gini coefficients and their decomposition results.

Year	Total	Intra-regional variation				Differences between regions						Contribution rate (%)		
		Northeast	East	West	Middle	E-NE	W-EN	W-E	M-EN	M-E	M-W	Intra	Regions	Density
2007	0.090	0.067	0.084	0.089	0.056	0.079	0.102	0.100	0.094	0.092	0.083	27.192	28.612	44.196
2008	0.083	0.070	0.069	0.091	0.045	0.090	0.109	0.088	0.100	0.067	0.077	27.596	28.154	44.250
2009	0.080	0.070	0.067	0.093	0.028	0.072	0.091	0.090	0.069	0.070	0.078	28.563	26.977	44.460
2010	0.083	0.060	0.074	0.096	0.038	0.073	0.092	0.094	0.077	0.071	0.082	29.036	26.423	44.540
2011	0.084	0.072	0.073	0.096	0.040	0.080	0.102	0.092	0.084	0.066	0.082	28.823	26.562	44.615
2012	0.092	0.078	0.078	0.110	0.045	0.087	0.110	0.100	0.088	0.069	0.091	29.543	20.048	50.409
2013	0.093	0.089	0.080	0.109	0.045	0.101	0.113	0.100	0.094	0.068	0.091	29.404	18.415	52.181
2014	0.095	0.093	0.083	0.107	0.049	0.107	0.118	0.100	0.099	0.072	0.090	28.887	16.683	54.429
2015	0.098	0.085	0.089	0.113	0.050	0.110	0.117	0.106	0.096	0.075	0.094	29.191	17.823	52.985
2016	0.097	0.075	0.083	0.117	0.046	0.097	0.114	0.107	0.086	0.069	0.097	29.570	14.409	56.021
2017	0.098	0.087	0.085	0.114	0.041	0.109	0.122	0.107	0.104	0.070	0.095	28.633	19.568	51.799
2018	0.110	0.074	0.092	0.133	0.055	0.111	0.130	0.121	0.109	0.079	0.111	29.180	17.330	53.490
2019	0.118	0.084	0.096	0.147	0.055	0.105	0.139	0.132	0.099	0.082	0.124	29.452	16.438	54.110
2020	0.127	0.132	0.108	0.148	0.038	0.147	0.178	0.137	0.130	0.082	0.120	27.905	24.464	47.631

In this study, ArcGIS software is used to draw a distribution map of the efficiency of HSFC in 30 provinces, autonomous regions, and municipalities in China in 2007 and 2020, and the regions are divided into 4 categories, namely, higher efficiency area, high-efficiency area, medium-efficiency area, and low-efficiency area, and the results are shown in Fig. 1. These results reveal the following facts: in 2007, the only provinces, autonomous regions, and municipalities with high efficiency in HSFC are Heilongjiang, Hebei, Tibet, Jilin, Tianjin, Hainan, Shandong, Ningxia, Beijing, and Qinghai, and most of the remaining provinces have a medium level of efficiency. By 2020, except for Zhejiang Province, which has risen to a high-efficiency level, the efficiency of HSFC in the rest of the provinces, autonomous regions, and municipalities declined. Specifically, Guizhou, Sichuan, Yunnan, Shaanxi, Guangdong, Guangxi, and other provinces decline from medium to low efficiency, and Hainan, Hebei, Tibet, Jilin, Shandong, Ningxia, Qinghai, and other provinces decline from higher efficiency to high efficiency.

In terms of spatial distribution, the efficiency of HSFC from 2007 to 2020 shows an increasing trend from south to north, which is manifested in the northeastern region and the north-western region as a medium–high-efficiency cluster and the central region and the southern–western region as a medium–low-efficiency cluster.

4.2. Analysis of regional differences in the efficiency of HSFC

4.2.1. The overall difference

To measure regional differences and evolutionary trends of HSFC efficiency, this paper adopts the Dagum Gini coefficient and its decomposition method, and the results are shown in Table 7. The resource endowment and natural environments of different regions differ greatly. The overall level and growth trend of HSFC efficiency in different areas are compared and analyzed.

