The Evaluation and Promotion Path of Urban Ecological Efficiency: An Empirical Study on "2+26" Cities

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Abstract: With the large-scale expansion of urbanization and rapid economic development, ecological environmental crises and resource shortages have frequently appeared. The environmental pollution and excessive consumption of resources in Chinese cities have become serious challenges. In the process of sustainable urbanization, how to realize the green development of the city while the economy develops rapidly is a problem that city managers are most concerned about. Urban ecological efficiency reflects the level of green development and the trend of economic growth. In order to analyze the improvement path and influencing factors of urban ecological efficiency, an indicator system was established from the perspective of input and output. After that, taking 28 cities in China from 2010 to 2018 as cases, the super-efficient DEA-Malmquist model is used for empirical analysis. The results show 1) The average value of "2+26" urban ecological efficiency is low with the value of 0.828, but this situation has changed with the implementation of the Beijing-Tianjin-Hebei economic integration strategy. Compared with 2010, the urban ecological efficiency of Beijing, Tianjin, Langfang, and Heze grew the fastest, with an increase of more than 50%; Changzhi, Jining and Puyang performed poorly, with urban ecological efficiency declining. 2) Spatially, urban ecological efficiency increases from southwest to northeast, and gradually forms a "step-like" and "block-like" distribution. 3) The industrial structure and urbanization level have a significant inhibitory effect on urban ecological efficiency. Environmental governance level has a certain promoting effect on urban ecological efficiency. Foreign direct investment has little effect on urban ecological efficiency. The results of this research will provide valuable ideas for city managers to design and take effective measures to enable Chinese cities to move towards sustainable development.

Keywords: urban ecological efficiency; super-efficiency DEA-Malmquist model; regressive analysis; "2+26" cities; sustainable development; green development

1. Introduction

Since the reform and opening-up its door to the world forty years ago, China's economic development and urbanization [1] have made remarkable achievements. However, rapid development of urbanization and industrialization in China has also brought many resource and environmental problems, and cities are facing many challenges on the road to sustainable development [2].It mainly includes serious air pollution [3], urban traffic congestion and excessive vehicle exhaust emissions [4], water shortages [5], continued ecosystem degradation [6], irregular urban landscapes and illegal buildings [7], and fragmentation [8]. Among them, air pollution is the most serious problem, and excessive PM2.5 emissions seriously endanger citizens' health [9]. In addition, China's carbon emissions rank first in the world [10], equivalent to the combined emissions of the United States and Europe [11].The above-mentioned aspects limit the sustainable development of urbanization, reduce the quality of life of urban residents, and weaken the carrying capacity of the ecological environment [12].

In order to alleviate these problems and improve the living environment of residents, Chinese government has adopted various measures to protect the ecological environment and prevent it from further deterioration. For example, state council of China issued "air pollution prevention and control action plan" in 2013[13]. In 2018, the State Council issued the "Opinions on Comprehensively Strengthening Ecological and Environmental Protection and Resolutely Fighting Pollution Prevention and Control". In addition, report at the 19th National Congress of the Communist Party of China (CPC) issued that the construction of ecological civilization is the fundamental and millennium plan for the sustainable development of the Chinese nation. Urban ecological efficiency can reflect the construction degree of urban ecological civilization [14]. Therefore, improving ecological efficiency is an inevitable choice for urban ecological civilization construction. It is important to measure the ecological efficiency of different cities to find out the gaps between cities and provide a basis for implementing effective policies. In this study, the super-efficiency DEA-Malmquist index model was used to evaluate urban ecological efficiency, and regression model was constructed to analyze its influencing factors. An empirical analysis was conducted based on 28 cities in Beijing-Tianjin-Hebei and surrounding areas during the period of 2010-2018.

This paper is organized as follows. Section 2 provides a literature review of the concept of ecological efficiency, the measurement of urban ecological efficiency. Section 3 describes the method-ology proposed for this study. Section 4 contains research on the measurement of ecological efficiency and influencing factors of different cities, and discusses different results. Section 5 summarizes the main results of this study and puts forward some rationalization suggestions.

2. Literature Review

2.1 Measurement of Ecological Efficiency

Ecological efficiency is the efficiency of ecological resources meeting human needs. It is the ratio of output to input. Eco-efficiency aims to find a balance between environmental protection and economic development, and strive to minimize the environmental impact while economic development, which fully reflects the ideological connotation of scientific development and harmonious development. Eco-efficiency was originally proposed by [15], and has since been redefined and promoted by [16]. Afterwards, many scholars have conducted a lot of research on "ecological efficiency". Yasmeen et al. [17] through empirical analysis shows that local governments, enterprises and citizens can adopt different ways to contribute to the sustainable development of the environment. Zameer et al. [18] used panel data from 2006 to 2018 in China to explore the coupling and coordination of natural resources, financial development and ecological efficiency. He found that regions with relatively backward economic development are too dependent on natural resources. Tan et al. [19] calculated the carbon tax imposed by the Chinese government and discussed the carbon dioxide emissions of energy-intensive industries and the impact on local ecological efficiency.

