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EVALUATION OF CHINA'S PROVINCIAL ECO-EFFICIENCY WITH THE EXPLAINABLE BOOSTING MACHINE (EBM) MODEL AND TOBIT REGRESSION

Evaluation of China's provincial eco-efficiency with the explainable boosting machine (EBM) model and Tobit regression

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Key words: ecological efficiency, regional differences, spatial agglomeration, spatial differences.

ABSTRACT

The explainable boosting machine (EBM) model measures China's provincial eco-efficiency, and the Tobit regression model reveals internal driving factors to provide consultation for promoting China's green development based on the panel data of 30 provinces from 2000 to 2018. The findings of this article are as follows: provincial-level regional ecological efficiency is low, growth is slow, regional differentiation is significant, and development still has a trend of incoordination and multi-polarization. From the perspective of global autocorrelation, the Moran index is significantly positive, and the province eco-efficiency of the first grade presents a positive spatial correlation and has the characteristics of spatial agglomeration. The regression analysis results show that the economic level, the FDI, the level of technological innovation, and the level of human capital are the main influencing factors of eco-efficiency, and there are spatial differences. Relevant suggestions are based on the status and influencing factors of the unbalanced development heterogeneity of provincial eco-efficiency in China.

Palabras clave: eficiencia ecológica, diferencias regionales, aglomeración espacial, diferencias espaciales.

RESUMEN

El modelo de máquinas de incrementación explicable (EBM, por su sigla en inglés) mide la ecoeficiencia provincial de China, y el modelo de regresión de Tobit revela factores impulsores internos para proporcionar consultas para promover el desarrollo verde de China sobre la base de los datos del panel de 30 provincias de 2000 a 2018. Los hallazgos de este artículo son los siguientes: la eficiencia ecológica regional a nivel provincial es baja, el crecimiento es lento, la diferenciación regional es significativa, y el desarrollo todavía tiene una tendencia de incoordinación y multipolarización. Desde la perspectiva de la autocorrelación global, el índice de Moran es significativamente positivo, y la ecoeficiencia provincial del primer grado presenta una correlación espacial positiva y tiene las características de la aglomeración espacial. Los resultados del análisis de regresión muestran que el nivel económico, la IED, el nivel de innovación tecnológica y el nivel de capital humano son los principales factores que influyen en la ecoeficiencia, y hay diferencias espaciales. Las sugerencias pertinentes se basan en la situación y los factores que influyen en la heterogeneidad desequilibrada del desarrollo de la ecoeficiencia provincial en China.

INTRODUCTION

Based on the extensive economic growth mode of high pollution, high energy consumption and high investment, China's economy has made great economic and social progress, and also caused serious resource consumption (**Fig. 1**), environmental pollution and destruction (**Fig. 2**). At present, the increasing demand for energy resources in China has caused the contradiction between ecological environmental protection, resource consumption and economic growth, to become a problem more and more outstanding. China's transformation from extensive economic development to intensive development has become the key to promoting China's ecological civilization construction and sustainable development. How to achieve a balanced development of economy and environment, and to improve ecological efficiency is an important issue facing China's economic development in the background of the "new normal" and the promotion of eco-civilization. Therefore, investigating regional eco-efficiency, deeply analyzing the trends and paths of the regional eco-efficiency dynamic evolution, and digging out the mechanism that affects eco-efficiency can deepen the research on China's eco-efficiency and provide certain experience and reference for promoting regional green and high-quality development.

In 1990, "ecological efficiency" was first put forward by Schaltegger and Sturn (1990). In 1992, eco-efficiency which is realized by satisfying the goods and services of human production and life, and reducing the ecological impact and resource consumption within the carrying capacity of the earth was put forward by the World Business Council for Sustainable Development (WBCSD). In 1993, the WBCSD further proposed seven elements to achieve the ultimate goal of ecological efficiency, which can be summarized as three goals, namely: 1) reduce the consumption of land, water, energy, etc.; 2) reduce the impact on nature; 3) increase the value of services (Sinkin et al. 2008). In 1998, the Organization for Economic Co-operation and Development (OECD) expanded the concept of eco-efficiency and applied it to more fields. It believed that eco-efficiency was to ensure social and economic development while taking into account the ecological environment and the rational use of resources, so as to achieve the state of sustained development of the economy.

