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Research article

Can the marketization of urban land transfer improve energy efficiency?

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ABSTRACT

Local government intervention in land resource allocation can lead to the misallocation of land resources and serious pollutant emissions. As an important market-oriented economic reform in China, the marketization of urban land transfer (MULT) might have the potential to contribute to improving resource allocation efficiency by curbing local government intervention. Therefore, this study aims to provide empirical evidence on the impact of MULT on energy efficiency. We improve the MULT evaluation method to test the mechanism through which MULT affects energy efficiency. The results show that, first, the proportion of land sold by allocation and listing methods, which is characterized by a low degree of marketization, has rapidly increased in recent years, lowering the overall level of MULT. Second, MULT has a direct and significant positive impact on improving energy efficiency. Third, the mechanism analysis indicates that MULT helps enhance energy efficiency by advancing industrial structure optimization and technological progress. Moreover, the heterogeneity analysis demonstrates that the impact of MULT on improving energy efficiency differs significantly in different reform stages and between central and peripheral cities. This study sheds light on the importance of land resource allocation in improving energy efficiency and thus has practical policy implications for promoting low-carbon energy transition in emerging countries.

1. Introduction

The world is facing rising concerns about energy shortage and environmental degradation (Shahbaz et al., 2013; Shan et al., 2021; Tao et al., 2022). Excessive energy consumption is considered to be the main cause of the energy crisis and environmental pollution (Tian et al., 2022). As the largest energy consumer in the world, China's energy efficiency improvement has an important impact on solving the world's energy shortage and environmental deterioration (Fu et al., 2022; Wan et al., 2021).

The land is valuable for local governments in China. To attract external investment, local governments choose the measures of agreement and allocation to transfer land at zero price or at a rate that is much lower than the expropriation cost. As a result, this may lead to serious land resource mismatch (Zhu, 2016; Huang and Du, 2017) and aggravates air pollution (Du and Li, 2021; Zhang et al., 2022). To solve the distortion of urban land resource allocation, the central government has initiated the market-oriented reform of land transfer, requiring local governments to adopt the market-oriented transfer methods of "*tendering, auctioning and listing,*" replacing traditional agreement and allocation approaches. The marketization of urban land transfer (MULT) has improved the efficiency of land resource allocation (Du and Li, 2021; Lu et al., 2020), but knowledge about its effects on energy efficiency and the environment is still lacking (Du and Li, 2021).

Studies on the impact of urban land allocation on the allocation of other resources are mainly conducted from two perspectives. On the one hand, some studies examine the impact of urban land resource allocation on pollutant emissions, revealing that in addition to exacerbating environmental pollution through overinvestment, local governments' intervention in land allocation can lead to land misallocation (Du and Li, 2021; Zhang et al., 2022). On the other hand, other studies investigate the influence of MULT on the efficiency of resource allocation. They found that MULT strengthens the function of the market mechanism in allocating land resources by curbing the impulse of local governments to attract land investment (Liu et al., 2018). Due to the screening effect of the market tendering mechanism, some enterprises with low production

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efficiency are unable to obtain more land resources to expand production. As such, they are unable to improve the efficiency of regional resource allocation (Du and Li, 2021; Jiang and Lin, 2021).

Taken together, although existing studies have provided insights into understanding the relationship between land and resource allocation, three important issues remain untested. First, existing literature mainly focuses on the impact of urban land resource allocation on production efficiency and environmental pollution (Lu et al., 2020; Jiang and Lin, 2021; Du and Li, 2021). However, few studies examine the impact of MULT on energy efficiency. As an important aspect of market-oriented reform, MULT has a significant and expansive impact on most aspects of China's economy (Jiang et al., 2021), while excessive and inefficient energy use is a major source of environmental pollution. Within the constraints of the current economic development level, improving energy efficiency and reducing energy use are the most effective approaches for addressing pollutant emissions and climate change (Wan et al., 2021).

Second, existing studies have neglected the mediating role of industrial structure optimization and technological progress in the process of land allocation influencing energy efficiency. As two important measures to improve energy efficiency and address environmental pollution (Welsch and Ochsen, 2005; Fei, 2020), industrial structure optimization and technological progress are affected by the allocation of land resources (Miao and Wang, 2014; Lu et al., 2020). Therefore, focusing on their mediating effects can more comprehensively reveal the influencing mechanism of land resource allocation on energy efficiency.

Third, existing research states that the three kinds of sales methods, public tendering (*zhaobiao*), quotation listing (*guapai*), and auctioning (*paimai*) have the same level of marketization (Lu et al., 2020). However, Cai et al. (2013) find that compared with the auctioning and tendering, listing methods are more susceptible to local government intervention and have a lower degree of marketization. Therefore, an error of overestimating the level of MULT occurs in the practice of not distinguishing between the three transfer methods. Existing research also does not include allocation (*huabo*) in evaluations, which leads to errors of overestimating the level of MULT. To solve the above evaluation problems, this study improves upon the previously applied evaluation method for MULT.

Therefore, this paper aims to explore the theoretical and practical paths to improve energy efficiency from the perspective of MULT. The contributions of this paper are threefold. First, the theoretical foundation and underlying mechanism of improving energy efficiency are proposed from the perspective of land resource allocation, providing a new perspective for improving energy efficiency. Second, based on the facts of the market-oriented reform of land transfer, this paper theoretically analyzes and empirically tests the underlying mechanism and heterogeneity of MULT on energy efficiency, deepening the theoretical understanding of the impact of land allocation on energy and the environment. Third, this study uses large-scale micro-transaction record data to improve the evaluation method of the marketization level of urban land transfer, enriching the relevant research on market-oriented reform and solving the problem of the previous overestimation of the marketization level of urban land transfer.

