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Research article

Does land transfer have an impact on land use efficiency? A case study on rural China

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Abstract: Land use efficiency is one of the core elements for the high-quality development of food production and agricultural industry, and land transfer can optimize the allocation of land resources, adjust the structure of the agricultural industry, and drive the improvement of agricultural labor productivity, thereby promoting land use efficiency and realizing agricultural modernization. Taking 30 provinces (autonomous regions and municipalities) in Chinese mainland from 2005 to 2019 as the research objects, this paper adopts panel OLS and panel Tobit estimation to study the overall impact of land transfer on land use efficiency. In addition, this paper explores the heterogeneous impact of land transfer on land use efficiency through cluster analysis and panel regression. Finally, this paper further analyzes the influence mechanism of land transfer on land use efficiency through industrial structure and labor productivity. The following conclusions are drawn. Firstly, land transfer significantly promotes the improvement of provincial rural land use efficiency. Secondly, the land use efficiency of various provinces (autonomous regions and municipalities) in Chinese mainland has the characteristics of periodic changes. From the perspective of time and space, there are large differences in the land use efficiency of various provinces, autonomous regions, and municipalities, and there are regional heterogeneity effects of land transfer on provincial rural land use efficiency. Thirdly, the industrial structure can enhance the promotion effect of land transfer on land use efficiency, and land transfer can promote the improvement of land use efficiency by improving agricultural labor productivity.

Keywords: land use efficiency; land transfer; heterogeneous impact; industrial structure; agricultural labor productivity

JEL Codes: G00, O13

1. Introduction

In recent years, with the economic development and population growth of various countries, the food demand and environmental pressure have been increasing, making land use the focus of governments (Corbelle-Rico et al., 2022). Land is the core production factor of rural development, and better realization of land transfer can play a vital role in agricultural modernization. Rural land use efficiency is a core agricultural indicator that governments pay close attention to. Improving land use efficiency can help ensure food security and promote agricultural modernization. Under the constraints of the total land area, in order to ensure food security and environmental protection, countries must optimize the agricultural structure, rationally allocate production resources, and improve land use efficiency, thereby increasing food supply. Therefore, how to realize the rational allocation of land resources so as to effectively improve the efficiency of land use, is particularly critical.

There is a close connection between land transfer and land use efficiency. On the one hand, land transfer is mainly divided from the narrow sense and the broad sense. Land transfer in a narrow sense means the transfer of the management rights of rural collective land, also known as agricultural land transfer. Land transfer in a broad sense includes not only the transfer of land management rights but also the transfer of collective land ownership. The land transfer in this paper belongs to the land transfer in a narrow sense, especially refers to the transfer of farmers' land management rights to other farmers or economic organizations on the premise of unchanged land contract rights. The transfer mechanism of the land use right helps promote the transfer of land resources from low labor productivity to high labor productivity, realize the Pareto improvement of land resource allocation, and improve land use efficiency (Du and Li, 2021). Therefore, land use efficiency can not only reflect the rational allocation of land resources but also effectively reflect the green development of agriculture. As an essential means of rational allocation of agricultural resources, land transfer has an increasingly significant impact on land use efficiency. On the other hand, land use efficiency mainly refers to the value realization degree of land resources in agricultural production, and reflects the rational use and allocation of land and other production factors. When analyzing land use efficiency, more attention should be paid to the ratio relationship between land input factors, expected and non-expected output factors in the agricultural production system. Therefore, land use efficiency is affected by land transfer, reflecting the rational allocation of land resources. To sum up, land transfer can be seen that as a market-oriented means to optimize the redistribution of land resources. It can make the land moderately concentrated, expand the land management scale of farmers, and improve the land use efficiency through the scale effect. Therefore, the complex relationship between land transfer and land use efficiency, makes it necessary for scholars from various countries to study how to improve land use efficiency. As one of the world's most populous and agricultural countries, China has always presented an urgent situation of more people and less land, and its land use efficiency has always been highly concerned by countries worldwide. Land transfer is a long-standing economic phenomenon in the history of China's economic development, and the relationship between farmers and land has always been the focus of China's rural reform. Based on this, taking the relationship between land transfer and land use efficiency in China as an example, we committed to fully reflecting the relationship between them.

The existing literature on land transfer and land use efficiency mainly focuses on the following two aspects.

The first is to study the measurement and influencing factors of land use efficiency. Firstly, scholars use different methods and models to measure and analyze the industrial land use efficiency. For industrial land use efficiency, Jiang (2021) used the SBM-DEA model to calculate the industrial land use efficiency in Central China from 2003 to 2012, and analyzed the temporal and spatial differences in cities of Central China. The research shows that the industrial land use efficiency in these areas is improving year by year with convergence. There are significant differences in industrial land use efficiency among different cities in Central China. Based on the data of China's Industrial Parks from 2003 to 2013, Xie et al. (2016) adopted the SBM-GML method to calculate the industrial land use efficiency and explore its influencing factors. The results show that the industrial land use efficiency of the Pearl River Delta region is the highest, and that of the central and southern region is the worst; the land policy has a heterogeneous impact on the industrial land use efficiency of different Industrial Parks. Secondly, according to the influencing factors and spatial and temporal characteristics of urban land use efficiency, scholars have analyzed them from multiple dimensions. Zhao et al. (2021a) analyzed the impact of government integration strategy on urban land use efficiency by dividing 29 cities in China's Yangtze River Delta into two scale types with two-stage least square (2SLS). The results show that regional economic integration can improve urban land use efficiency. Large cities mainly improve land use efficiency through scale and technology, while small cities only improve land use efficiency at the technical level. Koroso et al. (2020) used remote sensing data to analyze the temporal and spatial changing trend of land use in Ethiopia, and the ArcGIS software is employed to analyze satellite images. The study found that the urban land use efficiency in Ethiopia is generally low, and there are land hoarding and land use fragmentation in various cities. Based on the panel data of 285 cities in China from 2003 to 2015, Jiang et al. (2021) used the DEA method to calculate urban land use efficiency, and then they adopted the spatial Durbin model to analyze the spatial effect of land transfer marketization on urban land use efficiency. The results show that the marketization of land transfer can significantly improve local urban land use efficiency, but it can inhibit the urban land use efficiency in spatially related areas. Finally, scholars have deeply analyzed the calculation of rural land use efficiency and related influencing factors through different levels of data. Zhao et al. (2021) calculated the county agricultural land use efficiency through the panel data of 1961 counties in China, and analyzed its temporal and spatial characteristics and influencing factors. The results show that the agricultural land use efficiency of counties in China is seriously right inclined, and many counties' agricultural land use efficiency is lower than the average efficiency level. There is a "U" shaped relationship between non-agricultural employment and agricultural land use efficiency, and the development of land market and urban-rural mobility has a significant impact on agricultural land use efficiency. Based on the micro data of agricultural census in Guatemala, Britos et al. (2021) studied the impact of land market and land resource allocation on agricultural production efficiency. It is found that there is a positive correlation between land market and agricultural production efficiency, and the higher the distortion of resource allocation, the less active the land market is, which is not conducive to the improvement of agricultural production efficiency. Shi et al. (2021) measured the agricultural production efficiency through the survey data of 450 rural households in five cities in China's rice-producing provinces, and analyzed the relevant factors of agricultural production efficiency. It is found that agricultural mechanization has a positive impact on agricultural technological efficiency, but it has no impact on grain production efficiency, and farmers are still operating on a sub-optimal land scale.

