RESEARCH ARTICLE

Factor price distortion and ecological efficiency: the role of institutional quality

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Abstract
There is a lack of studies on whether market distortions inhibit the ecological efficiency. This study introduces the ecological efficiency based on the bootstrap-data envelopment analysis (DEA) method as the indicator of environmental performance in China, uses the transcendental logarithmic production function to calculate factor price distortion, and further identifies whether the factor price distortion has a negative impact on the ecological efficiency using the system generalized method of moments (GMM) method. Meanwhile, institutional quality is considered a threshold variable to examine the relationship between factor price distortion and ecological efficiency based on the threshold model. The result shows that factor price distortion significantly inhibits the improvement of ecological efficiency. Moreover, institutional quality is considered to be the threshold of factor price distortion affecting ecological efficiency. Further investigation of heterogeneity effect suggests that the inhibitory impact of factor price distortion on ecological efficiency is more significant in the central and western regions. This study provides a supplement to the study on environmental performance from the perspective of factor distortions and expands the framework of the influence mechanism of factor price distortion affecting ecological efficiency.

Keywords Factor price distortion · Ecological efficiency · Institutional quality · Threshold model · System GMM method

Introduction

Although China has made significant improvements in environmental efficiency in the past two decades, the rapid economic development has greatly increased energy consumption and caused serious environmental pollution. In recent years, more and more attention has been paid to the influencing factors of environmental performance, which is considered to be an important way to protect ecological environment (Sun and Loh 2019). Ecological efficiency is a complex concept which was first proposed by Schaltegger (1996), which has been widely used to measure sustainable development and ecological governance performance. The core of ecological efficiency is to measure the impact of economic development on the ecological environment. Most of the studies on the influencing factors of environmental efficiency focus on environmental regulation, financial development, and ownership structure (Wang et al. 2019a; Liu et al. 2019).

Factor price distortion, as an important factor affecting production cost and technology input, has not received enough attention. Young (2000) proposed that administrative intervention and government regulation result in the factor market distortion. Factor prices and allocation are still determined by the administrative forces, not by the supply and demand of market (Ouyang and Sun 2015). Wang and Chen (2015) suggested that electricity prices are controlled by the government. Factor price distortion fails to reflect the scarcity and opportunity cost of productive factor, thus resulting in the resource misallocation and productivity loss (Yang et al. 2018). On the one hand, the relatively low factor prices reduce the production costs and increase profits for enterprises (Lin and Chen

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2018); on the other hand, low prices also lead to excessive use of high polluted resources and reduce the willingness to invest in resource-saving technologies. As Wang et al. (2019b) pointed out, the fluctuation of energy price is closely related to the change of energy consumption. Although factor price distortion can bring about profit growth in the short term, it is not conducive to the improvement of environmental efficiency in the long term.

Energy price can reflect the changes of market supply and demand and the scarce extent of resources, which can send a clear and powerful signal to all stakeholders in the energy market (Wang and Chen 2015). However, factor price distortion, caused by the administrative monopoly power and government regulation, has impact on the resource allocation efficiency and ecological environment. In recent years, the role of institutional quality in the relationship between economic factors and pollution has attracted wide attention. The institutional system involves the rule of law, bureaucratic quality, property rights protection, contract enforcement, corruption, and government efficiency (Zakaria and Bibi 2019). The institutional system has an important impact on economic growth (Jones and Manuelli 2001). Tamazian and Rao (2010) found that the relationship between institutional quality and resource misallocation is significant. The improvement of institutional quality reduces air pollution and enhances environmental quality (Goel et al. 2013; Bhattacharya et al. 2017). Lau et al. (2014) also confirmed that institutional quality reduces the environmental costs of economic development. As a result, our study tries to incorporate factor price distortion, institutional quality, and ecological efficiency into an analytical framework, identifies whether the factor price distortion has a negative impact on the ecological efficiency, and analyzes the influence mechanism of institutional quality.

Based on the above research framework, our study's main contribution can be highlighted as following. First, there exists a limited understanding of the impact of factor price distortion on environmental performance. Our study introduces the ecological efficiency based on the bootstrap-DEA method as an indicator of environmental performance and constructs a dynamic panel model to investigate the effect of factor price distortion on ecological efficiency. Second, this study further uses the moderating effect model and threshold model to test the non-linear effect of institutional quality on the factor price distortion affecting ecological efficiency. Third, we also discuss the heterogeneous effect of factor price distortion on ecological efficiency. On the whole, our study provides a new perspective on the influence mechanism through which factor price distortion affects ecological efficiency by discussing the institutional quality and expands the empirical framework by heterogeneity effect.

The rest of the paper is organized as follows: The "Literature review" section reviews the related literature. The "Empirical methodology" section introduces the empirical methods, variable measurement, and data. The "Empirical analysis" section discusses and summarizes the empirical results. The "Conclusion" section puts forward the research conclusions and policy recommendations.

Literature review

The government uses administrative monopoly power to intervene in the pricing mechanism of factor market, leading to the factor price distortion. Factor price distortion means that the actual price of input factors deviates from the equilibrium price in the fully competitive market (Yang et al. 2018). Lin and Tian (2017) put forward that factor distortion refers to the influence of government pricing, subsidy and monopoly on price, and initial distribution of productive factors such as capital, labor force, energy, and land. Lin and Chen (2018) suggested that factor distortion mainly includes price adverse distortion and factor mismatch. Administrative intervention leads to capital distortion and hinders the improvement of social output (Boyreau-Debray and Wei 2005). Factor distortions lead to inappropriate allocation of factor, which will greatly reduce total productivity (Brandt et al. 2013; Hsieh and Klenow 2009; Boedo and Mukoyama 2012; Gilchrist et al. 2013).