2. The MULT and energy efficiency

2.1. Institutional background

Before 1978, according to China's Land Law, there was no land trading market in China, as all land ownership was assumed by the state or the collective, and land use rights were uniformly allocated by the state to land users. After the reform and opening up policy, the Chinese government gradually allowed the transaction of land use rights. During this process, the urban local government acted as the agent of the central government (Su et al., 2020), exercising the right to assign land use rights and forming a primary market for land use rights transactions. In the primary market, local governments can choose one of the five methods of allocation (*huabo*), agreement (*xieyi*), tendering (*zhaobiao*), listing (*guanpai*), and auctioning (*paimai*) to grant land use rights. In the early stages, after the state liberalized the transaction of land use rights, local governments with actual control over land transfer usually transferred land at prices far below the actual cost to attract investment from the outside, resulting in a serious waste of land resources.

To improve the efficiency of land resources, in July 2002, the central government issued the "*Provisions on the Sale of State-owned Land Use Rights by Tendering, Auctioning and Listing,*" obliging local governments to transfer all types of commercial, tourist, entertainment, and commercial housing land through tendering, auctioning, or listing starting in 2003. To further standardize the process of selling industrial land, the central government later issued the "*Notice of The State Council of Issues related to Strengthening Land Control,*" obliging local governments to transfer industrial land through tendering, auctioning, or listing beginning in 2007, advancing urban land transfer in the direction of market allocation.

2.2. The impact of MULT on energy efficiency

According to factor allocation theory, MULT has an impact on energy efficiency through two paths. First, the market-oriented transfer mode has a screening effect that can guide land resources to flow to enterprises and industries with higher production efficiency (Jin and Jayne, 2013; Du and Li, 2021; Jiang et al., 2021). At the same time, as a basic production factor with limited resources and weak substitution, land allocation also guides energy flow to industries and enterprises with higher production efficiency, improving overall energy utilization efficiency.

Second, the market-oriented transfer mode limits local governments' "*bottom-line competition*" behavior. Under the political competition system of official promotion, local governments usually adopt a bottom-line competition strategy of transferring land at a price that is lower than market norms and reducing compliance costs to attract investment from enterprises that generate economic benefits in the short term. As such industries are predominantly energy-intensive and high-pollution industries with low energy efficiency, the bottom-line competitive behavior has a negative impact on energy (Chen and Zhang, 2014). In contrast, the market-oriented transfer mode can restrict the expansion of enterprises with overcapacity and low energy efficiency by curbing the detrimental competitive behavior of local governments, and has a positive effect on the improvement of energy efficiency. As such, MULT helps improve energy efficiency.

2.2.1. The underlying mechanism of industrial structure optimization

MULT may affect industrial structure optimization in two primary ways. First, market-oriented urban land transfer alters the circumstances of low land prices granted to manufacturing enterprises and increases manufacturing enterprises' production costs. When land cost rises to a certain level, the external income obtained by some manufacturing enterprises cannot cover the new cost of land price. In particular, some resource-intensive manufacturing enterprises with low production efficiency that mainly rely on government support are more sensitive to changes in factor costs; thus, rising costs will exert greater pressure on these enterprises. To relieve this cost pressure, resource-intensive manufacturing enterprises are compelled to exit the market or engage in industry upgrades, which will inhibit scale expansion. At the same time, with the withdrawal or industrial upgrading of resource-intensive manufacturing enterprises, land resources and other production factors will continue to flow to manufacturing and service industries with higher income, promoting the continued development of the industrial structure (Lu et al., 2020; Liu et al., 2021). Second, following the initiation of MULT, to maximize land transfer revenue, local governments then promote the rapid increase of commercial land prices and housing prices by reducing the supply of commercial land. The rapid rise in housing prices not only absorbs a portion of the resources originally invested in manufacturing to real estate and related services, but also increases the cost of manufacturing, weakening the comparative advantages of manufacturing. Thus, MULT promotes industrial structure optimization through the rapid increase of housing prices (Miao and Wang, 2014).

The influence of industrial structure optimization on energy efficiency is closely related to the "structural dividend hypothesis" (Timmer and Szirmai, 2000; Peneder, 2002). When industrial structure changes cause energy to flow from low to high-productivity industries, overall energy efficiency will improve. In China, the overall energy efficiency of the resource-intensive manufacturing industry is at a low level among manufacturing industries (Li and Lin, 2017). Subsequently, the pressure of MULT on resource-intensive enterprises promotes the flow of resource elements from resource-intensive industries to high-end manufacturing and advances the improvement of the manufacturing industry's overall energy efficiency.

2.2.2. The underlying mechanism of technological progress

MULT promotes technological progress primarily in three ways. First, the market-oriented transfer mode inhibits the low-density development of urban land by increasing land transfer price, and promotes industrial spatial agglomeration. As the spatial agglomeration of production factors contributes to localization, face-to-face tacit knowledge spillover, and sharing (Banerjee and Roy, 2014), MULT promotes technology dissemination and innovation by inhibiting the low-density development of urban land. Second, MULT increases enterprises' production costs by raising land and housing prices. In the short term, enterprises can alleviate the rising cost pressure by adjusting the proportion of various factors input, but when the substitution effect among factors reaches a bottleneck, enterprises must rely on technological innovation to alleviate the cost pressure (Galor and Tsiddon, 1997; Lu et al., 2020). The cost pressure from MULT ultimately forces companies to introduce and innovate technology, driving technological progress. Finally, by creating an open, fair, and just market environment, MULT strengthens the incentive effect of market competition on entrepreneurs' technological innovation behavior and promotes technological progress.

Existing research has demonstrated that technological progress is the key to mitigating environmental pollution and improving energy efficiency (Kemp, 1994; Lovins and Lovins, 2004; Welsch and Ochsen, 2005; Fei, 2020). Technological progress primarily affects energy efficiency by reducing the factor input-output ratio (Freire-González et al., 2017). Its specific mechanism of action can be divided into two circumstances. First, under the condition of neutral technological progress, such progress saves the input quantity of all factors, which has a positive effect on energy efficiency (An et al., 2020). Second, in the early stage of economic development, societies tend to neglect the protection and efficient use of resources, but prioritize economic development. With the development of the economy and society, the importance of resources and the environment become more prominent. To promote the efficiency of resource utilization, policymakers have started to promote research and innovation on resource-saving technologies. Since the beginning of this century, facing enormous public opinion pressure from the international community and serious domestic energy and environmental challenges, China implemented a series of measures to protect the environment and improve energy efficiency (Liu et al., 2022a,b; Shi et al., 2022). Consequently, under the guidance of resource-saving policies, the cost pressure caused by MULT will be transformed into the power of technological innovation in energy utilization, which will have a positive impact on the improvement of energy efficiency.