Fig. 2 portrays the overall gap in the efficiency of HSFC in China from 2007 to 2020. According to Fig. 2, from 2007 to 2020, the overall gap of national HSFC efficiency showed a slowly rising trend, and the overall gap increased from 0.090 in 2007 to 0.127 in 2020, an increase of 41.11%. From the regional level, the regional gap in HSFC efficiency in the central region is small and has a decreasing trend. Moreover, the regional gap in HSFC efficiency in the western region is the largest among all regions and has a gradually increasing trend, which indicates that the unbalanced development of HSFC in the western provinces is high, and there is an apparent polarization phenomenon. For example, the efficiency of HSFC in Ningxia in 2020 is 0.941, while that in Guangxi in the same year is only 0.459. The gap in HSFC efficiency is substantial between the two provinces. Sichuan built a total of 324,800 ha of high-standard farmland and 35,900 ha of efficient water-saving irrigation farmland in 2022, with both metrics exceeding the annual target and earning the region a place in the list of provinces congratulated by the Ministry of Agriculture and Rural Affairs for HSFC in 2022. In comparison, Tibet only built 49,900 ha of land in 2022, which was less than one-sixth that of Sichuan province, and has not fulfilled the task assigned by the Ministry of Agriculture and Rural Affairs. Consequently, there is a

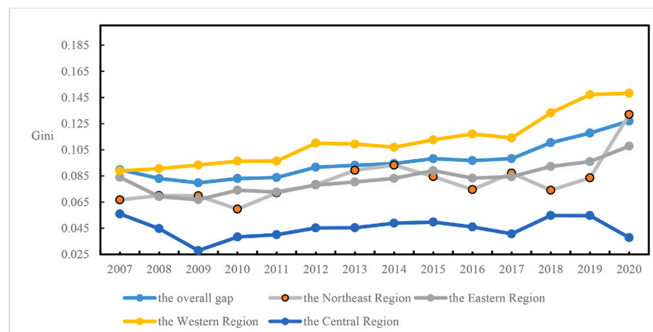

Fig. 2. Overall and intra-regional Gini coefficient differences and evolution trends of China's HSFC efficiency, 2007–2020.

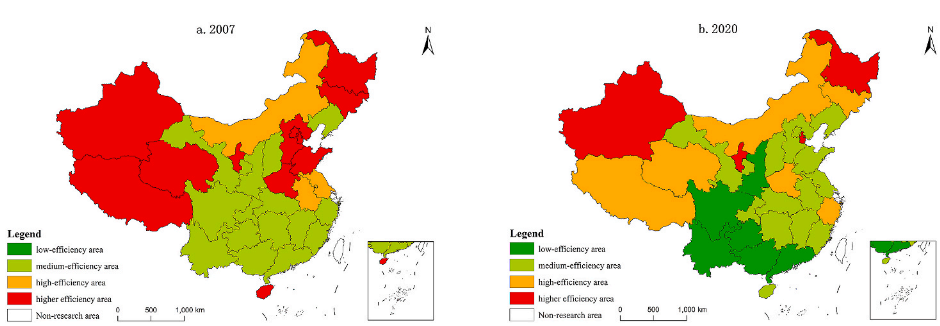

Fig. 1. Spatial distribution of the efficiency of HSFC in 2007 and 2020.

large gap in the construction of high-standard farmland between the two provinces.

The gap between the efficiencies of HSFC is large. In addition, the regional gap in the efficiencies of HSFC in the eastern and the northeast regions gradually increases. Particularly, the northeast region sees a large increase of 78.38% between 2018 and 2020. The reason behind this phenomenon may be that most central provinces are plain areas, thus the difference in the efficiency of HSFC between regions is relatively small. In contrast, the northeast region is the main black land reserve in China, accounting for approximately 44.78% of the total arable land area in the region. Therefore, there are large differences in the quality of arable land in the northeast, leading to a divergence in the efficiency of HSFC in various regions in the northeast.