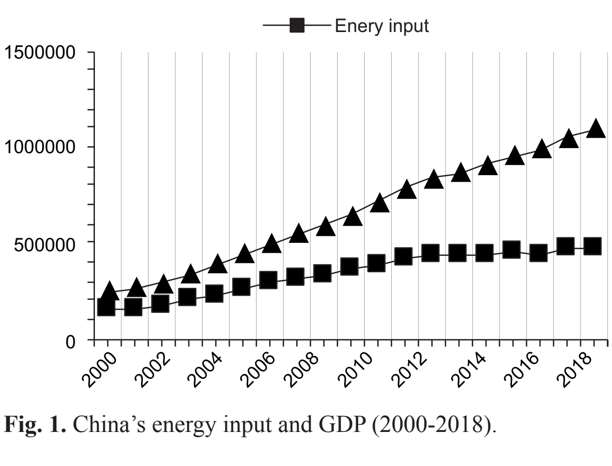

Fig. 1. China's energy input and GDP (2000-2018).

Fig. 2. China's emissions of three industrial wastes (2000-2018).

In recent years, scholars have done some research on the connotation, evaluation methods, and influencing factors of eco-efficiency from the perspective of regions, industries, and enterprises. First, at the enterprise level, Ma et al. (2015) took chemical companies as the research object and analyzed the effects of resource efficiency and ecological efficiency on industrial metabolism. Geissler et al. (2015) used data envelopment analysis (DEA) pathways, calculated the efficiency of the world's 24 largest phosphate mining companies with the models of Carnes, Cooper and Rodhes (CCR) (1978) and Banker, Carnes and Cooper (BCC) (1984), and provided policy recommendations for the sustainable development of phosphate resources. Angeles et al. (2017) studied the small-scale development of southeastern Spain from a micro perspective, the agricultural ecological efficiency of a farm, and a regression analysis of the factors that affect its ecological efficiency. The oriented DEA model was developed and the carbon footprint was used as an undesired output to study the Chilean raspberry industry's eco-efficiency (Rebolledo et al. 2019). The environmental efficiency of China's 31 major cities was explored by using the two-stage EBM model in order to analyze the impact of environmental pollution on public health by Li et al. (2017). The 28 EU member states' eco-efficiency was evaluated by using the DEA model, and concluded that Germany, Ireland, and the United Kingdom have the highest environmental eco-efficiency (Halkos and Petrou 2019), higher developed countries have relatively higher recovery rates.

Combing the research literature in recent years, overall, the research results based on the perspective of ecological efficiency are relatively rich. Scholars mainly evaluate the differences in ecological efficiency by studying the development characteristics of different regions or industries, but there are few studies on the factors affecting ecological efficiency from their spatial distribution.

The main contributions of this paper are summarized as follow. First, considering the impact of unexpected output, the China's regional ecological efficiency is analyzed by using the EBM model. Second, the spatial correlation, regional heterogeneity and dynamic evolution trend of China's ecological efficiency are evaluated and analyzed by using the Moran Index. Third, the Tobit regression model is used to analyze the relationship between China's regional ecological efficiency and its influencing factors from the economic, social, and environmental perspectives to strengthen regional cooperation for China. Promoting regional green and high-quality development provides specific experience and reference.

INDEX SYSTEM CONSTRUCTION AND DATA DESCRIPTION

Eco-efficiency indicator system

Combining with previous research and starting from the input-output perspective, we construct an eco-efficiency evaluation index system (**Table I**).