From the perspective of the impact of factor price distortion on environment performance, Sun and Lin (2014) suggested that energy subsidies distort price signals, leading to excessive use of energy consumption by enterprises. Lin and Chen (2018) find that factor market distortion affected by government intervention hinders the promotion of green total factor productivity. Eliminating market distortion has a positive effect on the improvement of energy efficiency (Lin and Du 2013). Fisher-Vanden (2003) confirmed the negative correlation between economic distortions and energy efficiency. Tombe and Winter (2015) find that policies disproportionately increase the energy prices of some producers relative to other producers, thereby reducing resource outcomes and misallocation of sector productivity. The resource redistribution caused by the correction of factor market distortion will significantly improve the total factor productivity of the heavy industry sector in China (Yang et al. 2018). Producers will improve efficiency by shifting to other alternative factors as factor prices increase (Fan et al. 2007).

Taking energy price distortion as an example, energy price controlled by state-owned enterprises leads to the energy price distortion (Li and Lin 2014; Sun et al. 2016). Although energy price distortion caused by regulation promotes economic development in the short run, it also has a negative impact on the environment (Ju et al. 2017). Energy price affects resource input, production costs, and energy-saving technology innovation. The government reduces energy costs through administrative power to prevent high energy prices from affecting production (Ouyang et al. 2018). Meanwhile, energy price has an important impact on energy consumption and conservation. Wang et al. (2009) hold that energy saving and energy efficiency are affected by the electricity price mechanism controlled by the government. The unreasonable energy price has a negative impact on the energy conservation and consumption reduction (He et al. 2014). The energy price distortion increases the consumption of energy-intensive products and reduces the investment in energy-saving technologies, resulting in excessive resources consumption (Li and Lin 2015).

Based on the relationship between institutional quality and environment performance, many studies have found that institutional quality is closely related to ecological performance (Wang and Chen 2012; Xu and Chen 2006; Jaraite and Di Maria 2012). Institutional quality plays a positive role in deregulations, simplifying rules, and promoting trade openness. Chen et al. (2019) propose that institutional quality improves the efficiency of resource allocation. Zhao et al. (2017) and Chen et al. (2019) also prove that marketization has a significantly positive impact on water resource utilization efficiency. Nakano and Managi (2008) find that regulatory reform is conducive to productivity growth in Japan's steam power sector. Fisher-Vanden (2003) proposes that market reform would lead to a structural shift to low-carbon intensive production based on dynamic computable general equilibrium in China. Fisher-Vanden et al. (2004) argue that ownership reform and higher energy prices have reduced energy intensity in China. Sinton and Fridley (2000) discuss the effectiveness of the transition from state-owned to collective, private, and foreign investment ownership in promoting energy efficiency. Institutional quality also promotes the improvement of efficiency, which has been confirmed in the power generation and distribution industries (Zhao and Ma 2013; Mou 2014).

To summarize, there are few studies on the effect of factor price distortions on ecological efficiency. The impact of factor price distortion on ecological efficiency may vary under different circumstances. These different conditions mainly come from the institutional quality, which has different effect of factor price distortion affecting ecological efficiency in different threshold intervals. In this study, we believe that factor price distortion is an important factor affecting ecological efficiency, which deserves further analysis of the influence mechanism through discussion of institutional quality. Therefore, this study takes the ecological efficiency as dependent variable and uses a threshold model to discuss the influence mechanism of factor price distortion on environmental efficiency. Generally speaking, we fill the academic gap to investigate how factor price distortion affects the ecological efficiency.

Empirical methodology

Estimation of factor price distortion

The factor price distortion shows the deviation between actual factor price and marginal output, which can be divided into absolute distortion of factor price and relative distortion of factor price (Lau and Yotopoulos 1971; Atkinson and Halvorsen 1984). Based on the meaning of factor price distortion, we can find that the marginal output of factor needs to be calculated to measure the factor price distortion. Some studies use the production function method to measure factor market distortion. The optional functions include the Cobb-Douglas (C-D) production function or transcendental logarithmic production function. Comparing the C-D production function with the transcendental logarithmic production function, we find that there is marginal output bias using the C-D production function. Therefore, transcendental logarithmic production function is selected to calculate factor price distortion.

The marginal revenue of each input factor is equal to its marginal cost, which is the equilibrium condition of profit maximization in a completely competitive market. The marginal revenue of productive factor deviates from marginal cost under the influence of government regulation and monopoly power. Therefore, we evaluate the factor price distortion as follows.

We directly get the actual factor price from official statistics. We calculate the marginal revenue of factor according to the following steps (Yang et al. 2018). First, we set the transcendental logarithmic production function as follows:

$$lnYit = \beta 0 + \beta 1 lnKit + \beta 2 lnLit + \frac{1}{2}\beta 3(lnKit)^2 + \frac{1}{2}\beta 4(lnLit)^2 + \beta 5 lnKit lnLit + \varepsilon it \quad (1)$$

Second, the marginal output of labor and capital factor is further calculated as follows:

$$MPL, it = (\beta 2 + \beta 4 lnLit + \beta 5 lnKit) Yit/Lit \quad (2)$$

$$MPK, it = (\beta 1 + \beta 3 lnKit + \beta 5 lnLit) Yit/Kit \quad (3)$$

Third, this study assumes that the price of labor is ω; the price of capital is γ. The absolute distortion of factor price is determined by the ratio of actual factor price to marginal output of factor. Specifically:

$$\text{dist}L = MPL/\omega \quad (4)$$

$$\text{dist}K = MPK/\gamma \quad (5)$$

Eq. (4) and (5) represent the absolute distortion of labor and capital factor, respectively. If the value of dist_K and dist_L are greater than 1, it means that the factor price distortion is negative; if the value of dist_K and dist_L are less than 1, it means that the factor price distortion is positive; if the value of dist_K and dist_L are equal to 1, it means that there is no distorted in the factor market.