4.2.2. *Differences between regions*

Fig. 3 illustrates the evolution of differences among four major regions in China. In general, except for the differences between central and eastern regions, which exhibit steady change, the difference between the other regions fluctuates or slowly increases. The largest increases are in the western and northeastern regions, indicating that the gap in HSFC efficiency in the western and northeastern regions is growing and is clearly dispersed. Specifically, the Gini coefficient of the eastern and northeastern regions increased from 0.079 in 2007 to 0.147 in 2020, with an average annual rise of 0.527%; the Gini coefficient of the western and northeastern regions increased from 0.102 in 2007 to 0.178 in 2020, with an average annual rise of 0.585%; the Gini coefficient of the western and eastern regions increased from 0.102 in 2007 to 0.120 in 2020, with an average annual increase of 0.138%; The Gini coefficient for the central and northeastern regions rises from 0.094 in 2007 to 0.130 in 2020, with an average annual increase of 0.276%; the Gini coefficient for the central and eastern regions rises from 0.092 in 2007 to 0.082 in 2020, with an average annual decrease of 0.076%; the Gini coefficient for the central and western regions rises from 0.083 in 2007 to 0.120 in 2020, with an average annual increase of 0.285%. In terms of differences between various regions, the gap in HSFC efficiency between the northeast and central regions shows a gradually widening trend, with fluctuations of a scale second only to the scale of the fluctuations in the west and northeast regions. Moreover, the gap between the central and eastern regions is always the least in size between all regions. This outcome is consistent with the previous conclusions. In addition, the gap in HSFC efficiency between central and western regions is smaller than that between western and northeastern regions, central and northeastern regions, and eastern and northeastern regions.

4.2.3. *Sources of differences and contributions*

Fig. 4 illustrates the sources and contributions of regional differences in the efficiency of HSFC. From the figure, it can be seen that the contribution rates of inter-group gap and super-variable density to the efficiency of HSFC in China fluctuate considerably, and the intra-group gap tends to be stable. Specifically, the contribution rate of the inter-group gap generally decreased during 2007–2020, and the contribution rate reached its lowest level of 14.41% in 2016. Overall, in most years, the contribution rate of the intra-group gap and super-variable density is larger than that of the inter-group gap. From the intra-group gap contribution rate, there is an overall slow upward trend during 2007–2020, and the contribution rate is always below 30%. In terms of the contribution rate of hypervariable density, the overall trend of fluctuation increased during the sample investigation, in which the contribution rate reached the highest in 2016, which was 56.02%, and then showed a downward trend, but all of them were above 40%. In summary, from the full sample period, the hypervariable density is the main source of the spatial imbalance in the efficiency of HSFC, indicating that the cross-overlapping problem among different regions has a great impact on the overall difference.

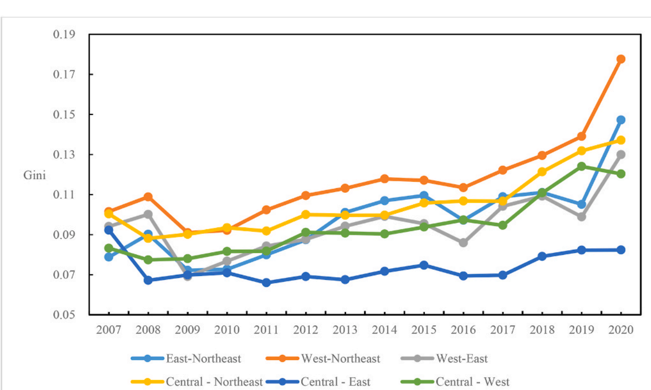

Fig. 3. Difference and evolution of Gini coefficient between regions of China's high standard farmland construction efficiency, 2007–2020.