Ngango and Hong (2021) employed the survey data of the eastern provinces of Rwanda in 2019 and used the propensity score matching model (PSM) to control the selective deviation of observation variables and analyze agricultural production and technological efficiency. The results show that the input of land factors has a significant positive impact on grain yield and can improve agricultural technological efficiency.

The second is to study the influence of land transfer on the rural land use efficiency. On the one hand, some scholars use DEA, SFA and other calculation methods to calculate the rural land use efficiency, and then further analyze the impact of land transfer on the land use efficiency. Based on the data of eastern India, Paltasingh et al. (2022) calculated the agricultural land efficiency through the DEA model, and analyzed the impact of land leasing and agricultural land efficiency. Research shows that the safer the land lease, the faster agricultural land use efficiency improved. Based on the field survey data of Jiangsu Province in China, Zeng et al. (2018) used the stochastic frontier analysis method to calculate the agricultural technical efficiency, and explored the impact of land transfer, land fragmentation and agricultural technical efficiency. The study found that land transfer can indirectly encourage the employment of non-agricultural personnel and improve the agricultural technical efficiency of farmers, while land fragmentation can not significantly improve agricultural technical efficiency. Wang et al. (2021) applied the Clundo model to analyze the relationship between land transfer and land use efficiency. The research results show that land transfer helps to improve land use efficiency. Based on the panel data of 30 provinces in China from 2000 to 2017, Fei et al. (2021) used the DEA method to calculate land use efficiency, so as to analyze the impact of land transfer on land use efficiency. The study found that the land use efficiency of land transfer provinces is higher than that of other provinces, indicating that land transfer can significantly improve land use efficiency. On the other hand, other scholars study the relationship between land transfer and land use efficiency through different dimensions of data. Based on the random sampling data of communities in Yunnan Province, China, Udimal et al. (2020) analyzed the influencing factors of agricultural land transfer. The study found that agricultural land transfer is closely related to farmers' age, education and other factors, and agricultural land transfer helps to improve land use efficiency. Leng et al. (2021) used the multi-period PSM-DID model to explore the impact of land transfer on land use efficiency. The study found that the impact of land transfer on land use efficiency has spatial heterogeneity. Based on Malawi's rural survey data, Ricker-Gilbert et al. (2019) studied the impact of land transfer on land use efficiency. The results show that land transfer can improve land use efficiency by promoting land transfer to more professional farmers. Liu et al. (2017) studied the impact of land transfer on agricultural productivity through County Rural Survey data in Gansu Province, China. The results show that land transfer can help reduce the consumption of chemicals in agricultural production, improve agricultural productivity and promote the sustainable development of agriculture by transferring cultivated land from farmers with low productivity to farmers with high productivity.

The above academic research shows that scholars focus on the temporal and spatial characteristics of land use efficiency and its influencing factors, providing relevant theoretical analysis and empirical methods for studying the impact of land transfer on land use efficiency. However, existing studies are still not thorough enough to analyze the impact of land transfer on rural land use efficiency, and there is still some research space. Based on this, this paper explores the impact of land transfer on land use efficiency and the action mechanism based on the panel data of 30 provinces (autonomous regions and municipalities) in Chinese mainland from 2005 to 2019. Compared with previous studies, the marginal contribution of this paper is mainly reflected in the following three aspects. First, this paper uses panel

OLS and panel Tobit estimation method to verify the hypothesis that land transfer can promote rural land use efficiency, enriching the time dimension of this research field and providing a solid argument for the significant improvement of land use efficiency by land transfer, which helps governments to take corresponding land measures to improve land use efficiency and solve the problems of food production and security. Second, based on the natural resources and geographical location of the Chinese mainland, the land use efficiency of provinces (autonomous regions and municipalities) has heterogeneity. Therefore, based on the difference in land use efficiency, this paper classifies 30 provinces (autonomous regions and municipalities) by K-means cluster analysis and then verifies the hypothesis that land transfer has a heterogeneous impact on land use efficiency in different regions by sub-sample regression. Finally, this paper further analyzes the mechanism of land transfer affecting rural land use efficiency through industrial structure and agricultural labor productivity, and comes to the conclusion that land transfer can promote the improvement of land use efficiency by improving agricultural labor production efficiency, and industrial structure can significantly enhance the promotion of land transfer on land use efficiency.

This paper is divided into five sections. Section two elaborates the research method and model. Section three describes the empirical results and analysis. The fourth section focuses on further discussion. Section five draws the conclusions.

2. Materials and methods

2.1. Theoretical analysis and research hypotheses

Land transfer is a market-oriented means to realize land scale management. It mainly improves land use efficiency through three aspects: rationalization of land market, increasing effect of land scale return, and reasonable distribution of production and input factors. Firstly, farmers can transfer management rights of surplus land through the land market to farmers with high agricultural production efficiency, expanding the land management scale and improving the production efficiency, thereby driving the improvement of land use efficiency. This is consistent with Schultz's theoretical small-scale peasant theory. In the fully competitive land market, land can be transferred from low-productivity farmers to high-productivity farmers to realize the rational distribution of land resources (Lu et al., 2019). Secondly, land transfer increases the land management scale of farmers with high agricultural production efficiency, who have rich production management experience and farming technology. They can increase the return to scale of land by increasing the investment of various production factors, thereby improving the land use efficiency and reducing land waste and low efficiency. Finally, land transfer can effectively solve the allocation problem between land input factors and other labor and capital factors to a certain extent, reduce the phenomenon of resource mismatch, thus improving labor and technological efficiency and promoting land use efficiency. On the one hand, farmers who transfer out of the land can adjust the land management scale and the input of other production factors after the land transfer, and they can use the land rent to improve the production technology to promote the land use efficiency. On the other hand, for farmers who obtain the land management rights, they can expand the current land management scale through land transfer, and combine more advanced agricultural mechanization technology and land management mode to optimize the allocation of various production factors and achieve Pareto optimization, thud improving the land use efficiency (Liu et al., 2021a). Therefore, land transfer mainly promotes the improvement of land use efficiency through the rationalization of land market, the increasing land scale return and the rational allocation of production factors. Based on this, Hypothesis 1 is proposed as follows:

Hypothesis 1: Land transfer can promote the improvement of land use efficiency.