3. Methods

3.1. Model setting

To assess the impact of MULT on energy efficiency, this study established the following panel regression model, referencing Yu (2018) and Zhang et al. (2020):

$$EE_{it} = \beta_0 + \beta_1 MK_{it} + \beta_n X_{it}^n + \eta_i + \lambda_t + \varepsilon_{it} \tag{1}$$

where i represents the city, t represents the year, EE represents energy efficiency, MK represents the level of MULT, X is a set of control variables affecting energy efficiency, η_i is the individual fixed effect, λ_t is *the* time fixed effect, and ε_{it} is the random disturbance term.

To test the mechanism of MULT on energy efficiency, following Baron and Kenny (1986), the mediation model is constructed as follows:

$$M_{it} = b_0 + b_1 MK_{it} + b_n X_{it}^n + \eta_i + \lambda_t + \varepsilon_{it} \tag{2}$$

$$EE_{it} = d_0 + d_1 MK_{it} + d_2 M_{it} + d_n X_{it}^n + \eta_i + \lambda_t + \varepsilon_{it} \tag{3}$$

where M represents the mediating variables of industrial structure optimization (*STR*) and technological progress (*TE*). The meanings of the remaining variables are consistent with those in Formula (1).

3.2. Variables and data

3.2.1. Energy efficiency

Energy Efficiency (*EE*). To control for the effect of regional differences and various policy shocks on the accuracy of energy efficiency measurement, this study follows Kang et al. (2022) and Kumbhakar et al. (2014), using a stochastic frontier model (SFA) to capture individual differences, time-varying shocks, and time-invariant shocks to measure energy efficiency. Filippini and Hunt (2015) extended the model of Kumbhakar et al. (2014), constructing an SFA model that can effectively control for unobserved heterogeneity, as this measurement model contains more information, the measurement accuracy is higher. Therefore, this study follows Filippini and Hunt (2015) to measure energy efficiency. The specific calculation process is divided into two stages. First, construct an energy demand model, and second, estimate energy efficiency.

Referencing Kumbhakar et al. (2014) and Filippini and Hunt (2015), the energy demand model is constructed as follows:

$$E = F(IND, GDP, POP, PHO, STR, OPE) \tag{4}$$

where E is energy consumption. Following existing studies (Yu, 2018; Han et al., 2018; Zhang et al., 2020; Kang et al., 2022), we use urban industrial electricity consumption to reflect energy consumption. To improve the accuracy of the energy efficiency measurement, a series of control variables are introduced, including the added value of the secondary industry (*IND*), gross domestic product (*GDP*), population scale (*POP*), information level (*PHO*), industrial structure (*STR*), and opening degree (*OPE*). The specific meanings and calculations of indicators are presented in Supplementary Table S1.

Taking the logarithm of both sides of Formula (4), Formula (5) is obtained:

$$\begin{aligned} LN\ E_{it} = \alpha_0 + \beta_1 LNIND_{it} + \beta_2 LNGDP_{it} + \beta_3 LNPHO_{it} + \beta_4 LNPOP_{it} \\ + \beta_5 LNOPE_{it} + \beta_6 LNSTR_{it} + \varepsilon_{it} \end{aligned} \tag{5}$$

where i represents the city and t represents the year. Following Filippini and Hunt (2015), the random error term is decomposed into four parts (time-varying efficiencies, time-invariant efficiencies, individual effects, and other effects), then Formula (5) is converted into Formula (6):

$$\begin{aligned} LN\ E_{it} = \alpha_0 + \beta_1 LNIND_{it} + \beta_2 LNGDP_{it} + \beta_3 LNPHO_{it} + \beta_4 LNPOP_{it} + \beta_5 LNOPE_{it} \\ + \beta_6 LNSTR_{it} + \mu_i + \nu_{it} - \eta_i + u_{it} \end{aligned} \tag{6}$$

where μ_{it} and η_i represent time-varying and time-invariant efficiencies, and u_{it} and ν_{it} represent individual effects and noise that vary with time and individual cases. The maximum likelihood method is used to estimate time-invariant (u_{it}) and the time-varying (η_i) efficiencies, which energy efficiency is the product of. To make the results more interpretable, the value of *EE* is scaled up by 100 in this study. The calculation results of energy efficiencies are presented in Fig. 1.

Fig. 1 indicates that the energy efficiency of Chinese cities from 2003 to 2016 increased first and then decreased. From 2003 to 2007, China conducted large-scale forced shutdowns and technological renovation of small enterprises with high energy consumption and pollution, which promoted energy efficiency improvement. After the US financial crisis in 2008, China launched a four trillion yuan investment plan to stimulate economic growth. Since the investment plan was primarily aimed at infrastructure construction, with a low level of energy efficiency; thus, the momentum of energy efficiency improvement in China was tempered to some extent (Liu et al., 2020).

3.2.2. The MULT

The marketization level of land transfer (*MK*). This study uses data covering large-scale land transfer transactions to measure the MULT level using the method of price-weighted land plot percentage and area percentage. The specific formula is:

$$MK = \sum_{i=1}^{5} Z_i f_i \Big/ \sum_{i=1}^{5} Z_i \tag{7}$$

where *MK* is the level of MULT, *i* represents different transfer methods ($i = 5$), Z_i represents the area or plots of *i* transfer methods, and f_i is the weight of various transaction methods. Weight is determined following Liu et al. (2016), taking the average auction price in the sample period as the benchmark price, and using the ratio of the average price of each transfer method to the benchmark price as the weight.