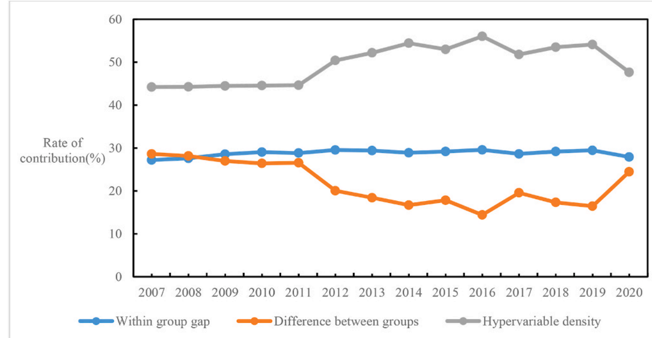

Fig. 4. Sources and contributions of regional differences in the efficiency of HSFC in China, 2007–2020.

4.3. *Convergence analysis of the efficiency of high standard farmland construction*

4.3.1. *σ Convergence analysis*

To quantify the convergence trend of HSFC efficiency in China, this paper uses the coefficient of variation to conduct a convergence test, and the results are shown in Fig. 5. In Fig. 5, it can be seen that the coefficient of HSFC efficiency in China shows an overall growth trend, indicating that the efficiency of HSFC has not shown convergence characteristics. At the regional level, the coefficient of HSFC efficiency in the central region shows a decreasing trend in general, indicating the characteristics of σ convergence. the coefficient of HSFC efficiency in the western and eastern regions shows a small rising trend and does not show the characteristics of σ convergence. Further, the coefficient of HSFC efficiency in the northeastern region has a fluctuating rising trend, with phased convergence and divergence characteristics: in the period from 2007 to 2010 is convergence, the period from 2010 to 2014 is a divergence, the

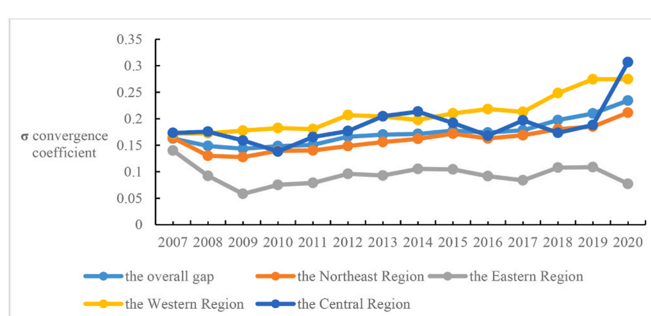

Fig. 5. σ Convergence coefficient of high standard farmland construction efficiency for the whole country and East, West and Northeast China, 2007–2020.

period from 2014 to 2016 is convergence, and the period after 2016 is mainly a divergence. By comparison, conclusion is consistent with the results of the Dagum Gini coefficient measurement in a previous paper.

4.3.2. β Convergence analysis

To comprehensively understand the convergence characteristics of HSFC efficiency, this study conducted a β convergence test on the efficiency of HSFC in China, and Table 9 presents the test results of β absolute convergence. From the table, it can be seen that the β coefficients of HSFC efficiency in the national, eastern, central, western and northeastern regions are significantly negative, indicating the existence of absolute β convergence characteristics in the national and four major regions. In terms of the convergence speed, the convergence speed of the eastern, central and western regions are all lower than the overall national level, and their convergence speed is ranked as central > eastern > western. A possible reason is that the efficiency of HSFC in the western region has a large regional difference, showing a trend of multi-polarization, and limited by geographical location, resource endowment and economic development, its agricultural development level is low. It is worth noting that although the construction efficiency in the northeast region passed the significance test, the speed of convergence could not be measured.

The heterogeneity of economic development levels and natural resource endowment in different regions underlying the convergence test results may change due to variations in external environmental factors. Therefore, this study constructs a panel model to conduct a conditional β convergence test on the construction efficiency of high-standard farmlands based on the consideration of the following factors: farmers' income levels, farmers' education levels, rural population size, GDP per capita, and financial autonomy. As shown in Table 10, the convergence coefficient β, both nationally and in the four major regions, is above the 1% statistical significance level test and is negative during the sample examination period, indicating that the efficiency of HSFC still converges toward the same steady-state after taking into account the aforementioned factors. Moreover, the convergence rates nationally as well as in the eastern and western regions all increase at certain levels, indicating that relevant environmental factors accelerate the convergence rate of HSFC efficiency in some regions.