China has a vast territory, and there are apparent differences in resource endowments among various regions, so is the rural land use efficiency in various regions. Therefore, there may be heterogeneity in the impact of land transfer on land use efficiency in various regions (Fei et al., 2021). On the one hand, the geographical location, environmental factors and land quality of all provinces (autonomous regions, municipalities) in Chinese mainland are obviously different. Generally speaking, farmers' planting situation in areas with suitable climate, fertile land and superior geographical location will be better than those in other areas, so the land use efficiency of this type of area will be higher. On the other hand, there are obvious differences in the industrial structure, agricultural technology level, and policy support among different regions in Chinese mainland, leading to regional differences in land use efficiency. Due to the differences of agricultural policy support, industrial structure, and regional development characteristics, the role of land transfer in promoting land use efficiency is heterogeneous. Based on this, Hypothesis 2 is proposed as follows:

Hypothesis 2: the promoting effect of land transfer on land use efficiency has regional heterogeneity.

Land transfer can promote land use efficiency by changing regional industrial structure and agricultural labor productivity. On the one hand, land transfer can speed up land marketization in various regions, promoting the rational development of agricultural structure. After land transfer, farmers have more ample funds to increase land investment, improve agricultural technology, optimize land use, and promote land use efficiency (Jiang et al., 2021). On the other hand, land transfer can promote agricultural labor productivity. Efficient land transfer makes land transfer from farmers with low agricultural labor productivity to farmers with high agricultural labor productivity, reducing resource mismatch and effectively improving agricultural labor productivity (Qiu et al., 2019). In addition, agricultural labor productivity can promote land use efficiency. After improving agricultural labor productivity, farmers who transfer out of land have more choices of economic activities. Whether they continue renting the land and choose work with higher economic benefits or allocate production factors through land rent, both can promote land use efficiency. The farmers who obtain the land rights have more advanced production technology and management experience, which can effectively improve the land use that was originally idle or inefficient, thereby realizing the large-scale land management and improving the land use efficiency. Based on this, this paper puts forward hypotheses 3 and 4 as follows:

Hypothesis 3: Industrial structure enhances the improvement effect of land transfer on land use efficiency.

Hypothesis 4: Agricultural labor productivity plays a mediating effect in land transfer affecting land use efficiency.

2.2. Research model and method

The research focus of this paper is to analyze the impact of land transfer on land use efficiency, specifically on rural land use efficiency. This paper takes the industrial structure as the moderating variable and the agricultural labor productivity as the mediating variable to analyze the influence mechanism of land transfer on land use efficiency. In view of data availability and completeness, the research samples of this paper are 30 provinces (autonomous regions and municipalities) in Chinese mainland, and the research time dimension is 2005–2019. Due to the vast territory of Chinese mainland, there is strong heterogeneity in the development of rural areas among provinces. This paper controls the individual effects of samples by adding provincial individual dummy variables into the model. In addition, time dummy variables of each year are added into the model to control the temporal trend effect of land use efficiency among samples. Considering their applicability and shortcomings, the panel OLS and the panel Tobit regression were finally selected as the parameter estimation method in this paper. Among them, the panel OLS estimation is suitable for the data dimension of the panel data, and its efficient and concise parameter estimation method has also been used by most scholars. According to the land use efficiency measured in this paper, the panel Tobit estimation can complete the parameter estimation of the influence coefficient more accurately. These methods can more fully reflect the relationship between land transfer and land use efficiency in this paper. Based on this, we use panel OLS and panel Tobit estimation, and takes Model (1) as the benchmark model to test whether there is an impact relationship between land transfer and land use efficiency, and whether there is regional heterogeneity in this impact relationship. The above methods are used to verify hypothesis 1 and hypothesis 2. Model 1 is shown in Formula (1).

$$LE_{it} = \alpha_0 + \alpha_1 lnLTS_{it} + \sum_{j}^{N} \rho_j CV_{ijt} + \tau_i + \gamma_t + \mu_{it} \tag{1}$$

Based on Model (1), this paper constructs Model (2) by adding the interaction term between land transfer and industrial structure to analyze further the moderating effect of industrial structure on the impact of land transfer on land use efficiency. This paper selects agricultural labor productivity as the mediating variable, and then constructs a mediating effect Model (3) to analyze whether agricultural labor productivity plays a mediating effect in the process of land transfer affecting land use efficiency. Model (2) and Model (3) help to further analyze the impact path of land transfer on land use efficiency, so as to verify Hypotheses 3 and 4. Model 2 is shown in Formula (2). Model (3) is shown in Formulas (3) and (4).

$$\mathrm{LE}_{it} = \beta_0 + \beta_1 FTS_{it} + \beta_2 lnLTS_{it} + \beta_3 FIS_{it} + \sum_{j}^{N} \rho_j CV_{ijt} + \tau_i + \gamma_t + \mu_{it} \tag{2}$$

$$lnLP_{it} = \gamma_0 + \gamma_1 lnLTS_{it} + \sum_{j}^{N} \rho_j CV_{ijt} + \tau_i + \gamma_t + \mu_{it} \tag{3}$$

$$\mathrm{LE}_{it} = \theta_0 + \theta_1 lnLTS_{it} + \theta_2 lnLP_{it} + \sum_{j}^{N} \rho_j CV_{ijt} + \tau_i + \gamma_t + \mu_{it} \tag{4}$$

In the above formulas, LE_{it} represents the land use efficiency of province i in year t; $lnLTS_{it}$ is the logarithm of land transfer level of province i in year t; FTS_{it} refers to the interaction term between land transfer and industrial structure of province i in year t, specifically, $FTS_{it} = lnLTS_{it} * FIS_{it}$; $lnLP_{it}$ indicates the logarithm of agricultural labor productivity of province i in year t; CV_{ijt} represents the j-th control variable of province i in year t; the estimation coefficients $\alpha_1, \beta_1, \gamma_1, \theta_1$ and θ_2 are the critical parameters of this paper; τ_i indicates the individual fixed effect; γ_t represents the time effect; $\alpha_0, \beta_0, \gamma_0, \theta_0$ are constant terms, and μ_{it} is the random interference term.