Fourth, we calculate the relative factor price distortion by the ratio of absolute distortion of labor to absolute distortion of capital.

$$\text{dist} = \frac{\text{dist}K}{\text{dist}L} = \frac{MPK}{MPL} \cdot \frac{\omega}{\gamma} \tag{6}$$

where dist indicates the relative distortion of factor price.

Calculation of ecological efficiency

Ecological efficiency represents the efficiency of economic activities in consideration of ecosystem resources and environmental impact (Fan et al. 2017). That is, the core of ecological efficiency is to create more economic value with less environmental impact, which reflects the coordination of economic performance and environmental impact.

There are some statistical limitations in traditional DEA method, which leads to the deviation of efficiency estimation in the case of small samples (Dyson et al. 2001; Song et al. 2013). The traditional DEA method also ignores the statistical test. The bootstrap method uses empirical data and repeats sampling to improve confidence interval estimation. Therefore, the advantage of bootstrap-DEA method is to correct the bias of estimation efficiency and obtains the confidence interval (Simar and Wilson 2000). The sample distribution obtained by the bootstrap method simulates the original sample distribution in the bootstrap-DEA model, thus correcting the error correction of efficiency estimation (Song et al. 2013). The bootstrap method is widely used in efficiency evaluation (Bagchi and Zhuang 2016). Following Wijesiri et al. (2015) and Song et al. (2013), the bootstrap-DEA is used to measure the ecological efficiency in China.

The core of bootstrap-DEA method is to simulate the original sample data and calculate the efficiency of a large number of simulation samples by the DEA method. In addition, the bootstrap does not require additional assumptions and samples and uses random simulations to maximize the use of existing information. The estimation process can be divided into the following steps.

First, we calculate the efficiency score ($\hat{\theta}_k$) for all decision-making units (DMUs) using the traditional DEA model. Second, for the efficiency score$\hat{\theta}_k$, N random efficiency values (θ^*_{kb}) were produced by the bootstrap method. We calculate $X^*_{kb} = \left(\hat{\theta}_k / \theta^*_{kb}\right) \times X'_k$, and the simulation samples $\left(X^*_{kb}, Y_k\right)$. Third, we calculate each simulation sample using the DEA model and repeat above steps to obtain a series of efficiency values $\hat{\theta}^*_{kb}(b = 1, \cdots, B)$. B indicates the total number of iteration.

$$\text{Bias}\left(\hat{\theta}_k\right) = E\left(\hat{\theta}_k\right) - \hat{\theta}_k \tag{7}$$

$$\text{Bias}\left(\hat{\theta}_k\right) = B^{-1} \sum_{b=1}^{B} \left(\hat{\theta}^*{}_{kb}\right) - \hat{\theta}_k \tag{8}$$

The corrected efficiency values are as follows:

$$\widetilde{\theta}_k = \hat{\theta}_k - \text{Bias}\left(\hat{\theta}_k\right) = 2\hat{\theta}_k - B^{-1} \sum_{b=1}^{B} \left(\hat{\theta}^*{}_{kb}\right) \tag{9}$$

The confidence interval is calculated as follows:

$$P_r\left(-\hat{b}_\alpha \leq \hat{\theta}^*_{kb} - \hat{\theta}_k \leq -\hat{\alpha}_\alpha\right) = 1 - \alpha \tag{10}$$

$$P_r\left(-\hat{b}_\alpha \leq \hat{\theta}_k - \widetilde{\theta}_k \leq -\hat{\alpha}_\alpha\right) \approx 1 - \alpha \tag{11}$$

$$\hat{\theta}_k + \hat{\alpha}_\alpha \leq \theta_k \leq \hat{\theta}_k + \hat{b}_\alpha \tag{12}$$

The selection of input and output indicators from economic development and environmental pollution is used to accurately evaluate the ecological efficiency based on the bootstrap-DEA method. The output indicators include the desirable outputs and undesirable outputs. The input indicators refer to labor, capital, and resource inputs, which are inputs in the production process. GDP is the final result of production activities in a certain period of time. Thus, regional GDP of province is chosen to represent the desirable output. Sulfur dioxide emissions, solid waste emissions, waste water emissions, smoke, and dust emissions are selected as the undesirable outputs as they are the main pollutants. Labor input is expressed by the total number of urban employees. Capital stock is estimated by the fixed asset investment. The total energy consumption, cultivated area, and total water consumption of province are considered as the resource inputs. Table 1 shows the input-output indicators of ecological efficiency based on the bootstrap-DEA method.

Empirical method

This section provides the empirical method to investigate the impact of factor price distortion on ecological efficiency. First, because ecological efficiency changes dynamically, many factors which are difficult to observe can be separated by controlling first-lagged ecological efficiency. Second, pollutant emissions are continuous indicators. The environmental pollution in the previous period will also affect the current

Table 1 Input-output indicators of ecological efficiency

	Category	Specific indicators
Input indicators	Labor input	Total number of urban employees
	Capital input	Fixed asset investment
	Resource inputs	Total energy consumption
		Cultivated area
		Total water consumption
Output indicators	Desirable output	GDP
	Undesirable outputs	Sulfur dioxide emissions
		Solid waste emissions
		Waste water emissions
		Smoke and dust emissions

ecological efficiency. Therefore, the first-lagged ecological efficiency is added to the model in this study. According to the framework, the estimated model based on Lin and Chen (2018) is as follows:

$$\mathrm{eco}_{i,t} = \lambda_0 + \lambda_1 \mathrm{eco}_{i,t-1} + \lambda_2 \mathrm{distortion}_{i,t} + X_{it}T + \varepsilon_{it} \quad (13)$$

where i represents province and t represents year; $\mathrm{eco}_{i,t}$ measures the ecological efficiency, which is considered as the dependent variable; $\mathrm{distortion}_{i,t}$ measures the factor price distortion, which is considered as the independent variable; X means the vectors of control variables that also affect ecological efficiency based on the previous studies. Subsequently, we further consider the interaction between factor price distortion and institutional quality to analyze the moderating effect.