According to our sample calculations, allocation, agreement, tendering, and listing transfer prices are 13.8%, 20.4%, 80.5%, and 54.3% of the benchmark price, respectively; thus, the weights of the above transfer methods are 0.138, 0.204, 0.805, and 0.543. Formula (7) is used to calculate the urban land transfer marketization indices MK_1 and MK_2, the proportion of plots used by MK_1, and the proportion of the area used by MK_2. In addition, previous literature primarily uses the proportion of the total quantity (plots or area) of tendering, auctioning, and listing to indicate the marketization level of land transfer (Lu et al., 2020). For comparison with our calculations, we present prior studies' results in Fig. 2, which are labeled MK_3 and MK_4.

Fig. 2 indicates that MK_1 and MK_2 slowly increase in the sample period, which differs from the conclusion (MK_3 and MK_4) in the existing literature. The trends of MK_1 and MK_2 demonstrate that the reform has not significantly improved the level of MULT.

Compared with the existing literature, the calculation results of this study can more accurately reflect the changing trend of the MULT level. First, after the market-oriented reform of urban land transfer, to continue intervention in the land use of the manufacturing industry, local governments chose the listing method for land transfer that is easy to mediate. As a result, the proportion of listed transfers with a low degree of marketization rose rapidly (Cai et al., 2019). According to the data calculated in this study, from 2003 to 2016, the proportion of the area sold using the listing method increased from 21.1% to 35.2%, with an average annual increase of 1 basepoint. The existing literature does not distinguish between tendering, auctioning, and listing transfer, obviously overestimating the MULT level. Second, although MULT has significantly reduced the proportion of land transfer by agreement, the proportion of allocation methods with a low level of marketization rapidly increased, offsetting the positive impact of the market-oriented reform. From 2003 to 2016, the proportion of transferred area increased from 26.9% to 55.4%, with an average annual increase of more than two points. Therefore, the common practice of not incorporating the allocation method into evaluation index systems will overestimate the MULT level.

3.2.3. Control variables

Following Han et al. (2018) and Kang et al. (2022), this study controls for the following variables: openness to the outside world (*OPE*), local government intervention (*GOV*), urban population (*POP*), urban economic scale (*GDP*), land finance scale (*MON*), scientific and cultural level of the labor force (*TER*), population density (*DEN*), and informatization level (*PHO*). The meaning and variables' calculation process are presented in Supplementary Table S1.

Data for calculating the marketization index of urban land transfer are obtained from the China Land Network (https://www.landchina.com/). We first exclude incorrect, repeated, and invalid records, then aggregate the microdata to prefecture and city level, matching it with the urban economic data from the China Urban Statistical Yearbook. To eliminate the influence of price factors, this study uses the provincial GDP deflator and urban consumer price index to convert the GDP, land transfer income, and local fiscal expenditure into the actual value in the base period of 2003. For foreign direct investment, this study uses the exchange rate and urban consumer price index to convert the actual value in RMB in 2003. The GDP deflator, urban consumer price index, and exchange rate are obtained from the China Statistical Yearbook. Considering that the values of some variables are quite different, except for proportional variables, this study conducts logarithmic processing for the remaining variables. Descriptive statistics of the variables are presented in Supplementary Table S2.

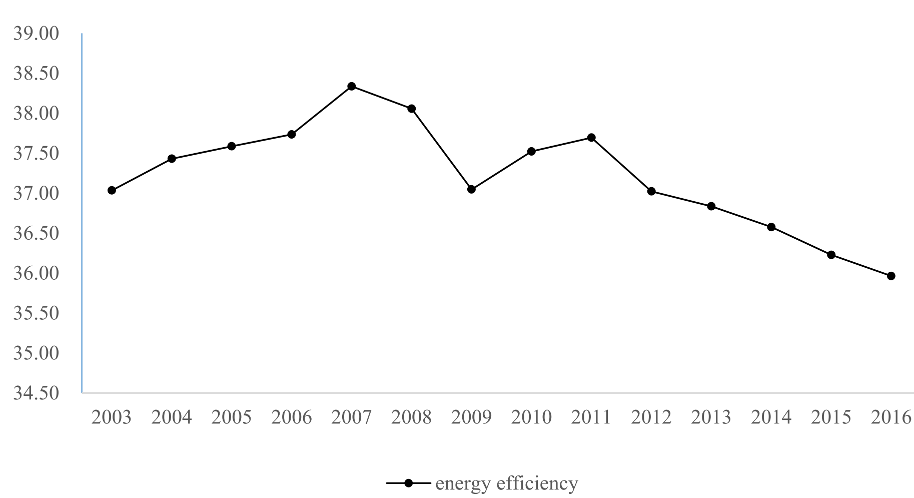

Fig. 1. Energy efficiency changes in Chinese cities.

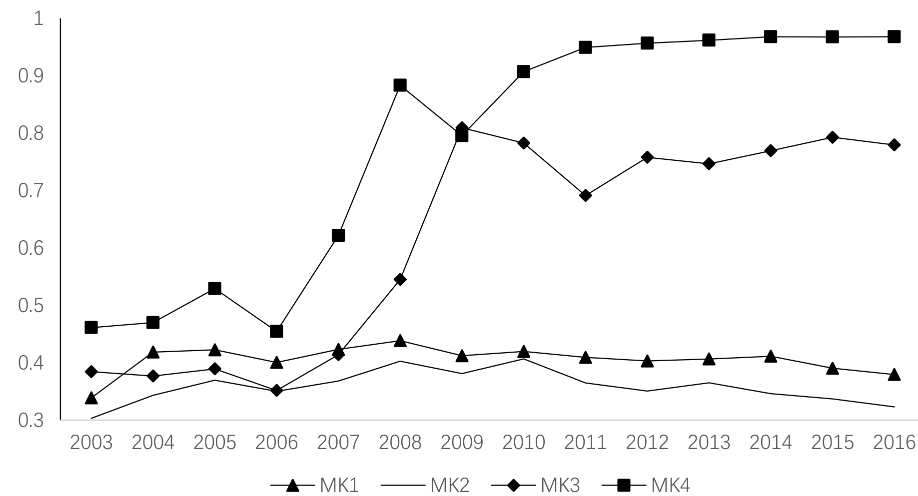

Fig. 2. Comparison of changes in the MULT level. Note: The original data are from China Land Network (https://www.landchina.com/). MK_1 is calculated using the method of price-weighted land plot ratio, and MK_2 is calculated using the method of price-weighted area ratio. MK_3 and MK_4 are calculated by the proportion of the total quantity (plots or area) of tendering, auctioning, and listing.