2.3. Variable Definitions and Data Sources

2.3.1. Variable description and measurement method

Land use efficiency is the explained variable in this paper. It mainly measures the relationship between a certain amount of land input and output and reflects the value realization degree of land resources and the rational allocation degree of production factors in the process of agricultural production during a period of time. The existing research estimates the land use efficiency mainly by means of single-factor and total-factor input-output indicators. However, the land use efficiency studied in this paper not only aims at the land production efficiency but also pays more attention to the environmental pollution emission in the process of agricultural production activities. Based on this, this paper selects the appropriate total-factor input-output indicators to measure the land use efficiency, so as to reflect the rational utilization of land in every province in Chinese mainland in recent years. This paper considers selecting super efficiency SBM-DEA model to measure the land use efficiency of provinces (autonomous regions and municipalities). The super efficiency SBM-DEA model can not only carry out dimensionless processing of data, but also integrate multiple unexpected output indicators into the calculation system of land use efficiency, giving more objective weights to these input-output indicators so as to measure land use efficiency scientifically. In addition, the super efficiency SBM-DEA model can also solve the problem that effective decision-making units cannot be sorted in the traditional DEA model, and distinguish all decision-making units with efficiency value greater than 1, so as to measure the land use efficiency more accurately (Liu et al., 2021a).

In terms of the selection of input indicators, considering the land of the Chinese mainland is mainly cultivated, this paper selects crop sown area and cultivated land area, which can reflect the land input level in agricultural production, as the token variables of input factors. The total agricultural production and total grain output are selected as the expected output indicators, because they can reflect the output quality and quantity of land. Based on the fact that the pollutants in the process of land cultivation are mainly pesticides, chemical fertilizers, residues of agricultural film and carbon dioxide, this paper selects the comprehensive index of agricultural pollution and agricultural carbon emission as the pollution output indicators (Xie et al., 2018). This paper employs the Max-DEA software to calculate the land use efficiency in 30 provinces (autonomous regions and municipalities) in Chinese mainland during 2005–2019. The calculation and description of specific input-output indicators are shown in Table 1.

Table 1. Calculation and explanation of input-output indicators.

Indicator type	Indicator name	Token variable	Variable unit
Input indicator	Land	Crop sown area	Thousand hectares
		Cultivated area	Thousand hectares
Output indicator			
Expected output	Gross agricultural output	Gross agricultural production	Hundred million yuan
	Total crop production	Total grain output	Ten thousand tons
Undesired output	Pollution output	Comprehensive index of agricultural non-point source pollution	None
	Carbon emissions	Agricultural carbon emissions	Ten thousand tons

Among the Table 1, Comprehensive index of agricultural non-point source pollution is calculated by entropy value method; chemical fertilizer application multiplied by fertilizer loss index, and the pesticide and agricultural film usage is multiplied by the corresponding residue coefficient; among them, the fertilizer loss coefficient, pesticide residue coefficient and agricultural film residue coefficient are 0.65, 0.5, and 0.1, respectively. Agricultural carbon emissions are the sum of the quantity of six kinds of carbon emission sources of chemical fertilizer, pesticide, agricultural film, agricultural diesel oil, agricultural irrigation and tillage are multiplied by the corresponding emission coefficient. The corresponding emission coefficients are 0.8956, 4.934, 5.18, 0.5927, 20.476 and 312.6, respectively.

The core explanatory variable of this paper is land transfer, which is mainly expressed as the transfer of land management rights by farmers to other farmers or economic organizations on the premise that the land contract rights remain unchanged. In related academic research, scholars often consider using the land transfer-in and transfer-out area in the rural survey data of individual regions to measure the land transfer. Although this measurement method is closer to the actual situation, it cannot fully reflect the land transfer situation in various regions of Chinese mainland. The land transfer in Chinese mainland mainly focuses on the land transfer in the rural area. Using the area of household contracted land that has been transferred to measure the land transfer can effectively reflect this feature. To this end, this paper uses the area of household contracted land that has been transferred in rural areas of each province (autonomous region and municipality) to measure the land transfer.

This paper further analyzes the path of land transfer affecting land use efficiency by selecting industrial structure as the moderating variable and agricultural labor productivity as the mediating variable. On the one hand, land transfer can adjust the industrial structure of each region, increase investment in agricultural development, improve agricultural technological efficiency, and then improve land use efficiency. On the other hand, land transfer can improve the production enthusiasm of farmers, promote the improvement of agricultural labor productivity, make the resource allocation more reasonable, and then improve the land use efficiency (Wang et al., 2016). Based on this, this paper selects industrial structure and agricultural labor productivity to analyze the impact path of land transfer on land use efficiency. Among them, the industrial structure considered in this paper represents the share of agriculture in all industries, and the primary industry is mainly dominated by agriculture. Therefore, this paper uses the proportion of the added value of the primary industry in each province to the regional GDP to measure. Agricultural labor productivity represents the ratio of labor achievements to labor input in a certain period of time. This paper uses the ratio of regional agricultural gross output to agricultural employment to measure.

In order to control the impact of other relevant characteristics on land use efficiency at the provincial levels, this paper mainly selects the quality of rural labor force, agricultural disaster rate, agricultural planting structure and agricultural multiple cropping index as the control variables of this paper from the perspectives of agricultural development and rural human capital (Farouq et al., 2021; Joseph, 2021; Liu et al., 2021b). There is a close connection between the quality of rural labor force and the land use efficiency. The higher the number of years of education per capita in rural areas, the higher the learning efficiency of advanced agricultural technology and land management will be, thus helping to improve the land use efficiency. This paper measures the quality of rural labor force by calculating the sum of average education years of residents of various cultural strata in rural areas. The large agricultural disaster area is not conducive to farmers' normal land production and management activities, thus inhibiting land use efficiency. In this paper, the ratio of crop disaster area to crop sown area is used to measure agricultural disaster area. Agricultural planting structure and agricultural multiple cropping index mainly represent the rational cultivation of land. The higher the planting structure and multiple cropping index are, the higher the land use efficiency is. In this paper, the ratio of planting area of food crops to non-food crops is used to measure agricultural planting structure, and the ratio of planting area of crops to cultivated land is used to measure agricultural multiple cropping index. The specific characterization of major research variables in this paper is shown in Table 2.