Influencing factors

Taking into account the differences in the development mode of various provinces in China and the characteristics of resource endowments, based on the existing research, combined with the physical-affair-human management system method, the factors affecting the level of ecological efficiency are summarized as economic development, technological innovation level, the level of openness, human capital, and urbanization. As the national per capita income level has greatly increased, people have higher requirements for the living environment, and thus take actions to improve environmental quality. In economically developed areas, more attention will be paid to environmental quality, and the people's environmental awareness will become stronger. Foreign direct investment (FDI) produces a marked effect in improving the ecological efficiency through income effect, technological effect, scale effect, and structural effect. Through innovation compensation effects, technological innovation continuously improves the level of technological innovation, deepens industrial division and industrial development, and plays an active role in ecological efficiency; human capital level can reflect the quality level of the whole people, affect people's environmental protection awareness, and then affect urban ecological efficiency. The level of urbanization indicates the population agglomeration, and high-quality talent clusters are conducive to the development and use of advanced technologies and contribute to clean development. Therefore, this article selects per capita gross domestic product

TABLE I. ECO-EFFICIENCY EVALUATION INDEX SYSTEM.

Index	Specific index composition	Index description
Investment indicators	Capital investment	Fixed assets/100 million yuan
	Labor input	Average number of employees/10 000 people
	Energy input	Energy consumption/10 000 tons of standard coal
Output indicators	Expected output	GDP/100 million yuan
	Unexpected output	industrial wastewater/10 000 tons
		Industrial waste gas/100 million cubic meters
		Industrial solid waste/10 000 tons

TABLE II. VARIABLES DESCRIPTION OF INFLUENCING FACTORS.

Explanatory variable	Definition	Symbol
Economic level	GDP per capita/(10 000 yuan/person)	PGDP
Technical innovation level	Number of patent applications/(a)	EI
Opening-up level	Foreign direct investment/(100 million yuan)	FDI
Human capital level	Education level per capita/(year/person)	HR
Urbanization level	Urbanization rate/%	URB

(GDP), technological innovation level, foreign direct investment, education level, and urbanization rate for research. The specific indicators are shown in **table II**. Hong Kong, Tibet, Macao, and Taiwan data still need to be completed or available, so these four areas are excluded. We selected the panel data of 30 China's provinces from 2000 to 2018. The specific data comes from a variety of statistical yearbooks.

Research methods

Ecological efficiency measurement-EBM model

In the case of undesired output, resources, energy consumption, and pollution emissions are in an "inseparable" and "radial" relationship, while traditional input factors other than energy such as labor, capital, etc., and output are "inseparable" and "radial". However, DEA model and SBM distance function can't measure and deal with input-output relations with radial and non-radial relations. On account of this, Tone and Tsutsui (2009) proposed a hybrid function model which includes both radial and non-radial distance functions. Since the parameter ε is used in the model, Tone calls it an epsilon-based measure (EBM) function. The EBM model can partly remedy the deficiency of the SBM model and the traditional DEA model. The mode is shown in Eq. (1).

$$\gamma^* = \min_{\theta,\lambda,s^-} \theta - \varepsilon_x \sum_{i=1}^{m} \frac{w_i^- s_i^-}{x_{i0}}$$

$$\begin{cases} \theta x_{i0} - \sum_{j=1}^{n} \lambda_j x_{ij} - s_i^- = 0, i = 1, \cdots, m \\ \sum_{j=1}^{n} \lambda_j y_{rj} \geq y_{r0}, r = 1, \cdots, s \\ \lambda_j \geq 0 \\ s_i^- \geq 0 \end{cases} \tag{1}$$

Where, γ^* indicates the optimal efficiency value of DEA measured by EB; θ represents the efficiency value under radial condition; s_i^- represents the slackness of the i-th input element under non-radial conditions; λ denotes relative weight of input elements; (x_{i0}, y_{r0}) represents the input-output vector of the o-th DMU; w_i^- indicates the weight of the first input element which reflects the importance of the input element, and satisfies $\sum_{i=1}^{m} w_i^- = 1$; ε_x represents the core parameter that includes both radial variation ratio and non-radial relaxation vector, and satisfies $1 \leq \varepsilon_x \leq 1$. Parameter w_i^- and ε_x need to be determined before establishing the EBM model. In case $\gamma^* = 1$; denotes that the decision-making unit technology is valid.