5. Conclusion and policy implications

Based on the panel data of 30 provinces, autonomous regions, and municipalities in China from 2007 to 2020, this paper measured and analyzed the efficiency of HSFC in each province using the 3-stage super-efficient SBM-DEA model. Moreover, this study evaluated and tested the evolutionary characteristics, regional differences, and convergence of HSFC efficiency in China and in four major regions using the M index, Dagum Gini coefficient, σ convergence, and β convergence, drawing the following conclusions:

First, the efficiency of HSFC in each Chinese province is influenced by the level of farmers' income, farmers' education, rural population size, per capita GDP, financial autonomy, and urbanization level. After removing their effects, the efficiency of HSFC in all Chinese provinces improved. It is apparent that environmental factors and random factors affect the efficiency of HSFC. If their influence is not accounted for, the efficiency of HSFC will be underestimated.

Second, after removing the influence of environmental factors and random errors, the efficiency of HSFC in four major regions fluctuated and decline from 2007 to 2020, and there was a spatial imbalance. Among these regions, the efficiency of HSFC in the northeast region was the highest, while that in the central region was the lowest. Over the full sample period, the efficiency of HSFC in the eastern, central, western and northeastern regions was mainly driven by agricultural technology progress.

Third, the disparity of HSFC efficiency in all regions of the country had an upward trend, and by region, only the intra-regional disparity of HSFC efficiency in the central region decreased slightly, while the rest of the regions had a slow upward trend, especially after 2017, the upward trend was apparent. In terms of the disparity between regions, except for the central and eastern regions where the difference showed a fluctuating downward trend, the remaining regional differences were all on the rise or had a fluctuating upward trend. This outcome indicates that the gap in HSFC efficiency between regions in China has been expanding. From the perspective of the contribution rate differences, the intergroup gap and intra-group gap of HSFC efficiency decreased slightly, and the contribution rate of super-variable density increased, and the rising trend was particularly apparent after 2017, becoming the main source of the spatial imbalance of HSFC efficiency.

Lastly, the results of convergence tests show that there was σ convergence in the efficiency of HSFC in the central region, while there was no σ convergence in the national, western, eastern and northeastern regions. There was β absolute convergence and β conditional convergence both national and four major regions. farmers' education level and rural population size had significant inhibitory effects on the enhancement of HSFC in the national and western regions. Furthermore, urbanization level has a significant inhibitory effect on the improvement of HSFC efficiency in the central region.

Based on the above findings, the following policy insights were obtained:

First, improve the efficiency of HSFC by local conditions. Although the resource endowment and geographic conditions of each region is different, which objectively causes gaps in HSFC, the regional disparity in the efficiency of HSFC has gradually expanded since 2017. Therefore, we need to remain vigilant and implement policies according to local conditions. The northeast region, as the main concentration area of black land, should continue to increase the protection of arable land and build high-standard farmland with high quality. Because of its stronger economic foundation, the Eastern region has set a higher standard for the construction of high-standard farmland and faces relatively less resistance in advancing such projects. The region should leverage the comparative advantage of rapidly developing digital technologies to accelerate the construction of digitalized high-standard farmland demonstration bases, enabling it to lead the surrounding areas in HSFC. In comparison, the central and western regions lack land resource advantages and construction support investment, exhibiting a large capital gap. Consequently, they should increase support for HSFC. To relieve the pressure on local finance, it is crucial that tiered and differentiated subsidy policies for HSFC are explored.

Table 9
β Absolute convergence test results.

Coefficient	National	East	Middle	West	Northeast
β	−0.456***	−0.196***	−0.447***	−0.127***	−1.069***
	(-11.08)	(-4.63)	(-6.81)	(-2.95)	(-6.24)
σ	−0.143***	−0.069***	−0.151***	−0.052***	−0.175***
	(-11.56)	(-5.49)	(-7.15)	(-3.83)	(−4.68)
λ (%)	4.68%	1.68%	4.56%	1.04%	/
N	420	126	84	168	42
R2	0.255	0.167	0.395	0.057	0.527
F	4.04	3.23	5.10	2.04	10.60

Table 10
Results of β-conditional convergence test.