4. Results

4.1. Baseline results

Table 1 presents the benchmark regression results. Columns (1)–(4) reveal that the coefficients of MK_1 and MK_2 are both significantly positive at the 1% level, indicating that MULT is conducive to energy efficiency. As determined in this study, MULT not only guides the allocation of energy to industries and enterprises with high production efficiency, but also restricts overinvestment through a screening effect. Therefore, MULT has a positive effect on energy efficiency.

Among the control variables, the coefficient of *LNMON* is significant and negative across all models, indicating that the expansion of the land financing scale has a negative impact on energy efficiency. By intervening in the allocation of land resources, the local government achieves the goal of maximizing its income from the land transfer, but this also leads to serious distortions in resource allocation (Cao et al., 2008; Du and Peiser, 2014). The coefficient of *LNGPV* is significantly positive in all models, indicating that local government spending has a positive effect on energy efficiency. Since the 11th Five-Year Plan, in the face of severe environmental protection pressure and energy security issues, the Chinese government has issued a series of fiscal and industrial policies for energy conservation and emissions reduction, achieving remarkable results (Cai et al., 2019). The coefficient of *LNPHO* is significantly negative in all models, indicating that informatization level improvement has a negative impact on energy efficiency. Generally speaking, informatization level improvement has a positive effect on energy efficiency by eliminating redundancy and waste in the production process (Moyer and Hughes, 2012). Considering the heterogeneity of information technology in different industries, uncertainty remains regarding the impact of information technology on energy efficiency. The coefficient of *LNPOP* is significantly positive in all models, indicating that the expansion of city size is conducive to energy efficiency. Relevant studies find economies of scale to have a positive effect on energy efficiency (Sadorsky, 2013). The coefficient of *LNDEN* is significantly negative in all models, indicating that population density has a negative impact on energy efficiency. The coefficients of *LNGDP, LNTER*, and *LNOPE* are insignificant, indicating that quality of labor, economic scale, and economic openness has no significant impact on energy efficiency.

Table 1
Baseline regression results.

Variable	*EE*	*EE*	*EE*	*EE*
	(1)	(2)	(3)	(4)
MK1	4.0878***	4.3906***		
	(0.8476)	(0.8495)		
MK2			3.3269***	3.7808***
			(0.7108)	(0.7154)
LNGDP		1.1863		1.1808
		(0.8430)		(0.8423)
LMON		−0.5781***		−0.6254***
		(0.1428)		(0.1437)
LNGOV		1.5119**		1.5264**
		(0.6117)		(0.6115)
LNTER		−0.0004		−0.0001
		(0.0003)		(0.0001)
LNPHO		−0.5213**		−0.5413**
		(0.2548)		(0.2547)
LNOPE		−0.0020		−0.0069
		(0.0593)		(0.0593)
LNDEN		−0.0420*		−0.0406*
		(0.0245)		(0.0245)
LNPOP		1.7134**		1.6903**
		(0.7627)		(0.7624)
CONS	35.2522***	19.5920	35.5557***	20.6620
	(0.4402)	(12.6319)	(0.4068)	(12.6204)
City effect	YES	YES	YES	YES
Time effect	YES	YES	YES	YES
R^2	0.0395	0.0499	0.0391	0.0505
N	3223	3223	3223	3223

Note: Standard errors are in parentheses and probability values are in parenthesis; *. P < 0.1, **p < 0.05, ***p < 0.01.

4.2. Robustness checks

4.2.1. Controlling for province fixed effects

Given the fact that both land and energy supply are affected by provincial government decisions in China (Zhang et al., 2022), we also test the robustness of the benchmark regression by controlling for fixed effects at the provincial level. The detailed results are presented in Supplementary Table S3. It demonstrates that after controlling for the provincial fixed effect, the coefficients of MK_1 and MK_2 remain significantly positive in all models, indicating that the benchmark regression is robust and reliable.

4.2.2. Alternative measures of the dependent variable

Following Guang et al. (2021), we also replace energy efficiency with energy intensity to test the robustness of the empirical model. Energy intensity is expressed as the ratio of energy consumption to GDP. The regression results are presented in Supplementary Table S4. It indicates that after controlling for other influencing factors, the coefficients of MK_1 and MK_2 are both significantly negative, indicating that MULT is conducive to reducing energy intensity. In other words, the benchmark regression is robust and reliable.

4.2.3. Estimation using the Tobit model

As energy efficiency is a limited interpretable variable, the results obtained using the ordinary least squares regression may contain errors (Guo et al., 2022). Therefore, the Tobin (1958) regression model is used to estimate Formula (1). The regression results are presented in Supplementary Table S5. The Tobit regression estimates demonstrate that the coefficients of MK_1 and MK_2 are significantly positive in all models, indicating that MULT advances energy efficiency.

4.2.4. Endogeneity analysis

Although the implementation of the market-oriented reform policy of urban land transfer can be considered a quasi-natural experiment, considering the inertia of energy efficiency change, panel fixed effects models have an inherent endogeneity problem caused by serial correlation. Following Roodman (2006), this study adopts the dynamic panel generalized method of moments for regression. The results are presented in Supplementary Table S6, demonstrating that the coefficients of the MK_1 and MK_2 are both significantly positive, confirming that the MULT advances energy efficiency.