Due to the complexity of the relationship among economy, resources and environment, there are both expected output and unexpected output, and the radial and non-radial relationship exist in the meantime. Therefore, based on the EBM model, it is extended to the EBM model including unexpected output to measure the static ecological efficiency. Model (2) is listed as follows:

$$\gamma^* = \min \frac{\theta - \varepsilon_x \sum_{i=1}^{m} \frac{\omega_i^- s_i^-}{x_{io}}}{\varphi + \varepsilon_y \sum_{r=1}^{s} \frac{\omega_r^+ s_r^+}{y_{ro}} + \varepsilon_b \sum_{p=1}^{q} \frac{\omega_p^{b-} s_p^{b-}}{b_{po}}}$$

$$\begin{cases} \sum_{j=1}^{n} x_{ij}\lambda_j + s_i^- - \theta x_{io} = 0, i = 1, \cdots, m, \\ \sum_{j=1}^{n} y_{rj}\lambda_j - s_r^+ - \varphi y_{ro} = 0, r = 1, \cdots, s, \\ \sum_{j=1}^{n} b_{pj}\lambda_j + s_p^{b-} - \varphi b_{po} = 0, p = 1, \cdots, q, \\ \lambda_j \geq 0, s_i^- \geq 0, s_r^+ \geq 0, s_p^{b-} \geq 0 \end{cases} \tag{2}$$

Spatial correlation analysis

Global Moran's I index

The global Moran's I index verifies whether the ecological efficiency is spatially correlated as a whole. The global Moran's I index can be defined as:

$$Moran'I = \frac{n \sum_{i=1}^{n} \sum_{j=1}^{n} W_{ij}(x_i - \bar{x})(x_j - \bar{x})}{\left(\sum_{i=1}^{n} \sum_{j=1}^{n} W_{ij}\right) \sum_{i=1}^{n} \left(x_i - \bar{x}\right)^2} \tag{3}$$

Local Moran's I index

Local spatial autocorrelation test is the local form of Moran's I index, which can be used to reflect the agglomeration and dispersion effect of local area, and show the spatial autocorrelation degree of local spatial unit and adjacent unit. It can be defined as follows:

$$I_i = \frac{(x_i - \bar{x})\sum_{j=1}^{n} w_{ij}(x_j - \bar{x})}{S^2} \tag{4}$$

Tobit regression model

The Tobit regression model is established based on the MLE method, which can better avoid the problems of inconsistency and bias of parameters. Therefore, the truncated Tobit regression model with limited dependent variables was used to analyze the influencing factors. The specific model form is set as follows:

$$\begin{aligned} \rho_i^* &= \alpha_0 + \sum_{j=1}^{l} \alpha_j x_{ij} + \varepsilon_i \\ \rho_i &= \rho_i^*, 0 \le \rho_i^* \le 1 \\ \rho_i &= 0, \rho_i^* < 0 \\ \rho_i &= 1, \rho_i^* > 1 \end{aligned} \tag{5}$$

Where: ρ_i^- represents the latent variable; ρ_i represents the actual explained variable; x_{ij} represents the explanatory variable; α_0 represents the constant term α_j represents the correlation coefficient vector; $\varepsilon_{it} \sim N(0, \sigma^2)$.

Analysis of empirical results

Calculation of regional eco-efficiency and analysis of differences

In this paper, the EBM model is used to calculate the data of 30 provinces in China, and the size of China's regional ecological efficiency value from 2000 to 2018 is obtained (**Fig. 3**). The calculation results are divided into East, West and Central regions, and the average distribution is calculated. The results are shown in **Table III**.

Judging from the overall trend of changes, the national eco-efficiency presents a trend of rising first and then falling, and the average level is relatively stable. As shown in **table III**, the national average eco-efficiency level from 2000 to 2018 was relatively stable. The China's central and western regions gradually increased in the interweaving, but it was still below one, and did not reach the effective production frontier. Although the eastern region showed a downward trend as a whole, it was still higher than the national average.