$$\mathrm{eco}_{i,t} = \lambda_0 + \lambda_1 \mathrm{eco}_{i,t-1} + \lambda_2 \mathrm{distortion}_{i,t} + \lambda_3 \mathrm{market}_{i,t} + \lambda_4 \mathrm{distortion*market} + X_{it}T + \varepsilon_{it} \quad (14)$$

where $\mathrm{market}_{i,t}$ represents the institutional quality. The meanings of the other variables are consistent with the baseline regression model.

Estimation system

GMM is the extension of instrumental variable technique. The main advantages of GMM are as follows: (1) the model is not required to be serial independent and homoscedastic; (2) an effective solution to overcome the endogenous problem (Blundell and Bond 1998). The problem of weak instruments is the limitation of GMM method (Racicot 2015). This study uses the system GMM estimator proposed by Blundell and Bond (1998). There are following reasons to use the system GMM method. First, the system GMM estimator can control the endogeneity of regressors, heteroskedasticity, unobserved individual heterogeneity, and simultaneous reverse causality. Second, compared with the ordinary least squares (OLS) and Within Groups estimator, the system GMM estimator excludes the bias and inconsistent estimates of these two methods. Third, the system GMM estimator combines in a system the equation in first-differences with an equation in levels (Chen and Guariglia 2013). Compared with the simple first-differenced GMM, the system GMM estimator significantly improves the efficiency and reduces the finite sample bias. We regard all regression variables as endogenous regression variables in the model and test them by using their lag level in differential equations and their lag differences in horizontal equations. We use the Sargan statistics to examine the effectiveness of the instruments.

Based on the previous literature, economic development, industrial structure, urbanization, foreign direct investment, import, and export are selected as control variables affecting ecological efficiency (Yu et al. 2013). Per capita GDP captures the regional economic development, which is represented as *pgdp*. Industrial structure is measured by the ratio of output value of the tertiary industry to that of the secondary industry, which is represented as *industry*. Urbanization is measured by the ratio of urban population to total populations, which is represented as *urban*. *open* is represented as the ratio of import and export to GDP. *fdi* is measured by the ratio of foreign direct investment to GDP.

Data and descriptive statistics

The data of this study are from China Statistical Yearbook, China Macroeconomic Database, China Compendium of Statistics, China Environmental Statistics Yearbook, China Labor Statistics Yearbook, China Environmental Yearbook, China Population and Employment Statistics Yearbook, China Energy Statistics Yearbook, China Province Marketization Index Report, Ministry of Commerce Statistical Database, and National Bureau of Statistics. There is a lag in the publication of pollution emission data. Considering the availability of data, the objects of this study are 30 provinces during the period of 2000–2015 in China (excluding Tibet due to lack of data). Table 2 presents the statistical descriptions of main variables that are covered in this study.

According to the above research method, the factor price distortion index of each province in each year is obtained. We divide the whole country into the east, northeast, central, and west regions and calculate the average factor price distortion index of each region separately. Figure 1 shows the trend of average factor price distortion index from 2000 to 2015. According to Fig. 1, the average factor price distortion of 30 provinces in China shows the fluctuating downward trend during the period of 2000–2015. The value of national average factor price distortion dropped from 7.0701 in 2000 to 2.2116 in 2015. This confirms that there is serious factor price distortion in China, and the factor price distortion has been greatly improved in recent decades. The average factor price distortion index in the eastern and northeastern regions is

Table 2 Statistical descriptions of main variables

Variable	N	Mean	Std Dev	Min	Max
eco	464	0.8156	0.0909	0.5204	0.9682
distortion	464	3.4038	2.8908	0.3000	17.5900
pgdp	464	9.9218	0.8128	7.9226	11.5895
industry	464	1.1793	0.2951	0.2478	2.0119
urban	464	0.4873	0.1524	0.2000	0.9000
open	464	0.4446	0.5520	0.0500	2.4400
fdi	464	0.3459	0.2900	0.0105	1.7695
market	464	5.3879	2.7642	− 0.0900	18.5800

The variables are in italics

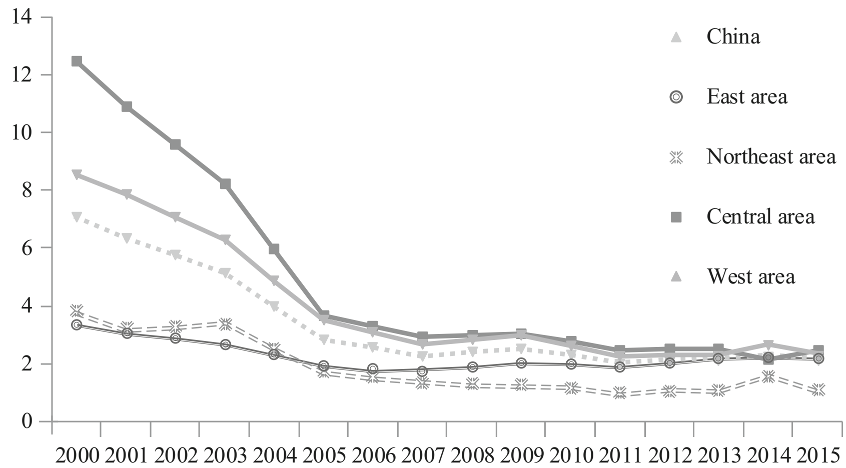

Fig. 1 Trends of factor market distortion in China and the four major regional from 2000 to 2015

lower than the national average value, while the average factor price distortion index in the central and western regions is higher than the national average value. The market-oriented reform in the eastern region is better than that in other regions, which makes the factor price distortion relatively low in the eastern region.