4.3. Mechanism analysis of MULT on energy efficiency

The regression results of the mediating effects are presented in Table 2. Columns (1) and (2) present the regression results of Formula (2), and columns (3) and (4) are the regression results of Formula (3). The coefficients of MK_1 are significantly positive in columns (1) and (2), indicating that MULT has a significant promotional effect on industrial structure optimization and technological progress. Furthermore, the coefficients of MK_1, *LNSTR*, and *LNTE* are significantly positive in columns (3) and (4). According to the mediating model, the influence of MULT on energy efficiency is transmitted through technological progress and industrial structure optimization. The regression results with *MK2* in columns (5)–(8) are consistent with the results for *MK1*, indicating that the conclusion is robust and reliable.

4.4. Heterogeneity analysis of the impact of MULT on energy efficiency

4.4.1. Impact of MULT on energy efficiency at different reform stages

After the central government's implementation of the market-oriented reform policy for commercial land in 2003, market-oriented reform of industrial land transfer was implemented in 2007. Considering the different policy objectives in the above two periods, the influence and mechanism of MULT on energy efficiency may differ. Therefore, this study divides the sample into two parts, taking 2007 as the boundary and applying the mediating effect model to verify the influence and mechanism of MULT on energy efficiency. The results are presented in Tables 3 and 4.

Table 3 presents the results from 2003 to 2006. In column (1), the regression coefficient of MK_1 is not significant, indicating that MULT had no significant impact on industrial structure optimization. In column (2), the regression coefficient of MK_1 is significantly positive, indicating that MULT had a significant positive impact on technological progress. In column (3), the regression coefficients of MK_1 and *LNSTR* are both significant, indicating that both MULT and industrial structure optimization had significant effects on energy efficiency. The coefficient of MK_1 in column (4) is significantly positive, indicating that MULT promoted energy efficiency. Finally, the regression coefficient of *LNTE* in column (4) is insignificant, indicating that the impact of technological progress on energy efficiency is insignificant.

In Table 3, since the regression coefficients of MK_1 in column (1) and *LNTE* in column (4) are not significant, it is not possible to directly determine whether industrial structure optimization and technological progress had mediating effects. As such, the Sobel (1982) test is applied. The results of industrial structure optimization show that $Z = 0.4055$, and the corresponding p-value is 0.6851 (greater than 0.05), indicating that the mediating effect of industrial structure optimization is not significant. In conclusion, the market-oriented reform of commercial land transfer launched in 2003 had an insignificant mediating effect through industrial structure optimization and technological progress. In other words, from 2003 to 2006, MULT primarily had a positive impact on energy efficiency through screening and guiding effects within the industry. The regression results with MK_2 in columns (5)–(8) are consistent with MK_1, indicating that the initial conclusion is robust and reliable.

Table 4 shows the regression results from 2007 to 2016. The regression coefficients of MK_1 are significantly positive in columns (1)–(4), indicating that MULT had a significant positive impact on energy efficiency, industrial structure optimization, and technological progress. Furthermore, in columns (3) and (4), the regression coefficients of

Table 2
Results for mechanism analysis.

Variable	*LNSTR*	*LNTE*	*EE*	*EE*	*LNSTR*	*LNTE*	*EE*	*EE*
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
MK1	0.1990***	0.483***	4.2130***	4.0455***				
	(0.0307)	(0.1111)	(0.8554)	(0.8463)				
MK2					0.1190***	0.2631***	3.6652***	3.8241***
					(0.0259)	(0.02934)	(0.7177)	(0.7176)
LNSTR			0.8925*				0.9720*	0.4352**
			(0.5103)				(0.5084)	(0.1421)
LNTE				0.4153***				
				(0.1424)				
CONS	12.0195	−0.6516	8.8648	20.6144*	12.0981***	−0.4446	8.9028	21.7833
	(0.4560)	(1.6522)	(14.0387)	(12.0945)	(0.4573)	(1.6541)	(14.034)	(12.682)
Control variable	YES	YES	YES	YES	YES	YES	YES	YES
City effect	YES	YES	YES	YES	YES	YES	YES	YES
Time effect	YES	YES	YES	YES	YES	YES	YES	YES
Hausman test	426.85	246.19	118.49	121.27	416.15	232.10	112.86	118.98
	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]
R^2	0.4529	0.7775	0.0499	0.0537	0.4490	0.7766	0.0505	0.0542
N	3223	3223	3223	3223	3223	3223	3223	3223

Note: Standard errors are in parentheses and probability values are in square brackets; *p < 0.1, **p < 0.05, ***p < 0.01.

Table 3
The influence of the MULT on energy efficiency over 2003–2006.

Variable	*LNSTR*	*LNTE*	*EE*	*EE*	*LNSTR*	*LNTE*	*EE*	*EE*
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
MK1	−0.0521	0.3479**	4.2130***	4.3814***				
	(0.0439)	(0.1770)	(0.8554)	(1.6092)				
MK2					−0.0354	0.0872	5.0379***	5.2131***
					(0.0325)	(0.1458)	(1.031)	(1.639)
LNSTR			−0.8925*				−2.3269	
			(0.5103)				(1.2649)	
LNTE				0.1628				0.2166
				(0.4500)				(0.3179)
CONS	3.7869***	12.3752**	8.8648	95.8994*	3.7822*	12.7736**	110.198***	100.049***
	(1.3340)	(0.0189)	(14.0387)	(49.0081)	(2.2305)	(5.3874)	(38.3093)	(38.3093)
Control variable	YES	YES	YES	YES	YES	YES	YES	YES
City effect	YES	YES	YES	YES	YES	YES	YES	YES
Time effect	YESE	YESE	YESE	YESE	YESE	YESE	YESE	YESE
Hausman test	53.64	56.44	64.50	54.47	51.62	50.58	55.56	63.68
	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]
R^2	0.1483	0.2285	0.1287	0.1251	0.1499	0.2231	0.1486	0.1478
N	755	743	755	743	755	743	755	743

Note: Standard errors are in parentheses and probability values are in square brackets; *p < 0.1, **p < 0.05, ***p < 0.01.