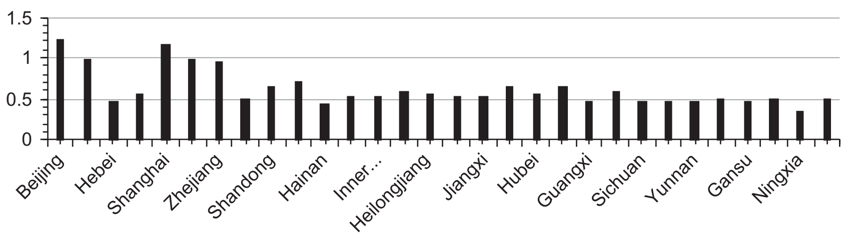

Fig. 3. Average value of eco-efficiency of 30 provinces in China from 2000 to 2018.

TABLE III. THE AVERAGE ECO-EFFICIENCY OF CHINA'S EASTERN, CENTRAL AND WESTERN REGIONS FROM 2000 TO 2018.

Year	Eastern	Central	Western	Year	Eastern	Central	Western
2000	0.7567	0.6739	0.3372	2010	0.7829	0.6441	0.5538
2001	0.7559	0.6637	0.3749	2011	0.7523	0.6112	0.5218
2002	0.7580	0.6527	0.4092	2012	0.7605	0.6314	0.5279
2003	0.7601	0.6416	0.4434	2013	0.7404	0.5992	0.5106
2004	0.7563	0.6322	0.4846	2014	0.7359	0.5905	0.5101
2005	0.7758	0.6163	0.4979	2015	0.7315	0.5609	0.4918
2006	0.7605	0.6101	0.5531	2016	0.7271	0.6082	0.4853
2007	0.7572	0.6123	0.6095	2017	0.7226	0.5726	0.4759
2008	0.7451	0.5904	0.5696	2018	0.7182	0.5642	0.4665
2009	0.7433	0.5996	0.5085	Mean	0.7495	0.6145	0.4911

The average eco-efficiency of the Eastern, Central, and Western regions in China are 0.7495, 0.6145, and 0.4911, respectively, indicating that the three major region eco-efficiency have significant differences. According to the change trend of the ecological efficiency of the three economic zones, it can be seen that from 2000 to 2018, the Eastern region eco-efficiency is the largest, followed by the Central region, and the Western region is the smallest. From the perspective of the change trend, the Eastern region eco-efficiency is gradually decreasing, but the ecological efficiency is still at a relatively high level; the change trend of the Central and Western regions eco-efficiency is basically the same as that of China; in the meantime, the Western region eco-efficiency is at a low level, which is also in line with China's current economic development. The China's eastern region has a high level of economic development, which has a superior geographical location and is easy to attract investment and advanced technology, which can reduce energy consumption and pollution emissions in the manufacturing process. The China's Central region has a cluster of energy supply and manufacturing, which has a large number of energy and environment-intensive industries, with high energy consumption and pollution emissions, and low eco-efficiency. The Western region which is still in the mid-stage of industrialization is an underdeveloped region with the worst transition conditions, communication networks, and energy infrastructure among the three major regions in China. Moreover, the Western region's economic development is still the primary task of regional development. At the same time, there are also large differences between provinces in the same region. Taking the central region as an example, Henan Province with the highest average ecological efficiency is 0.6595, and Ningxia with the lowest is only 0.3478. However, analyzing only the regional trends in ecological efficiency is not enough. So, we need to further analyze the interaction relationship of eco-efficiency in the region from a spatial perspective.

Spatial analysis of regional ecological efficiency differences

Global spatial autocorrelation analysis

The results of the global Moran's I are shown in **table IV**. We found that the global Moran's I index is all greater than zero, and pass the 5% significance test. The Z-values are all greater than 1.65, indicating that there is a significant spatial positive correlation between the eco-efficiency regions. The characteristics of ecological efficiency spatial agglomeration are significant, which may be due to the superior geographical location between adjacent provinces. The physical location facilitates the strengthening of exchanges and cooperation, technology diffusion, personnel mobility, etc., while strengthening economic cooperation, it also strengthens the spatial relevance of ecological efficiency. This shows that it is necessary to introduce spatial correlation into eco-efficiency research.