Table 2. Specific description of research variables.

Variable name	Abbreviation	Unit	Characterization variables
Land efficiency	LE	None	Measured by the super-efficiency SBM-DEA method
Land transfer	LTS	Thousand hectares	Measured by the area of household contracted land
Industrial structure	FIS	Ratio	The ratio of the added value of the primary industry to the regional GDP
Agricultural labor productivity	LP	Ten thousand yuan/person	The ratio of gross agricultural output to agricultural employment
Quality of the agricultural labor force	REDU	Year	The sum of average years of education per capita in rural areas
Agricultural disaster rate	AD	Ratio	The ratio of crop affected area to crop sown area
Agricultural planting structure	MCP	Ratio	Grain crop planting area / (crop sown area-grain crop planting area)
Agricultural multiple cropping index	PS	Ratio	The ratio of crop sown area to cultivated land area

It is worth noting that the variables selected in this paper do not have the multicollinearity problem through the correlation test. In order to eliminate the problem of heteroscedasticity in the data, this paper pre-processes the relevant quantitative data, and applies the natural logarithm to the variables in the form of absolute numbers, such as land trans, agricultural labor productivity and agricultural labor quality. Natural logarithm processing is performed in the subsequent models (Zhu et al., 2021).

2.3.2. Descriptive statistics of variables and data sources

Descriptive statistics of all variables studied in this paper are recorded in Table 3, which display descriptive statistics of not only the whole sample variables but also variables of three types of different land use efficiency regions divided by the K-means clustering method. The specific variable statistics are shown in Table 3.

It can be seen from Table 3 that there are significant differences in land transfer between the whole sample in Chinese mainland and regions with different land use efficiency, and land use efficiency is positively correlated with land transfer. From the perspective of control variables, the education level, agricultural disaster rate and agricultural planting structure of regions with low land use efficiency are significantly lower than those of other regions, which may be related to local economic development, geographical location and environmental climate. The agricultural planting structure of the medium land use efficiency region is obviously lower than that of other regions, which may be caused by different land planting situation in various regions.

Table 3. Descriptive statistical analysis of variables.

VarName	The whole sample			Regions with high land use efficiency			Regions with medium land use efficiency			Regions with low land use efficiency		
	Obs	Mean	SD	Obs	Mean	SD	Obs	Mean	SD	Obs	Mean	SD
LE	450	0.87	0.15	195	0.99	0.06	120	0.87	0.08	135	0.69	0.08
lnLTS	450	15.34	1.38	195	15.61	1.21	120	15.31	1.69	135	14.97	1.23
FIS	450	10.79	5.75	195	9.15	5.52	120	11.94	6.88	135	12.12	4.23
lnLP	450	1.02	0.65	195	1.22	0.65	120	1.05	0.55	135	0.71	0.62
lnREDU	450	2.06	0.07	195	2.07	0.08	120	2.07	0.05	135	2.03	0.08
AD	450	0.21	0.15	195	0.18	0.13	120	0.17	0.14	135	0.28	0.15
MCP	450	1.26	0.37	195	1.37	0.43	120	1.38	0.23	135	0.99	0.20
PS	450	2.84	3.57	195	3.53	5.11	120	2.22	1.00	135	2.38	1.70

In view of the availability and completeness of the data, this paper selects the data of 30 provinces (autonomous regions and municipalities) in Chinese mainland from 2005 to 2019 as the research samples. Due to the excessive lack of rural data in Tibet, its panel data could not be kept consistent and are eventually deleted. For the missing data in rural areas of other samples, this paper uses interpolation to supplement them (Li et al., 2021f; Yang et al., 2021). In this paper, the data on land transfer are mainly obtained through the "China Rural Management Statistical Annual Report". The data of land use efficiency and other variables are mainly from "China Rural Statistical Yearbook", "China Statistical Yearbook", "China Population and Employment Statistical Yearbook", statistical yearbooks of provinces (autonomous regions and municipalities), as well as China Economic Information Network database and the Easy Professional Superior (EPS) database (Li et al., 2021b).

3. Empirical results and analysis

3.1. Benchmark model tests

Based on the benchmark regression model (1), the panel OLS and panel Tobit estimation methods are used to conduct quantitative tests on the whole sample to verify whether land transfer has a positive effect on land use efficiency. The specific regression results are shown in Table 4, where Columns (1), (3) and (5) are the empirical regression results of whether individual, time, and control variables are added under the panel OLS estimation method, while Columns (2), (4), and (6) are the empirical regression results of whether individual, time, and control variables are added under the panel Tobit estimation method.

It can be seen from Table 4 that the estimated regression coefficients of land transfer in Columns (1) – (6) are all significantly positive at the 5% level. These empirical results indicate that land transfer can significantly promote land use efficiency no matter control variables individual and time effects are added, or under different parameter estimation methods. The reasons are as follows. First, land transfer is a market-oriented means to optimize the reallocation of land resources. As the land transfer market becomes more mature, the flow of land resources among farmers is more rational, which can make the land transfer from farmers with low agricultural production efficiency to large agricultural farmers with high agricultural production efficiency. This helps to adjust the scale of farmers' land management and reduce land fragmentation, thereby promoting land use efficiency (Wang et al., 2016). Second, in a large agricultural country like China, it is common for small farmers to rent out their land and go out to work. Land transfer can effectively solve the problem of unreasonable allocation of land resources among farmers. Small farmers with low agricultural labor productivity do not have a high demand for land. They will consider working as migrant laborers with higher profits, so they will not use land for farming and other agricultural production activities. Therefore, they will be more inclined to sublease the land management rights to other large agricultural households with high agricultural labor productivity for land rents. Large agricultural households have a comparatively more scientific and advanced farming model, which can effectively implement agricultural mechanization management and production activities for the leased land, investing in corresponding production factors, so that the allocation of land resources can reach Pareto optimal, thus promoting the development of land resources and increasing land use efficiency (Li et al., 2021g). Based on this, Hypothesis 1 is verified: land transfer can significantly promote the improvement of land use efficiency.