We further use the ArcGIS software to analyze the spatial distribution of provincial factor price distortion. Based on the law of natural fracture, China's provincial factor price distortion can be divided into five types: the higher distortion, high distortion, medium distortion, low distortion, and the lower distortion. The spatial evolution of China's inter-provincial factor price distortion is analyzed. Figure 2 reports the spatial distribution of provincial factor price distortion in 2000 and 2015. The regions with high factor price distortion include Sichuan, Guizhou, Hunan, Hubei, and Henan, most of which belong to the central and western regions in 2000. The regions with low factor price distortion are mainly concentrated in Beijing, Tianjin, Shanghai, Hainan, and Fujian, most of which belong to the eastern region in 2000. Guizhou is still the region with high factor price distortion in 2015. The regions with higher factor price distortion are concentrated in Sichuan, Shanxi, Gansu, and Hebei, while the regions with low factor market distortion are concentrated in Hunan, Qinghai, Inner Mongolia, Liaoning, and Jilin in 2015.

Empirical analysis

Baseline regression analysis based on the dynamic model

The system GMM estimation is used to investigate the impact of factor price distortion on ecological efficiency in China. It is necessary to analyze the effectiveness of instrumental variables and the rationality of model. First, the first- and second-order autocorrelation AR (1) and AR (2) of the perturbation term need to be confirmed, which is used to identify the effectiveness of instrumental variables. We also make sure that the null hypothesis has no residual correlation. Second, we

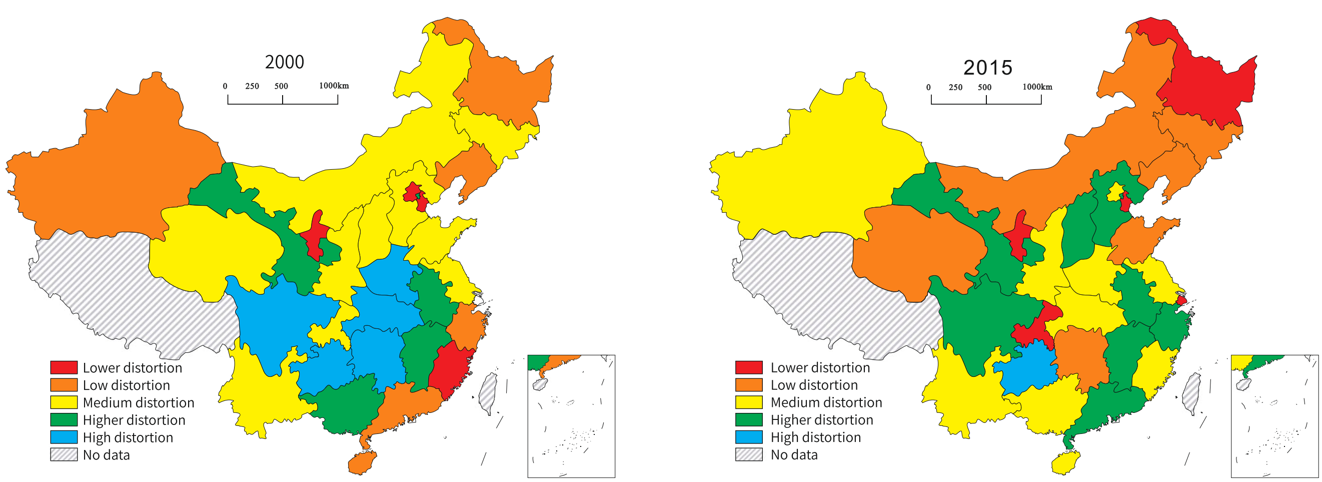

Fig. 2 Spatial pattern of factor market distortion in China

continue to test whether the GMM model is over recognition. The Sargan test is used to identify whether there is over recognition of instrumental variables.

The regression results of system GMM estimation in China during the period of 2000–2015 are presented in Table 3. According to Table 3, AR (1) and AR (2) suggest that the first-order correlation is significant and the second-order correlation is insignificant, indicating that the model accepts the related null hypothesis in the system GMM method. The Sargan test indicates that all regression models fail to reject the null hypothesis that the selected instrumental variables are not over recognition. This result suggests that the instrumental variables used in the dynamic system GMM estimation are valid.

Table 3 shows the empirical results of the impact of factor price distortion on ecological efficiency based on the dynamic system GMM method, which solves the dynamic panel endogeneity and excessive recognition of instrumental variables. We use the method of adding one control variable at a time to display the results in order to enhance the robustness of the results. The regression coefficient of factor price distortion is significantly negative at the 1% level in column (6), that is, the higher the degree of factor price distortion, the lower the ecological efficiency. As a result, we find that factor price distortion has significantly negative role in promoting the ecological efficiency.

Analysis of moderating effect

Table 4 presents the moderating effect of factor price distortion affecting ecological efficiency in column (1). The coefficient of factor price distortion is − 0.0050 at the 1% level. This result indicates that if the factor price distortion increases by 1%, the ecological efficiency will reduce by 5.0%. That is to say, factor price distortion hinders the improvement of ecological efficiency. The coefficient of institutional quality is 0.0235 at the 1% level. This result means that an increase in institutional quality by 1% will lead to 2.35% increase in ecological efficiency. As a result, institutional quality promotes the improvement of ecological efficiency. The better institutional quality improves resource allocation efficiency, increases R&D investment, and ultimately improves ecological efficiency. We find that both government behavior and institutional cause are factors affecting ecological efficiency. In addition, institutional quality is conducive to the improvement of ecological efficiency; however, institutional quality also promotes technological progress, which may in turn promote energy consumption and offset the ecological effects of institutional quality improvement. The factor price distortion may enhance the rebound effect.