Based on local Moran's I index, Moran scatter graph can be obtained. The local Moran scatter points in 2000 and 2018 were shown in **figure 4**. There are four quadrants in the scatter plot. The first quadrant shows that the eco-efficiency level of the region itself and surrounding areas is relatively high, and the degree of spatial difference between the two is relatively small. The second quadrant indicates that the ecological efficiency of the region itself is low, and the surrounding area is high. The third quadrant indicates that the eco-efficiency level of the region itself and surrounding areas is low. The fourth quadrant

TABLE IV. GLOBAL MORAN'S I AND INSPECTION VALUES.

Year	Moran's I	P-value	Z-value	Year	Moran's I	P-value	Z-value
2000	0.233	0.008	2.323	2010	0.297	0.004	2.933
2001	0.220	0.018	2.087	2011	0.256	0.008	2.393
2002	0.242	0.007	2.482	2012	0.296	0.003	2.752
2003	0.253	0.008	2.389	2013	0.302	0.003	2.772
2004	0.278	0.004	2.678	2014	0.273	0.006	2.522
2005	0.261	0.007	2.482	2015	0.291	0.004	2.686
2006	0.390	0.000	3.535	2016	0.323	0.001	3.189
2007	0.332	0.001	3.171	2017	0.389	0.000	3.534
2008	0.235	0.008	2.325	2018	0.445	0.000	4.235
2009	0.296	0.004	2.930	EE mean	0.421	0.000	3.642

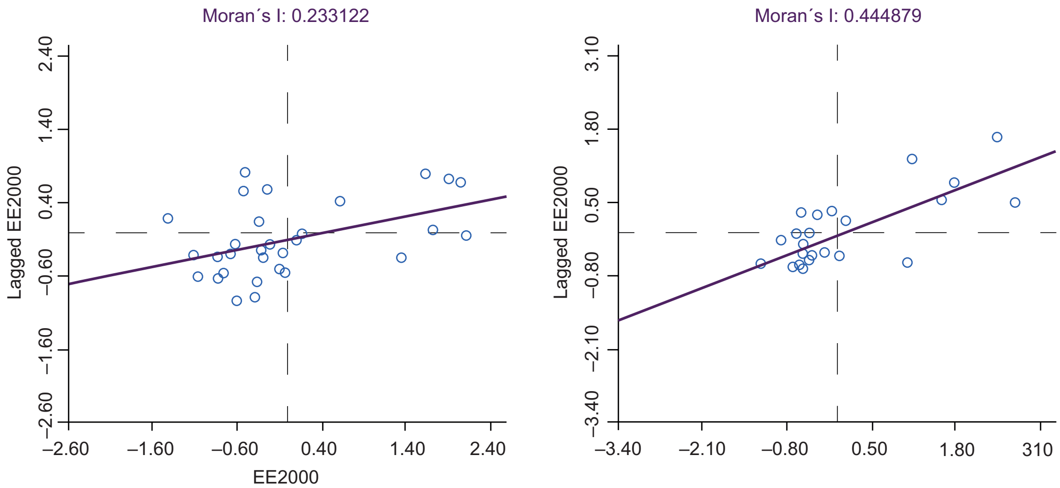

Fig.4. Local Moran scatter plot of eco-efficiency in 2000 and 2018.

indicates that the ecological efficiency of the region itself is relatively high, and the surrounding areas are relatively low.

Table V shows the position of each province on the scatter chart in 2000 and 2018. It can be seen from **table V** that most provinces mainly fall into the first and third quadrants, further verifying that China's provincial eco-efficiency has the characteristics of spatial agglomeration. Among them, Beijing, Tianjin, Shanghai (first quadrant), Hebei, Anhui (second quadrant), Guizhou, Yunnan, Hunan, Sichuan, Qinghai, Ningxia, Shaanxi, Shanxi, Gansu, Liaoning, Jilin, Xinjiang, Inner Mongolia, Heilongjiang (third quadrant), Guangdong (fourth quadrant) did not migrate within the scope of the study, and the rest of the provinces experienced varying degrees of fluctuations. Moreover, the relatively high level of ecological efficiency in relatively developed regions may be due to the advantages of regional economic strength driving the construction of eco-civilization. Within the scope of the study, most provinces are in the third quadrant, showing that China's provincial-level eco-efficiency is common and the construction of eco-civilization still needs to be strengthened.