Table 4
The influence of MULT on energy efficiency over 2007–2016.

Variable	*LNSTR*	*LNTE*	*EE*	*EE*	*LNSTR*	*LNTE*	*EE*	*EE*
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
MK1	0.3048***	0.4614***	3.1936**	3.7356***				
	(0.0459)	(0.1624)	(1.3919)	(1.3923)				
MK2					0.1290***	0.1987*	2.5552***	2.7310***
					(0.0326)	(0.1136)	(0.9850)	(0.9852)
LNSTR			January 0, 3968***				1.2819**	
			(0.5217)				(0.6420)	
LNTE				0.3182*				0.3544*
				(0.1837)				(0.1840)
CONS	16.3539***	−2.7698	37.7781	36.3150***	16.4667***	−3.6869**	34.8012*	59.1814***
	(0.5249)	(1.8539)	(0.6397)	(0.7675)	(0.5279)	(1.7887)	(19.0725)	(15.8916)
Control variable	YES	YES	YES	YES	YES	YES	YES	YES
City effect	YES	YES	YES	YES	YES	YES	YES	YES
Time effect	YES	YES	YES	YES	YES	YES	YES	YES
Hausman test	541.35	182.21	22.26	32.31	513.28	172.38	101.12	98.82
	[0.0000]	[0.0000]	[0.0138]	[0.0007]	[0.0000]	[0.0000]	[0.0000]	[0.0000]
R^2	0.5885	0.7910	0.5885	0.0627	0.5832	0.7873	0.0598	0.0611
N	2468	2480	2468	2480	2468	2480	2468	2480

Note: Standard errors are in parentheses and probability values are in square brackets.*p < 0.1, **p < 0.05, ***p < 0.01.

LNSTR and *LNTE* are significantly positive. According to Baron and Kenny (1986), there is a mediating effect between industrial structure optimization and technological progress. In other words, the impact of MULT on energy efficiency is partially due to industrial structure optimization and technological progress. The regression results with MK_2 in columns (5)–(8) are consistent with MK_1, indicating that the above conclusion is robust and reliable.

The results in Tables 3 and 4 demonstrate significant differences in the impact of MULT on energy efficiency in different stages. From 2003 to 2006, MULT primarily improved energy efficiency through internal screening and guidance of the industry. The reason for the difference between the two periods is that although the first implementation of market-oriented reform of commercial land transfer was conducive to the role of the market mechanism in the allocation of commercial land resources, it may have exacerbated the mismatch of production factors in different industries. Specifically, taking the lead in promoting the market-oriented reform of commercial land transfer has enriched local fiscal revenue and enhanced the ability of local governments to participate in the bottom-line competition. Local governments use the income from commercial land transfer to increase subsidies for resource-intensive and technologically deficient manufacturing enterprises, which is not conducive to technological progress or industrial structure optimization. Therefore, the market-oriented reform for commercial land transfer implemented in 2003 had an uncertain impact on technological progress and industrial structure optimization, with no significant mediating effect.

After the market-oriented reform of industrial land transfer was implemented in 2007, local governments' practice of horizontal subsidies to the industrial sector was curbed, and the intermediary role of industrial structure optimization and technological progress began to emerge. Under the political tournament system of official promotion, if the central reform policy is inconsistent with the interests of the local governments with the actual implementation power, the local governments will strategically promote the reform according to their own interests, weakening the reform effect. Therefore, in the process of designing a top-level system, the central government should fully consider local governments' interest appeals and endeavor to be compatible with these interests.

4.4.2. Regional heterogeneity of the impact of MULT on energy efficiency

Considering that the development patterns and energy efficiency changes of central and peripheral cities in provinces are different (Kang et al., 2022), this study also tests the heterogeneity of the impact of MULT on energy efficiency in central and peripheral cities. The central city is the capital city of each province, and the remainder is peripheral cities. The regression results of central cities are presented in Table 5 Panel A. Although the regression coefficients of MK_1 in columns (1) and (2) are significant, the coefficients of MK_1, *LNSTR*, and *LNTE* in columns (3) and (4) are not significant, indicating that the mediating effect of industrial structure optimization and technological progress is not significant in central cities. The regression results with MK_2 in columns (5)–(8) are consistent with MK_1, indicating that the conclusion is robust and reliable.

Table 5 Panel B presents the regression results for peripheral cities, revealing that the coefficients of the MK_1 are significantly positive in columns (1)–(4), indicating that MULK has a significant positive impact on energy efficiency, industrial structure optimization, and technological progress. Furthermore, in columns (3) and (4), the coefficients of *LNSTR* and *LNTE* are significantly positive. The regression results with MK_2 in columns (5)–(8) are consistent with MK_1, indicating that the conclusion is robust and reliable. Based on the results shown in columns (1)–(8), it can be concluded that the influence of MULT on energy efficiency is transmitted through industrial structure optimization and technological progress.

In conclusion, in peripheral cities, the impact of MULT on energy efficiency is partially due to the transmission of industrial structure optimization and technological progress, but in central cities, this transmission path is not significant. Some possible reasons for the insignificant impact of MULT on energy efficiency in central cities may be related to the special urban development mode in China. In contrast to the western urban development model based on spontaneous market forces, Chinese cities are more influenced by the administrative power of the government, particularly central cities with higher administrative levels. Such cities have incomparable advantages in administrative resources and development positioning, with development modes that also differ from those of peripheral cities. Compared with peripheral cities, central cities have more administrative resources and power. In addition to land resources, central cities can rely on the considerable bargaining power in the policymaking process for more resources to support other jurisdictions; thus, local governments are less reliant on the use of land to attract investment, making the impact of MULT on energy efficiency insignificant. Because the resource endowment and economic development modes of different cities are not the same, the impact of the same policy in different cities is heterogeneous. Therefore, regional differences should be fully considered in the top-level design of the MULT system, and targeted measures should be strategically developed according to policy objectives and constraints.