On the one hand, institutional quality promotes the improvement of ecological efficiency; on the other hand, institutional quality alleviates the distortion of factor price, which in turn affects ecological efficiency. We find that the coefficient of the multiplication of factor price distortion and institutional quality is negative, which is significant at the 1% level. This result suggests that the negative effect of factor price distortion on ecological efficiency is stronger in provinces with weak institutional quality. Institutional quality plays a positive role in removing the distortion of factor price. The possible explanation for this result is as follows. The power of government to control resources is restricted under the condition of better institutional quality. The optimization of institutional quality and the improvement of government efficiency promote the

Table 3 Regression of factor price distortion on ecological efficiency based on GMM

	(1)	(2)	(3)	(4)	(5)	(6)
distortion	− 0.0036*** (− 2.81)	− 0.0035*** (− 2.67)	− 0.0037** (− 2.61)	− 0.0033** (− 2.37)	− 0.0033** (− 2.32)	− 0.0030** (− 2.29)
pgdp		0.0007 (0.17)	0.0004 (0.12)	− 0.0141** (− 2.36)	− 0.0141** (− 2.35)	− 0.0147** (− 2.43)
industry			− 0.0034 (− 0.50)	0.0039 (0.58)	0.0048 (0.63)	0.0064 (0.89)
urban				0.1723*** (2.52)	0.1748*** (2.55)	0.1885*** (2.99)
open					− 0.0015 (− 0.21)	− 0.0022 (− 0.30)
fdi						− 0.0275*** (− 2.46)
eco_{t-1}	0.9199*** (5.11)	0.9139*** (9.53)	0.9130*** (9.36)	0.9086*** (9.49)	0.9079*** (9.67)	0.9070*** (9.02)
constant	0.0860*** (2.59)	0.0836** (2.23)	0.0912** (2.27)	0.1456*** (3.01)	0.1447*** (3.01)	0.1518*** (3.29)
sample size	435	435	435	435	435	435
AR(1)	0.0407	0.0434	0.0355	0.0319	0.0394	0.0271
AR(2)	0.6064	0.5829	0.5146	0.4299	0.4128	0.3364
Sargan Value	29.698	28.376	27.775	26.158	24.097	22.982

The variables are in italics

*Indicates significance at the 10% level

**Indicates significance at the 5% level

***Indicates significance at the 1% level

T values are in parenthesis

Table 4 Results of moderating effect and threshold effect

	(1) moderating effect	(2) threshold effect
distortion	− 0.0050*** (− 3.06)	
*distortion*market*	− 0.0457*** (− 3.55)	
market	0.0235*** (5.72)	
pgdp	− 0.0095** (− 2.12)	0.0693*** (8.59)
industry	0.0092 (1.24)	− 0.019** (− 2.08)
urban	0.1680*** (4.27)	0.0304 (0.36)
open	− 0.0141 (− 1.55)	0.0198 (1.59)
fdi	− 0.0232*** (− 2.58)	− 0.0344*** (− 2.88)
constant	0.0657** (2.07)	0.1446*** (2.96)
distortion(market < 7.780)		− 0.0180* (− 1.78)
distortion(7.940 ≤ market < 7.780)		− 0.0008*** (− 3.53)
distortion(market > 7.940)		− 0.0063 (− 0.87)

The variables are in italics

*Indicates significance at the 10% level

**Indicates significance at the 5% level

***Indicates significance at the 1% level

T values are in parenthesis

innovation of clean technology and the application of energy-saving technology. Enterprises reduce the use of high-polluting factors and increase the investment in energy-saving technologies, thus reducing emission reduction costs. In contrast, the government pays more attention to achieving economic growth while ignoring energy saving, emission reduction, and environmental pollution in regions with weak institutional quality. A large number of production factors flow into the high-pollution industry in order to obtain short-term economic growth. The growth of enterprise performance depends more on the input of low-cost factors than on technological innovation. Thus, the negative effect of factor price distortion on ecological efficiency is more significant in provinces with weak institutional quality.

Analysis of threshold effect

The influence of factor price distortion on ecological efficiency not only will be moderated by the degree of institutional quality but also may be an obvious threshold effect. That is to say, with the gradual improvement of institutional quality, the impact of factor price distortion on ecological efficiency is likely to undergo a transitional change, showing the strong fluctuating upward trend. This effect is not entirely linear and smooth growth. Therefore, in order to further explore the mechanism of factor price distortions affecting ecological efficiency, this study considers that the institutional quality may have a significant leap-forward impact on the path of factor price distortion affecting ecological efficiency. We introduce the institutional quality as a threshold variable into the regression using the threshold model. This study constructs a piecewise function of institutional quality, factor price distortion, and ecological efficiency and tests the number and value of threshold. The estimated threshold model can be expressed below:

$$\begin{aligned} \mathrm{eco}_{i,t} = {} & \beta_0 + \beta_1 \mathrm{distortion}_{i,t} \cdot I\left(\mathrm{market}_{i,t} \le \gamma_1\right) \\ & + \beta_2 \mathrm{distortion}_{i,t} \cdot I\left(\gamma_2 < \mathrm{market}_{i,t} \le \gamma_1\right) \\ & + \beta_3 \mathrm{distortion}_{i,t} \cdot I\left(\mathrm{market}_{i,t} \ge \gamma_2\right) + X_{it}T + \alpha_i \\ & + \varepsilon_{it} \end{aligned} \tag{15}$$

Where market is the institutional quality; γ_1 and γ_2 represent threshold values; $I(*)$ represents an indicative function.