	National	East	Middle	West	Northeast
β	−0.514***	−0.197***	−0.440***	−0.216***	−1.111***
	(0.047)	(0.055)	(0.079)	(0.062)	(0.222)
Farmers' income level	−0.040	−0.045	−0.004	−0.017	0.091
	(0.044)	(0.068)	(0.037)	(0.034)	(0.293)
Educational attainment of farmers	−0.031**	−0.028	−0.003	−0.015*	−0.347
	(0.016)	(0.022)	(0.013)	(0.009)	(0.231)
Rural population size	−0.006***	−0.001	0.001	−0.007***	−0.005
	(0.002)	(0.003)	(0.002)	(0.002)	(0.016)
GDP per capita	0.005	0.035	0.081*	0.002	0.194
	(0.042)	(0.057)	(0.045)	(0.031)	(0.307)
Financial autonomy	−0.078	−0.107	−0.112	0.021	−0.622
	(0.106)	(0.123)	(0.126)	(0.098)	(0.706)
Urbanization level	0.186	0.351	−0.377**	0.089	−0.415
	(0.278)	(0.336)	(0.187)	(0.282)	(2.906)
λ (%)	5.55%	1.69%	4.46%	1.87%	/
Con_s	0.324	0.037	−0.681**	0.103	−1.111
	(0.324)	(0.403)	(0.301)	(0.274)	(0.222)
N	385	117	78	151	39
R2	0.3012	0.206	0.460	0.213	0.585
F	21.43	3.73	7.91	5.09	5.84

Second, it is significant that regional cooperation and mutual learning are strengthened. It is crucial that planners consider regional differences in the process of HSFC, especially in the western region, where there are notable regional disparities. Therefore, provinces with lower HSFC efficiency should strive to implement projects based on the experiences and models of those with high construction efficiency. They should absorb, improve, innovate, adjust resource allocation, strengthen inter-regional cooperation, and ensure that they share and promote the use of advanced technologies that facilitate the development of high-standard farmland. This will promote the coordinated development of HSFC within the region, and narrow internal regional disparities.

Third, the impact of factors such as farmers' income and education levels, rural population size, and financial autonomy on the efficiency of HSFC is notable. When formulating HSFC policies, the influence of the factors listed above should be considered. To promote HSFC, China should strengthen education and training for farmers, improve farmers' knowledge of HSFC, guide farmers in performing land transfers, promote the increase of rural populations in specific counties, and broaden available channels for farmers to obtain employment and increase their incomes. In addition, to improve the efficiency of the use of financial funds, when increasing the financial investment subsidies for HSFC, local governments should reasonably standardize the use process of financial funds and strengthen supervision over the use of funds.

Lastly, local government should investigate the mechanisms that lead to the convergence of HSFC efficiencies at a higher level. They should focus on specific regions exhibiting high efficiency of HSFC, developing them into national HSFC demonstration areas. This will enhance their radiating and driving effects, promoting collaborative development of high-standard farmland in the region. Additionally, they should focus on areas with low construction efficiency, continuously amplifying policy support, strengthening investments in digital technologies, and establishing a digital platform for HSFC. This approach will accelerate quality improvements for high-standard farmland and ultimately promote the convergence of HSFC efficiency at a higher level.

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CRediT authorship contribution statement

Hui Liu: Writing – review & editing, Supervision, Project administration, Methodology, Funding acquisition, Formal analysis. **Wei Zhang:** Writing – original draft, Visualization, Software, Methodology, Data curation.

Declaration of competing interest

We declare that we have no financial and personal relationships with other people or organizations that can inappropriately influence our work, there is no professional or other personal interest of any nature or kind in any product, service and company.

Data availability

Data will be made available on request.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2024.142200.