5. Conclusions and policy recommendations

As the world's largest energy consumer, the improvement of China's energy efficiency plays a critical role in alleviating the global energy crisis and environmental degradation. This study used the micro-level transaction record data of land transfer to improve the evaluation method of land transfer marketization, empirically testing whether MULT affected energy efficiency. The research findings are threefold. First, the level of MULT did not significantly improve in the sample period, which contradicts the conclusions of existing studies (Lu et al.,

Table 5
The influence of MULT on energy efficiency in central vs. peripheral cities.

Panel A Central cities								
Variable	LNSTR	LNTE	EE	EE	LNSTR	LNTE	EE	EE
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
MK1	0.2569**	0.6292**	−3.5591	−4.0564				
	(0.1010)	(0.2687)	(2.4913)	(2.4976)				
MK2					0.2808***	0.5862**	−1.3030	−1.8950
					(0.0911)	(0.2443)	(2.3302)	(2.2886)
LNSTR			−2.6497				−2.9269	
			(1.9177)				(1.9457)	
LNTE				−0.2917				−0.3936
				(0.7247)				(0.7297)
CONS	−1.2492	0.5198	223.9311***	227.3928***	−1.0466	1.0982	218.8002***	222.2986***
	(2.1628)	(5.7549)	(52.3547)	(52.5993)	(2.1379)	(5.7359)	(52.4931)	(52.7861)
Control variable	YES	YES	YES	YES	YES	YES	YES	YES
City effect	YES	YES	YES	YES	YES	YES	YES	YES
Time effect	YES	YES	YES	YES	YES	YES	YES	YES
Hausman test	33.48	1539.19	65.63	61.22	17.49	28.11	60.96	57.70
	[0.0000]	[0.0000]	[0.0138]	[0.0007]	[0.0642]	[0.0017]	[0.0000]	[0.0000]
R2	0.7120	0.9585	0.3442	0.3370	0.7172	0.9586	0.3371	0.3288
N	196	229	196	229	196	229	196	229
Panel B Peripheral cities								
Variable	LNSTR	LNTE	EE	EE	LNSTR	LNTE	EE	*EE*
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
MK1	0.1937***	0.4557***	4.5646***	4.8504***				
	(0.0320)	(0.1165)	(0.8959)	(0.8977)				
MK2					0.1125***	0.2439***	3.8393***	4.0275***
					(0.0268)	(0.0974)	(0.7471)	(0.7475)
LNSTR			1.0742**				1.1678**	
			(0.5299)				(0.5280)	
LNTE				0.4189***				0.4403***
				(0.1470)				(0.1468)
CONS	12.0942***	−0.6336***	2.0676	16.0751	12.1628***	−0.4593	1.8615	17.1913
	(0.4560)	(0.1560)	(14.534)	(13.122)	(0.4697)	(1.7096)	(14.524)	(13.115)
Control variable	YES	YES	YES	YES	YES	YES	YES	YES
City effect	YES	YES	YES	YES	YES	YES	YES	YES
Time effect	YES	YES	YES	YES	YES	YES	YES	YES
Hausman test	426.85	732.76	110.39	112.23	327.35	209.62	106.02	108.75
	[0.0000]	[0.0000]	[0.000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]
R2	0.4496	0.7684	0.0487	0.0522	0.4458	0.7676	0.0488	0.0521
N	3027	2994	3027	2994	3027	2994	3027	2994

Note: Standard errors are in parentheses and probability values are in square brackets; *p < 0.1, **p < 0.05, ***p < 0.01.

2020). Although the proportion of the total amount of tendering, auctioning, and listing with a higher marketization level has rapidly increased, the proportion of listing and land allocated with a lower marketization level also increased, diminishing the overall level of marketization.

Second, MULT not only directly promotes energy efficiency, but also improves energy efficiency by promoting industrial structure optimization and technological progress. Specifically, the screening effect of MULT can ensure that enterprises with high production efficiency can obtain scarce land resources and energy, with a positive role in improving energy efficiency. In addition, MULT forces resource-intensive manufacturing enterprises with low efficiency to withdraw from production, promoting industrial structure optimization and improving energy efficiency. Finally, the industrial agglomeration, improvements in the market institutional environment, and the cost pressure brought by MULT promote technological research and innovation, which have a positive effect on energy efficiency.

Third, the impact of MULT on energy efficiency was significantly different in different reform stages and cities. The marketization policy of commercial land transfer enhanced the ability of local governments to engage in bottom-line competition, weakening the role of land transfer marketization in promoting energy efficiency. In addition, compared with peripheral cities, central cities rely less on land to attract investment, leading to the insignificant impact of land transfer marketization on energy efficiency.

The conclusions of this study have important policy implications for improving the market-oriented allocation of land factors and energy efficiency. Based on our findings, we propose the following three policy recommendations. First, the central government should continue to promote market-oriented land reform and strengthen the supervision of local governments' land transfer behavior. Second, establish a robust market environment and fully release the energy-saving effect of industrial structure optimization and technological progress in the process of MULT. Third, regional economic differences should be taken into account to advance the market-oriented reform of land transfer in light of local conditions. To optimize the positive effect of land transfer marketization on energy efficiency, reforms should be implemented pertinent to variations in resource endowments and economic development levels in different cities.

This study has encountered some limitations that await investigations in future studies. First, due to data availability, this study does not cover recent years, especially the covid-19 pandemic period, where unexpected global shocks might affect the impact of MULT on energy efficiency. Second, the relationship between MULT and energy efficiency may differ across other city-level heterogeneous characteristics.

Credit author Statement

Yanjun Yang: Conceptualization; Formal analysis; Writing – original draft; **Rui Xue**: Conceptualization; Methodology; Validation; Supervision; Writing – review & editing; **Xiaoxi Zhang**: Data curation; Software; Writing – review & editing; **Yutai Cheng**: Resources; Project administration; **Yuli Shan**: Investigation; Methodology; Supervision; Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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.jenvman.2022.117126.

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