Table 4. Benchmark regression results of the whole sample in Chinese mainland.

	OLS (1)	Tobit (2)	OLS (3)	Tobit (4)	OLS (5)	Tobit (6)
	LE	LE	LE	LE	LE	LE
lnLTS	0.0289***	0.0289***	0.0145**	0.0145**	0.0142**	0.0142**
	(6.4813)	(6.0727)	(2.1560)	(2.1034)	(2.2087)	(2.1248)
lnREDU					0.4693***	0.4693***
					(2.8036)	(3.2919)
AD					−0.0846***	−0.0846***
					(−2.7101)	(−3.7642)
MCP					0.0317**	0.0317*
					(2.1961)	(1.7800)
PS					0.0014	0.0014
					(1.1281)	(0.8470)
Individual effect	NO	NO	YES	YES	YES	YES
Time effect	NO	NO	YES	YES	YES	YES
Control variable	NO	NO	NO	NO	YES	YES
_cons	0.4249***	0.4249***	0.8080***	0.8080***	−0.1916	−0.1916
	(6.0641)	(5.8028)	(8.9487)	(9.1517)	(−0.5089)	(−0.6167)
N	450	450	450	450	450	450
R^2	0.076		0.881		0.889	

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

3.2. Cluster analysis and heterogeneity test

3.2.1. Cluster analysis based on provincial land use efficiency

The above theoretical and empirical analysis can reasonably verify the conclusion that land transfer promotes the improvement of land use efficiency. In order to further analyze whether land transfer has a heterogeneous effect on land use efficiency in different regions, this paper considers using the cluster analysis to classify 30 provinces (autonomous regions and municipalities) in Chinese mainland, and then an econometric model is adopted to verify the heterogeneity (Li et al., 2021c). Based on the differences in land use efficiency of various regions, this paper considers the K-means cluster analysis method to reasonably classify the 30 samples from 2005 to 2019. As a commonly used cluster analysis method, the K-means method can achieve a more efficient classification of groups with different characteristics. Aiming at the difference of land use efficiency among provinces (autonomous regions and municipalities) in different years, this paper adopts the year-by-year cluster method and divides 30 samples into three categories. The specific cluster analysis results are sorted and recorded in Table 5 and Table 6.

Table 5. Clustering of provincial land use efficiency from 2005 to 2019.

Year	Number of provinces with high land use efficiency	Number of provinces with medium land use efficiency	Number of provinces with low land use efficiency
2005	14	9	7
2006	12	3	15
2007	13	3	14
2008	13	4	13
2009	14	9	7
2010	11	9	10
2011	10	8	12
2012	12	6	12
2013	11	6	13
2014	12	11	7
2015	13	8	9
2016	19	7	4
2017	14	6	10
2018	18	7	5
2019	17	6	7
Total	203	102	145

Table 5 mainly records the year-by-year classification of 30 provinces in Chinese mainland from 2005 to 2019. The numbers in Table 5 indicate the number of provinces of Chinese mainland 30 provinces in different stages of land use efficiency in different years. According to the cluster analysis of Table 5, the land use efficiency of provinces (autonomous regions and municipalities) in Chinese mainland has the characteristics of periodic change. From the time dimension, the number of provinces with high land use efficiency shows a "U"-shape trend; the number of provinces with low land use efficiency shows a downward fluctuation trend, and the number of provinces with medium land use efficiency first fluctuates and then tends to be stable. The number of provincial land use efficiency gradually declines from 2005 to 2011. After reaching the peak of the "U" shape in 2011, it increases gradually in the following years. The number of provinces with medium land use efficiency fluctuates from 2005 to 2014 and tends to be relatively stable after 2015. The number of provinces with low land use efficiency has been fluctuating from 2005 to 2019, and its overall trend is downward (Pang and Wang, 2020).

Table 6. Provincial land use efficiency clustering from 2005 to 2019.

Province	Times of high land use efficiency	Times of medium land use efficiency	Times of low land use efficiency
Anhui	2	10	3
Beijing	15	0	0
Fujian	13	2	0
Gansu	0	1	14
Guangdong	12	3	0
Guangxi	0	4	11
Guizhou	8	3	4
Hainan	4	7	4
Hebei	1	12	2
Henan	7	8	0
Heilongjiang	15	0	0
Hubei	0	7	8
Hunan	13	2	0
Jilin	15	0	0
Jiangsu	15	0	0
Jiangxi	14	1	0
Liaoning	13	2	0
Inner Mongolia	0	1	14
Ningxia	0	0	15
Qinghai	3	3	9
Shandong	7	8	0
Shanxi	0	1	14
Shaanxi	0	4	11
Shanghai	15	0	0
Sichuan	15	0	0
Tianjin	3	6	6
Xinjiang	0	1	14
Yunnan	0	0	15
Zhejiang	8	7	0
Chongqing	5	9	1
Total	203	102	145

Table 6 mainly records the specific summary of the three different land use efficiency categories in Chinese mainland from 2005 to 2019. There are significant differences in the classification of land use efficiency among provinces (autonomous regions and municipalities) in Chinese mainland from 2005 to 2019. The overall classification shows that the number of times of high land use efficiency times is the largest for most provinces, indicating that the overall land use situation in each province is good. However, the differences in land use efficiency are very significant. This paper distinguishes the areas with high, medium and low land use efficiency according to the number of times that each province is included in each category. The first category contains places where the land use efficiency is at a high level all the year round, mainly including Beijing, Fujian, Guangdong, Guizhou, Heilongjiang, Hunan, Jilin, Jiangsu, Jiangxi, Liaoning, Shanghai, Sichuan and Zhejiang, a total of 13 provinces (autonomous regions and municipalities). The second category contains places where the land use efficiency is at a medium level all the year round, including Anhui, Hainan, Hebei, Henan, Shandong, Hubei, Tianjin, and Chongqing, a total of 8 provinces (autonomous regions and municipalities). The remaining nine places, namely Gansu, Guangxi, Inner Mongolia, Ningxia, Qinghai, Shanxi, Shaanxi, Xinjiang and Yunnan, are classified as the third category with low land use efficiency most of the time. From the perspective of space, the places with higher land use efficiency are mainly economically developed provinces along the eastern coast of mainland China, with superior geographical locations, abundant funds and advanced technology, which make land use efficiency of these areas higher than other areas. The provinces with low land use efficiency are mainly concentrated in the remote western regions. Compared with other regions, they have greater development potential, and their land use efficiency is limited by various factors and is at a low level (Lu et al., 2020).