References

Ali, A.I., Seiford, L.M., 2020. Exploring the impact of environmental regulations on firm efficiency using data envelopment analysis. J. Bus. Res. 112, 354–362.
Baumol, W.J., 1967. Macroeconomics of unbalanced growth: the anatomy of urban crisis. Am. Econ. Rev. 57 (3), 415–426.
Bradfield, T., Butler, R., Dillon, E., Hennessy, T., Kilgarriff, P., 2021. The effect of land fragmentation on the technical inefficiency of dairy farms. J. Agric. Econ. 72 (2), 486–499.
Chen, S., 2010. Reform of tax distribution system, local fiscal autonomy and public goods supply. China Economic Quarterly 9 (4), 1427–1446.
Chen, Y.S., Sun, Z.F., Wang, Y.M., Han, Y., 2023. Impact of high-standard farmland construction on Farmers' Income Growth-Quasi-natural experiments from China. Front. Sustain. Food Syst. 7, 1303642.
Cullinane, K., Song, D.W., Ji, P., 2002. A simultaneous determination of the relative efficiency and Malmquist productivity index for container ports. Transport. Res. Pol. Pract. 36 (3), 225–242.
Gong, Y., Zhang, Y., Chen, Y., 2023. The impact of high-standard farmland construction policy on grain quality from the perspectives of technology adoption and cultivated land quality. Agriculture 13 (9), 1702.
Guo, W., Wang, K., 2016. Analysis of farmers' satisfaction with high-standard farmland construction during the 12th five-year plan period: a case study of a town in Shanghai. Agricultural technology economy (07) 39–45.
Guo, Y., Zhang, X., Li, J., Wang, Y., 2020. Comprehensive evaluation of high-standard farmland construction efficiency in China: evidence from 13 provinces. Land Use Pol. 99, 104897.