Table 5 displays the results of threshold model by equation. According to Table 5, the threshold effect is significant, which passes the 10% statistical significance test. The results show that there is a double threshold effect. It is significant that the threshold is between 95% confidence interval. The threshold values of institutional quality are 7.780 and 7.940, the threshold intervals are market < *7.780*, *7.940* ≤ market < *7.780*, and market > *7.940*, which correspondingly reflect the provinces with low, medium, and high degree of institutional quality.

The estimated result of threshold effect is shown in column (2) of Table 4. We observe that there are three threshold intervals. market < *7.780* means that the degree of institutional quality is less than 7.780, *7.940* ≤ market < *7.780* represents that the degree of institutional quality is between 7.780 and 7.940, market > *7.940* indicates that the degree of institutional quality is large than 7.940. The coefficients of factor price distortion are significantly negative in the first and second interval. Subsequently, it turns insignificant in the third interval.

Table 5 Results of threshold model by equation

Variable	Threshold number	Bootstrap LM value	*P* value	Threshold	95% confidence interval
distortion	2	5.298*	0.067	7.780	(7.510, 7.780)
				7.940	(7.850, 10.000)

The variables are in italics

*Indicates significance at the 10% level

**Indicates significance at the 5% level

***Indicates significance at the 1% level

We observe that the institutional quality improves the negative effect of factor price distortion on ecological efficiency. The institutional quality is related to factor allocation efficiency. The improvement of institutional quality increases the technological innovation of environmental protection and optimizes the efficiency of pollution governance. Therefore, the inhibitory effect of factor price distortion on ecological efficiency is weaker in provinces with better institutional quality.

The inhibitory effect of factor price distortion is insignificant in the regions with better institutional quality because of the better pricing mechanism of factor market and the efficiency of factor allocation. The improvement of institutional quality prevents factor prices from being interfered by the government. Factor price is an effective signal, which affects the flow of factors between different regions. Producers will reduce the use of high-pollution factors and improve the energy-saving technological innovation to save environmental costs. All of these are line with the improvement of ecological efficiency.

Heterogeneity test

To further identify the characteristic of ecological efficiency in different regions, we divide the whole samples into two groups: the eastern region, and the central and western regions according to the China Statistical Yearbook. We compare the non-linear relationship between factor price distortion and ecological efficiency in different levels of economic development.

Table 6 displays the dynamic system GMM method results of heterogeneity test. The results show that the effect of factor price distortion on ecological efficiency is not significant in the eastern region. There is a significant negative relationship between factor price distortion and ecological efficiency in the central and west regions, that is, the factor price distortion hinders the improvement of ecological efficiency in the central and west regions. As previously mentioned, we observe that the ecological efficiency of the eastern region is the highest, compared with that of the central and western regions. The advantages of economic development and clean energy technology in the east region are conducive to improving ecological efficiency. The imbalance between energy technology and ecological environment in the central and western regions is obvious. As a result, the inhibitory impact of factor price distortion on ecological efficiency is more significant.

Robustness test

We conduct several tests of the result in order to check the robustness. Following Lin and Du (2013), the factor price distortion is recalculated[1], which is considered as the alternative measurement. We repeat the estimation in Eq. (13) by using the alternative variable as a proxy. The results of the impact of alternative proxy on ecological efficiency are displayed in Table 7 as the robustness test. We find that the coefficients of the key explanatory variables are significantly negative, indicating that the results are consistent with expectation. We observe that the result of factor price distortion hindering the improvement of ecological efficiency is robust.

Discussion

Our study has made some expansion from the perspective of practice and theory. First, Sun and Lin (2014), Ouyang et al. (2018), and Lin and Chen (2018) analyze the influence of factor market distortion on energy consumption, energy efficiency, and green total factor productivity. In making a distinctive contribution, we demonstrate a negative correlation between factor price distortion and ecological efficiency. In summary, these evidences not only support the hypotheses but also indirectly illustrate the contribution of the study. Second, the moderating effect and threshold effect of institutional quality in the relationship between factor price distortion and ecological efficiency are examined. Third, the government behavior plays an important role in promoting the development of ecological efficiency. Therefore, the government governance and institutional quality are important ways to improve the environmental efficiency from the perspective of practice.

The empirical results show that factor price distortion significantly inhibits the improvement of ecological efficiency. Moreover, institutional quality plays an important role in the relationship between factor price distortion and ecological efficiency. Thus, we suggest that the negative impact of factor price distortion on ecological efficiency is weakened in the

[1] $factor_{i,\ t} = [\max(factor_{i,\ t}) - factor_{i,\ t}] / \max(factor_{i,\ t}) * 100\%$, $factor_{i,t}$ is the index of factor market.

Table 6 Results of heterogeneity test

	Model (1)	Model (2)
	East region	Central and west regions
distortion	− 0.0013 (− 0.59)	− 0.0028*** (− 3.21)
pgdp	0.0218*** (3.32)	− 0.0278*** (− 4.81)
industry	0.0021 (0.23)	0.0044 (0.57)
urban	− 0.0346 (− 0.73)	0.3035*** (5.02)
open	0.0025 (0.50)	0.0842*** (2.95)
fdi	− 0.0319*** (− 4.72)	− 0.0065 (− 0.30)
eco_{t-1}	0.7152*** (3.94)	0.8887*** (5.25)
constant	0.0613* (1.81)	0.2334*** (5.92)
Sample number	150	285
AR (1)	0.0432	0.0549
AR (2)	0.7009	0.7821
Sargan value	21.216	20.048