Analysis of Tobit regression results

Using Stata14.0 software, the panel Tobit model was used to analyze the influencing factors of the provincial eco-efficiency in China, and the regression results of the Eastern, Western and Central regions are listed in **Table VI**.

1) The impact of per capita GDP on the eco-efficiency of the country and the three major regions is positively correlated, which is in line with China's reality. Except for the Western region, All passed the 5% significance level test. The

TABLE V. ECO-EFFICIENCY EVOLUTION PATH OF 30 PROVINCES IN CHINA.

Year	The first quadrant	The second quadrant	The third quadrant	The fourth quadrant
2000	Fujian, Zhejiang, Shanghai, Tianjin, Beijing	Guangxi, Jiangxi, Anhui, Jiangsu, Hebei	Guizhou, Yunnan, Hunan, Chongqing, Hubei, Sichuan, Qinghai, Ningxia, Shaanxi, Shanxi, Gansu, Liaoning, Jilin, Xinjiang, Inner Mongolia, Heilongjiang	Henan, Shandong, Hainan, Guangdong
2018	Shanghai, Beijing, Jiangsu, Zhejiang, Tianjin, Shandong	Hebei, Fujian, Anhui, Jiangxi, Hainan	Guangxi, Guizhou, Yunnan, Hunan, Hubei, Sichuan, Henan, Qinghai, Ningxia, Shaanxi, Shanxi, Gansu, Liaoning, Jilin, Xinjiang, Inner Mongolia, Heilongjiang	Chongqing, Guangdong

TABLE VI. TOBIT PANEL REGRESSION RESULTS.

Explanatory variables	National	East	Central	West
PGDP	0.2126^{***} (p=0.002)	0.3656^{***} (p=0.001)	0.0112^{**} (p=0.045)	0.0542 (p=0.234)
EI	0.0893^{**} (p=0.005)	0.0546^{*} (p=0.064)	-0.1037^{**} (p=0.012)	-0.2112^{***} (p=0.004)
FDI	0.2370^{***} (p=0.003)	0.3558^{***} (p<0.001)	0.2340^{**} (p=0.032)	0.1542^{**} (p=0.049)
HR	0.1453^{***} (p=0.006)	0.2337^{***} (p=0.001)	0.1114^{**} (p=0.024)	-0.0542 (p=0.106)
URB	0.0033 (p=0.204)	-0.2656 (p=0.109)	-0.1819^{**} (p=0.045)	0.1513 (p=0.223)

Note: ***, **, and * indicate the significance levels of 1%, 5%, and 10%, respectively. See **table II** for names of explanatory variables.

level of economic development shows a positive effect on ecological efficiency. The improvement of the level of economic development will bring about a large amount of investment in technology and capital, bring about the upgrading of the industrial structure, and inject vitality into the improvement of the regional environmental level and the promotion of sustainable economic development. All regions should coordinate the relationship between economic development and environmental protection, develop the economy based on not damaging ecological benefits, and improve the region's eco-efficiency.