3.2.2. Heterogeneity test based on clustering results

The above sections illustrate the obvious regional heterogeneity of land use efficiency from time and space dimensions. From theoretical analysis and descriptive statistics, we can find that land transfer has a heterogeneous impact on land use efficiency in different types of regions. Based on this, this paper further verifies the regional heterogeneity of land transfer promoting land use efficiency with empirical analysis. Based on the benchmark Model (1), panel OLS and panel Tobit estimation are used for sub-sample regression analysis. The specific empirical regression results are shown in Table 7, in which Columns (1) – (2) list the empirical results of regions with high land use efficiency, Columns (3) – (4) display the empirical results of regions with medium land use efficiency, and Columns (5) – (6) show the empirical results of regions with low land use efficiency.

It can be seen from Table 7 that the estimated regression coefficients of land transfer variables are only significantly positive in Columns (5) – (6), and their signs in Columns (1) – (4) are negative and not significant. The above empirical results indicate that land transfer has significant regional heterogeneity effects on land use efficiency. This is mainly reflected in the fact that land transfer has a significant effect on improving the land use efficiency of regions with low land use efficiency, while the effect of land transfer on the land use efficiency of other types of regions is not significant. There are regional differences in land use efficiency.

Further analysis of the above results may be closely related to the development characteristics of each region (Liu et al., 2020; Li et al., 2021a; Lin et al., 2022). Firstly, for regions with high land use efficiency, the impact of land transfer on their land use efficiency is not significant, because this type of region is mainly in the eastern coastal China, where the economic development level and land transfer degree are higher than other regions. Land transfer in rural areas along the eastern coast is difficult to promote land use efficiency through market-oriented means and financial support in the short term, and there is a bottleneck effect. Secondly, in regions with low land use efficiency which are mainly located in remote western China, land transfer can significantly promote the improvement of land use efficiency. This situation is inseparable from the development characteristics and policy support in these regions. On the one hand, the economic development of the remote western regions is relatively backward, and there is a great potential for development, so they receive greater policy support. With the support of policies, land transfer can allocate land resources more efficiently, and combined with advanced agricultural production technology and subsidy mechanism, farmers' enthusiasm for production are improved, thereby promoting the improvement of land use efficiency. In addition, the economic development of remote areas in western mainland China is mainly based on agriculture. Land transfer improves the land use efficiency by improving agricultural technology and rational allocation of resources, thus accelerating the development of local characteristic agriculture (Chen et al., 2018). Based on this, Hypothesis 2 is verified. Land transfer has a heterogeneous effect on land use efficiency, which is manifested in that land transfer can significantly improve land use efficiency in regions with low land use efficiency.

Table 7. Empirical regression results of regional heterogeneity.

	OLS (1)	Tobit (2)	OLS (3)	Tobit (4)	OLS (5)	Tobit (6)
	LE	LE	LE	LE	LE	LE
lnLTS	−0.0048	−0.0048	−0.0116	−0.0116	0.0339*	0.0339**
	(−0.5994)	(−0.5252)	(−0.6993)	(−0.8545)	(1.9234)	(2.1102)
lnREDU	0.2113	0.2113	0.8706**	0.8706***	0.3282	0.3282
	(0.8537)	(1.0609)	(2.3598)	(3.1775)	(1.1269)	(1.2724)
AD	−0.1279**	−0.1279***	−0.0724	−0.0724*	−0.0479	−0.0479
	(−2.5098)	(−3.9815)	(−1.5432)	(−1.9649)	(−0.8787)	(−1.1906)
MCP	0.0268*	0.0268	−0.2216	−0.2216**	0.0896*	0.0896**
	(1.7041)	(1.4264)	(−1.4347)	(−2.0145)	(1.9684)	(1.9958)
PS	−0.0002	−0.0002	0.0363***	0.0363***	0.0192***	0.0192**
	(−0.2130)	(−0.1466)	(3.3219)	(4.7454)	(3.1633)	(2.4152)
Individual effect	YES	YES	YES	YES	YES	YES
Time effect	YES	YES	YES	YES	YES	YES
_cons	0.6122	0.6122	−0.6701	−0.6701	−0.6027	−0.6027
	(1.1013)	(1.4076)	(−0.7106)	(−0.9429)	(−1.1564)	(−1.2400)
N	195	195	120	120	135	135
R^2	0.468		0.747		0.671	

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

4. Discussion

4.1. Influence mechanism analysis

Through the above benchmark regression and sub-sample regression, this paper verifies that land transfer can significantly promote the improvement of land use efficiency, and this promotion effect has regional heterogeneity. In order to further analyze how land transfer affects land use efficiency, based on the benchmark Model (1), this paper constructs the moderating effect Model (2) and the mediating effect

Model (3), respectively, so as to explore the role of industrial structure and agricultural labor productivity on the impact of land transfer on land use efficiency (Liao et al., 2021; Li et al., 2021e; Haas et al., 2021). The panel OLS estimation method is used to analyze Models (2) – (3) empirically. The specific empirical regression results are shown in Table 8, where Column (1) lists the empirical regression results of exploring the moderating effect of industrial structure, and Columns (2) – (4) lists the empirical regression results of exploring the mediating effect of agricultural labor productivity.

Table 8. Empirical regression results for mechanism analysis

	OLS (1)	OLS (2)	OLS (3)	OLS (4)
	LE	LE	lnLP	LE
FTS	0.0010*			
	(1.6770)			
lnLTS	0.0055	0.0142**	0.0654***	0.0098
	(0.6601)	(2.2087)	(2.6936)	(1.5667)
FIS	−0.0104			
	(−1.1494)			
lnLP				0.0666***
				(3.2056)
Individual effect	YES	YES	YES	YES
Time effect	YES	YES	YES	YES
Control variable	YES	YES	YES	YES
_cons	0.0686	−0.1916	−2.5561***	−0.0213
	(0.1843)	(−0.5089)	(−2.8927)	(−0.0571)
N	450	450	450	450
R^2	0.891	0.889	0.961	0.892

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

It can be seen from Column (1) in Table 8 that the estimated regression coefficient of the interaction term FTS between land transfer and industrial structure passes the significance test at the 10% level, and the sign is positive. The above empirical results indicate that industrial structure has a positive moderating effect on the impact of land transfer on land use efficiency; that is, the industrial structure can enhance the promotion effect of land transfer on land use efficiency.