The variables are in italics

*Indicates significance at the 10% level

**Indicates significance at the 5% level

***Indicates significance at the 1% level

T values are in parenthesis

provinces with better institutional quality. The possible explanation for this result is as follows. First, factor price distortion reduces the production cost of backward production enterprises and subsidizes the investment of enterprises in the form of excess profits. Therefore, factor price distortion raises the exit barriers of backward enterprises and hinders the upgrading of industrial structure. Second, enterprises make excessive use of high-pollution factors and rely on political relations to obtain production factors in the case of factor price distortion. There is less motivation and pressure to invest in R&D, which restrains energy-saving technologies, and aggravates environmental pollution. Third, this is probably the misallocation of productive factors, which is caused by the government intervention. The local governments allocate more resources to local enterprises for the sake of their interest, which is not conducive to factor flow and resource allocation. A large number of resources flow to polluted industries, energy-intensive industries, and capital-intensive industries. For example, if energy factor price fails to reflect the supply and demand of energy, enterprises will use excessive resources to maintain revenue of the monopoly, which will ultimately affect the ecological efficiency.

We also confirm that the negative effect of factor price distortion on ecological efficiency is stronger in provinces with weak institutional quality. The institutional quality influences the flow and allocation of production factors. The governments should not directly intervene in the market in the regions with better institutional quality. Enterprises increase R&D investment, improve technological innovation, and alleviate the negative impact of price distortion on ecological efficiency in the market environment where property rights are protected. Thus, we deeply analyze the moderating effect of factor price distortion affecting ecological efficiency from the perspective of institutional quality, which is different from the existing study.

Table 7 Robustness tests for alternative measurement

	Model (1)	Model (2)
distortion	− 0.0520*** (− 2.52)	− 0.0747*** (− 3.45)
pgdp		− 0.0068 (−0.93)
industry		0.0138** (1.93)
urban		0.2022*** (2.70)
open		− 0.0063 (− 0.91)
fdi		− 0.0313*** (− 2.63)
eco_{t-1}	0.9029*** (6.02)	0.9232 (8.41)
constant	− 0.0057 (− 0.35)	0.0497 (1.29)
sample size	435	435
AR (1)	0.0314	0.0311
AR (2)	0.7712	0.6315
Sargan value	27.883	27.109

The variables are in italics

*Indicates significance at the 10% level

**Indicates significance at the 5% level

***Indicates significance at the 1% level

T values are in parenthesis

Conclusion

This study focuses on ecological efficiency from the perspective of government behavior and institutional quality. Government intervention has an impact on economic development and industrial structure, resulting in excessive consumption of resources and insufficient investment in innovation. The factor price distortion is caused by government intervention and local protectionism. The purpose of this study is to analyze the relationship among factor price distortion, institutional quality, and ecological efficiency. Based on the above empirical results, the conclusions are summarized as follows.

First, our study uses the transcendental logarithmic function to measure the factor price distortion in China during the period of 2000–2015 and find that the average factor price distortion of 30 provinces shows the fluctuating downward trend in China. The spatial distribution of provincial factor price distortion shows that the regions with low factor price distortion are mainly concentrated in eastern region, while the regions with higher factor price distortion are concentrated in west region. Second, the bootstrap-DEA method is used to measure the ecological efficiency as the indicator of environmental performance. Third, our study identifies whether factor price distortion has negative impact on the ecological efficiency based on the system GMM method. The results show that factor price distortion significantly inhibits the improvement of ecological efficiency. Fourth, how institutional quality affects the relationship between factor price distortion and ecological efficiency is analyzed. The result indicates that the negative effect of factor price distortion on ecological efficiency is stronger in provinces with weak institutional quality. Moreover, institutional quality is considered to be the threshold of factor price distortion affecting ecological efficiency. Further investigation of heterogeneity effect indicates that the inhibitory impact of factor price distortion on ecological efficiency is more significant in the central and western regions.

Based on the above research results, the government should reform the factor market, improve the institutional quality, optimize the government governance, and improve the ecological environment performance. The following policy suggestions are put forward.

Firstly, government intervention has an important impact on factor price distortion, resulting in excessive consumption of resources and low investment in technology innovation. Removing factor market distortion and the improvement of resource allocation efficiency are the core of sustainable economic growth. The reform of factor market and market-oriented price policy are conducive to resource allocation and resource flow. Factor market reform can get rid of the dependence of enterprise growth on factor market, encourage R&D investment and technological innovation, improve production efficiency, and reduce pollution emissions. Therefore, the government should speed up the reform of factor market.

Secondly, our study suggests that it is necessary to speed up the construction of market mechanism and improve the institutional quality to cross the threshold as soon as possible to promote the ecological efficiency. We emphasize the importance of resource consumption and environmental pollution in the process of economic development. We aim at sustainable development and ecological civilization, follow the natural law, pay attention to environmental protection, and improve the efficiency of resource utilization and ecological efficiency. Industrial structure and technological innovation are closely related to the improvement of ecological efficiency. Therefore, the governments should close small enterprises with high energy consumption and pollution emission, improve the ability of independent innovation, and realize the transformation from economies of scale to technological and economic effects. In addition, strengthening the social responsibility of state-owned enterprises in energy saving and emission reduction, actively promoting circular production and cleaner production, and vigorously developing low-carbon environmental protection industries are also effective ways to improve the ecological efficiency.

Thirdly, it is necessary to break the limitation of administrative region, break down the institutional barriers that hinder regional cooperation, strengthen the economic integration and cooperation, and promote the free flow of capital, talents, and other essential resources. The government should strengthen environmental regulation, implement strict and effective resource and environment management policies, and regulate the structure and scale of energy. These measures are conducive to reducing pollution emissions and improving ecological efficiency.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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