2) The impact coefficient of the level of R&D investment is positive or negative, indicating the spatial difference of factors affecting eco-efficiency. Compared with other influencing factors, the impact coefficient is small, indicating that although R&D investment has an influence on eco-efficiency, The level of R&D investment in most regions is not enough to change the level of regional eco-efficiency.
3) The coefficient of FDI impact on eco-efficiency is significantly positive, and all have passed the 5% significance level test. This is in line with China's adherence to the policy of opening to the outside world in recent years, constantly introducing high-tech, low-energy, low-polluting, and high-value-added foreign-funded enterprises or industries, optimizing the industrial structure, and reducing industrial production through the formulation of environmental protection laws and regulations. The process of resource consumption, reduction of pollutant generation and discharge, and vigorous development of circular economy are inseparable.
4) HR has a positive impact on the ecological efficiency of the whole country, Eastern and Central regions, and a negative effect on the Western region. In China's Eastern and Central regions, the per capita education level is higher, the people' awareness of environmental protection is also stronger, and people have higher requirements for the living environment, so they can take actions to improve the environmental quality and affect the ecological efficiency; For the Western region, the negative effect may be due to its relatively backward education and relatively weak environmental awareness of the people. In order to develop the economy and pursue GDP performance, some enterprises or industries with high pollution, high energy consumption, and low value-added will be introduced, which will cause a large amount of sewage discharge and industrial waste. The environmental pollution problems, such as the emission of harmful gases, have caused the deterioration of the regional ecological environment and the reduction of ecological efficiency.
5) The level of urbanization has a positive effect on the eco-efficiency of the whole country and the west, and has a negative impact on the Eastern and Central regions, and has a more significant impact on the Central region. The Western region may not show the effect of improving ecological efficiency, because of its relatively backwardness and low level of urbanization. For the Eastern and Central regions, the rapid progress of urbanization has increased the pressure on various resources (land, water, energy), and the pollution of sewage, garbage, and exhaust gas caused by the transfer of a large number of people has caused the deterioration of the regional ecological environment and led to severe ecological and environment pressure. The reduction in efficiency has caused a negative effect on the level of urbanization.

CONCLUSIONS AND POLICY RECOMMENDATIONS

Based on the panel data of 30 provinces in China, the EBM model was used to measure ecological efficiency, and the Moran I index and Tobit regression were used to test its internal driving factors. The results showed that China's overall trend of ecological efficiency level is stable, and the regional view of ecological efficiency from high to low is east, middle, and west. The Western region may be in the middle or early stage of industrialization, economic development is still the primary task, and ecological construction is neglected. From a local perspective, the ecological efficiency of Beijing, Shanghai, Tianjin, Jiangsu, Zhejiang and other regions is better. The reason may be inseparable from the geographical location and economic level. The growth of provincial eco-efficiency is relatively slow, the differences between regions are significant, and there is still a trend of incoordination and multi-polarization in regional development. Eco-efficiency is positively correlated in space, and there are interactions between provinces. China's provincial-level eco-efficiency levels account for the vast majority, and the eco-efficiency level still needs to be improved. The results of driving factors show that the level of economic development and FDI positively promote regional eco-efficiency. The level of technological innovation, the level of human capital, and the level of urbanization have spatial differences in the impact of eco-efficiency, and the level of urbanization has less significant impact on eco-efficiency. It can be seen that in addition to the level of economic development and FDI, other factors have different effects on regional ecological efficiency.

In order to achieve coordinated regional development, gradually reduce regional differences and promote the construction of China's eco-civilization, the following suggestions are listed as follows. First, China should transform the mode of economic development and advocate low-carbon and energy-saving. In recent years, China's energy-saving and emission-reduction policies have shown certain results, but in order to improve China's eco-efficiency level, more stringent management policies are needed. Through the active guidance of the government, deepening system reforms, optimizing the industrial structure, accelerating technological research and development, and strengthening pollution emission supervision, the harmonious development of economic and eco-civilization can be realized. Second, we should strengthen regional cooperation and jointly explore new channels for development. Strengthen the economic and resource linkages between regions, seek development paths that conserve resources, protect the environment, and economic growth, give play to the initiative and creativity of each region, and jointly promote economic growth and the construction of eco-civilization. Third, China should increase investment in technological innovation to improve the level of innovation and green technology innovation, increase the technological transformation and reduce pollution emissions, and implement a responsibility system. In the end, supervision of social enterprises should be strengthened, the production process of enterprises should be regulated, and pollution emissions should be restricted so that the government and enterprises can achieve synergy, continue to develop, and then promote eco-civilization construction.

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Conflict of interest

The authors declare that there is no conflict of interest.

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