According to the empirical results in Columns (2) – (4) in Table 8, the estimated regression coefficients of land transfer variables are significantly positive at the level of 5% in Columns (2) – (3), but not significant in Column (4). The estimated coefficient of agricultural labor productivity passes the significance test of 1% in Column (4), and the sign is positive. Therefore, agricultural labor productivity can be used as a mediating variable, and plays a positive mediating effect in the process of land transfer affecting land use efficiency; that is, agricultural labor productivity strengthens the role of land transfer in improving land use efficiency.

There may be the following reasons for the above two situations. On the one hand, land transfer can improve the regional industrial structure, promote the rational development of agricultural structure, improve the level of agricultural marketization and farmers' income, thus improving the land use efficiency. In addition, this paper has validated that land transfer can significantly improve land use efficiency in areas focused on agricultural development in the heterogeneity analysis. Based on this, the rational development of industrial structure can increase the promotion effect of land transfer on land use efficiency (Jiang et al., 2021). On the other hand, the key to the optimal allocation of land is that land transfer can transfer land management rights from those with low agricultural labor productivity to those with high agricultural productivity, and efficient land transfer is the key to optimizing the allocation of land resources and improving the land use efficiency (Li and Mo, 2021). Besides, efficient land transfer can improve the agricultural labor productivity of farmers and reduce land resource misallocation, helping large agricultural households with high agricultural labor productivity to conduct large-scale operations and improve land use efficiency. Based on this, land transfer can effectively improve land use efficiency by promoting agricultural labor productivity. In conclusion, Hypotheses 3 and 4 of this paper are verified. The industrial structure and agricultural labor productivity both can intensify the promotion effect of land transfer on land use efficiency.

4.2. Robustness test

The above analysis shows that land transfer significantly promotes the improvement of land use efficiency through industrial structure and agricultural labor productivity, and this promotion effect has regional heterogeneity. In order to test the robustness of this conclusion, this paper replaces the model and the measurement method of the explained variable (Zhang et al., 2020; Kanwal et al., 2021; Li et al., 2021d). Based on the Hausmann test, this paper selects a two-way fixed effect model to test the impact of land transfer on land use efficiency. Referring to the DEA method used by scholars to calculate efficiency, this paper selects the SBM-GML method to calculate land use efficiency (LE2 for short) (Xie et al., 2018). The SBM-GML method can overcome the problem of no feasible solution for cross-period comparison. By adding the analysis of undesired output factors in the model, this paper calculates the globally comparable land use efficiency to effectively reflect the relationship and difference of land use efficiency in different years (Xie et al., 2016). The specific empirical regression results of the robustness test are shown in Table 9, where Column (1) lists the empirical regression results of the two-way fixed-effect model, and Columns (2) – (4) lists the empirical regression results after changing the land use efficiency measurement method.

Table 9. Empirical regression results of the robustness test

	FE (1)	OLS (2)	FE (3)	Tobit (4)
	LE	LE2	LE2	LE2
lnLTS	0.0142**	0.0147***	0.0147***	0.0147***
	(2.0057)	(3.5562)	(3.6182)	(3.8329)
Individual effect	YES	YES	YES	YES
Time effect	YES	YES	YES	YES
Control variable	YES	YES	YES	YES
_cons	−0.2964	1.2571***	1.2849***	1.2571***
	(−0.9207)	(5.7112)	(6.9386)	(7.0352)
N	450	450	450	450
R^2	0.202	0.883	0.793	

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

It can be seen from Table 9 that the estimated regression coefficients of land transfer in Columns (1) – (4) are all significantly positive at the 5% level. These empirical results show that, whether changing the parameter estimation method or changing the measurement method of the explained variable, land transfer can significantly promote the improvement of land use efficiency. Therefore, the conclusions of this paper are robust.

5. Conclusions

Based on the rural panel data of 30 provinces (autonomous regions and municipalities) in Chinese mainland from 2005 to 2019, this paper explores the overall impact of land transfer on land use efficiency. Then, this paper divides 30 samples according to the differences in land use efficiency through K-means cluster analysis to explore the heterogeneous impact of land transfer on land use efficiency in different types of regions. Finally, by further analyzing the action mechanism of industrial structure and agricultural labor productivity on land transfer affecting land use efficiency, this paper obtains the following conclusions.

1. Land transfer can significantly promote the improvement of land use efficiency. As a market-oriented way to optimize the reallocation of land resources, land transfer can effectively transfer land management rights from farmers with low agricultural productivity to farmers with high agricultural productivity, so as to rationally allocate land resources and other production input factors, thus improving land use efficiency.
2. Through the cluster analysis, it can be found that the land use efficiency of provinces (autonomous regions and municipalities) in Chinese mainland presents different periodic changes and spatial differences. Land transfer has a heterogeneous effect on land use efficiency in different regions. This heterogeneity is mainly related to regional resource endowments, policy attention and agricultural development status. Land transfer has a more significant promoting effect on the land use efficiency in regions with lower land use efficiency, while it has no significant effect on the land use efficiency of other regions, indicating that there are regional differences in the impact of land transfer on land use efficiency of different types of regions.
3. Industrial structure has a positive moderating effect, and labor productivity has a positive mediating effect, and both of them enhance the promoting effect of land transfer on land use efficiency. On the one hand, land transfer can effectively adjust regional industrial structure, making the industrial structure more rational, thereby reducing land resource misallocation and improving the land use efficiency. On the other hand, land transfer can promote the agricultural labor productivity of farmers, make the allocation of resources more reasonable, and effectively promote the improvement of land use efficiency.

Based on the above conclusions, this paper further puts forward relevant policy suggestions as follows (Fan et al., 2020; Li et al., 2021f; Li et al., 2022). Firstly, governments should actively promote the transfer of rural land and let the agricultural land flow to farmers with production and management technology advantages as much as possible, so as to improve the utilization efficiency of agricultural land and help to improve the technical efficiency of grain production. Secondly, according to the regions with different resource endowments, governments can actively pay attention to the agricultural development of various regions, make rational use of regional resource advantages, which can promote balanced development among regions. Finally, the government can strengthen the human capital input of the agricultural labor force, broaden the agricultural information channels of farmers, and comprehensively improve agricultural labor productivity, so as to improve the efficiency of land use.

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Conflict of interest

All authors declare no conflicts of interest in this study.

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