Halonen-Akatwijuka, M., Pafilis, E., 2014. Location and ownership of public goods. Econ. Lett. 123 (3), 395–397.
Hao, S., Wang, G., Yang, Y., Zhao, S., Huang, S., Liu, L., Zhang, H., 2024. Promoting grain production through high-standard farmland construction: evidence in China. J. Integr. Agric. 23 (1), 324–335.
Huang, H., Yao, S.B., 2021. Measurement of rural ecological public goods supply efficiency and analysis of influencing factors. Journal of Northwest A&F University (Social Science Edition) 21 (5).
Jia, N., Zhong, H., 2022. The causes and consequences of China's municipal amalgamations: evidence from population redistribution. China World Econ. 30 (4), 174–200.
Li, L., Han, J., Zhu, Y., 2023. Does environmental regulation in the form of resource agglomeration decrease agricultural carbon emissions? Quasi-natural experimental on high-standard farmland construction policy. J. Clean. Prod. 420, 138342.
Li, L., Liu, W., Liu, L., Li, J., Ma, X., 2020. Analysis on the technical efficiency of regional innovation system in China based on a three-stage SBM-DEA model. Technol. Forecast. Soc. Change 160, 120276.
Li, X., Zhang, L., Zhao, X., Huang, J., Wu, K., 2019. Soil quality assessment under high-standard farmland construction in China. Environ. Earth Sci. 78 (10), 314.
Liu, W.L., Xia, Y., 2018. Research on the supply efficiency of rural basic public services in our country: based on three-stage DEA model and three-stage Malmquist model. Modern Economic Research 3, 123–132.
Liu, Y., Jia, X., Li, X., Liu, Y., 2018. Spatial analysis of high-standard farmland suitability based on GIS and AHP in Henan Province, China. Sustainability 10 (9), 3042.
Liu, Y., Liao, W., Zhang, X., Qiu, H., 2023. Impact of high-standard farmland construction policy on chemical fertilizer reduction: a case study of China. Front. Environ. Sci.
Lu, Z.Y., Du, Y.T., 2012. An empirical study on the high-quality development of digital economy enabling agriculture. China Journal of Circulation Economics 36 (11), 3–14.
Ma, X., He, R., 2020. Evaluation of investment capital efficiency of high-standard farmland construction projects in our country. Statistics and decision (12), 85–89.
Ma, X., Shao, J., 2018. Comprehensive Evaluation of high standard basic farmland construction in counties in Chongqing mountainous area: a case study of Dianjiang County in Chongqing. J. Nat. Resour. (12), 2183–2199.
Niu, Z., Yan, H., Huang, M., Hu, Y.F., Chen, J.Q., 2016. Estimation of farmland productivity based on MODIS-OLI remote sensing data fusion technology. J. Nat. Resour. (5), 875–885.
Pu, L., Zhang, S., Yang, J., Yan, F., Chang, L., 2019. Assessment of high-standard farmland construction effectiveness in liaoning province during 2011–2015. Chin. Geogr. Sci. 29 (4), 667–678.
Qin, G.Q., Du, B.R., Liu, T.J., Zhu, Y.C., 2019. Farmer differentiation, rule change and participation in small collective governance of irrigation and water conservancy. China Rural Economy (3), 111–127.
Ramanathan, R., Sarkis, J., 2010. Theoretical and empirical validation of the DEA/AR efficiency measure: a simulation approach. Eur. J. Oper. Res. 201 (2), 462–473.
Song, W., Wu, K., Zhao, H., Zhao, R., Li, T., 2019. Arrangement of high-standard basic farmland construction based on village-region cultivated land quality uniformity. Chin. Geogr. Sci. 29, 325–340.
Sun, C.H., Liu, C.J., 2017. The combination of two tragedies: commons and anticommons tragedies. J. Econ. 122, 29–43.
Tang, J.L., Ni, Y.L., 2018. Analysis of the supply efficiency of irrigation and water conservancy facilities in China: based on the test of three-stage DEA model. Journal of Agricultural and Forestry Economics and Management 17 (1), 23–35.
Tang, W., Huang, K., Zhou, F., 2023. Can high-standard farmland construction policy promote agricultural green development? Evidence from quasi natural experiments in hunan, China. Pol. J. Environ. Stud. 32, 5333–5346.
Wang, X., Shi, W., Sun, X., 2018. Comprehensive Benefit evaluation and regional differences of high-standard farmland construction projects in Huang-Huai-hai. Trans. Chin. Soc. Agric. Eng. (16), 238–248+300.
Wang, Y., Li, G., Wang, S., Zhang, Y., Li, D., Zhou, H., Yu, W., Xu, S., 2022. A comprehensive evaluation of benefit of high-standard farmland development in China. Sustainability 14 (16), 10361.
Wei, M.S., Yan, T.W., Luo, S.X., 2023. The impact of large-scale operation and technological progress on green and low-carbon development of agriculture: a quasi-natural experiment based on the establishment of major grain producing areas. China Rural Economy 458 (2), 41–65.
Xiong, B., Xia, J., Lin, W., Yan, W., 2016. Performance evaluation of high-standard farmland construction in sichuan province. China Population, Resources and Environment (S2), 219–222.
Xiong, F., Zhao, X., Guo, Z., Zhu, S., 2023. Research on the effects of rural land consolidation on agricultural carbon emissions: a quasi-natural experiment based on the high-standard farmland construction policy. Chin. J. Eco-Agric. 31 (12), 2022–2032.
Xu, J., Xia, S., Li, W., 2020. Study on time sequence and patern of high-standard farmland construction: a case study in China. Fresenius Environ. Bull. 8252.
Xu, R., Zhan, Y., Zhang, J., He, Q., Zhang, K., Xu, D., Qi, Y., Deng, X., 2022. Does construction of high-standard farmland improve recycle behavior of agricultural film? Evidence from Sichuan, China. Agriculture 12 (10), 1632.
Yang, Liu, Ren, Y., Tang, Z.W., Zhu, Y.C., 2020. The impact of institutional rules on the collective governance performance of small irrigation and water y facilities: based on the mediating role of universal morality. Journal of Soft Science 34 (8), 51–56.
Zhong, F.N., 2007. Adjustment of labor market is the key to Increase farmers' income: a review of Rural Development and Increase of Farmers' Income. Chinese Rural Economy (05) 78–80.
Zhu, N., 2002. The impacts of income gaps on migration decisions in China. China Econ. Rev. 13 (2), 213–230, 2002.