In 1989, Fare et al. [20] first proposed and used DEA technology to measure the environmental technology efficiency. Kuosmanen and Kortelainen [21] measured the ecological efficiency of the Finnish transportation industry based on DEA technology. Yang et al. [22] used the DEA model to evaluate the ecological energy efficiency of 30 provinces in China from 2007 to 2015, and studied the temporal and spatial differences in ecological efficiency. The results show that China's ecological energy efficiency is low, and regional differences are significant. Ruan et al. [23] takes the Yangtze River Delta region as the research object and uses the DPSIP-DEA model to measure the safety of tourism ecology from the perspective of efficiency. Dong et al. [24] used the data envelopment analysis method to calculate the ecological efficiency of 30 provinces and cities in China, and used the ecological footprint model to measure the ecological footprint of each province and city, and explored the temporal and spatial evolution of urban ecological efficiency from 2007 to 2016.

2.2 Influencing Factors of Urban Ecological Efficiency

At present, most scholars' research on ecological efficiency mainly focuses on the influencing factors.

Through his research on the Beijing-Tianjin-Hebei region, Zhou et al. [25] found that the rapid development of the city has changed the original landscape pattern and ecological functions, resulting in a decline in ecosystem services and many environmental problems. The faster the urban development, the more serious this phenomenon is. Matos et al. [26] studied 42 cities in Lisbon, Portugal, and modeled the impact of urban green space characteristics and other environmental factors on air quality. The study found that city managers should improve air quality by increasing green space. Cole [27] found through research that the price of land, labor, and capital determines the proportion of polluting companies in a country. Improving the level of technology is conducive to reducing this proportion, thereby reducing pollution emissions. Antweiler et al. [28] studied pollution emissions from the perspective of trade and found that the structural effects between countries are conducive to reducing pollution emissions. Through research on panel data of prefecture-level cities in China, He and Wang [11] found that changes in the economic structure will increase the emissions of dust and sulfur dioxide, but will reduce the emissions of nitrogen oxides, and this impact has significant temporal and spatial heterogeneity. Zhao et al. [29] analyzed the eco-efficiency of 256 cities in China and found that every increase of 1 unit in the industrial structure will increase the eco-efficiency by 0.0741 units, but the high dependence on natural resources will inhibit the advancement of the industrial structure from promoting eco-efficiency.

The above researches broaden the study ideas of urban ecological efficiency, but there are still some shortages: i. The urban ecological efficiency can reflect the green development level of the city. It considers the coordinated development of economic growth and the ecological environment, and provides a more comprehensive perspective for exploring the green and healthy development of cities. Therefore, in addition to studying the impact of external factors on urban ecological efficiency, we should also explore the impact of decomposition factors on urban ecological efficiency. However, most studies ignore this. ii.Most previous studies investigated the issues related to urban ecological efficiency and environment at provincial level, and regional urban agglomeration studies are comparatively rare.

The contribution of this research is that we extend research at the provincial level to the city level using the big panel data set of “2+26” cities. We also applied the Malmquist index to the model and calculated the decomposition index of urban ecological efficiency, providing improved strategies and policies for different types of cities. At the same time, we use regression models to explore the impact of external conditions on urban ecological efficiency. The significance of this study is that we provide empirical evidence for ways to improve urban ecological efficiency. It also gives a direction for different types of cities to adopt differentiated strategies and offers a reference for other developing countries to promote green development.

3. Methods and Data

3.1 Study Area

Beijing-Tianjin-Hebei region is the focus of China's economic development. How to stop the continuous deterioration of the environment and accelerate environmental protection and restoration has always been the focus of the Chinese government. In 2017, the Ministry of Environmental Protection of the People's Republic of China issued the "2017 Air Pollution Prevention and Management Plan for the Beijing-Tian-Hebei region and its Surrounding Areas" [30]. The results show that 28 cities are considered to be the ones where air pollution spreads. These cities include Beijing, Tianjin, Shijiazhuang, Tangshan, Handan, Xingtai, Baoding, Cangzhou, Langfang, Hengshui, Taiyuan, Yangquan, Changzhi, Jincheng, Jinan, Zibo, Jining, Dezhou, Liaocheng, Binzhou, Heze, Zhengzhou, Kaifeng, Anyang, Hebi, Xinxiang, Jiaozuo, and Puyang (Hereinafter referred to as "2+26" cities. See Figure 1). Environmental pollution in these cities is serious. Especially in autumn and winter, PM2.5 value often exceeds the standard [13]. Therefore, it is necessary to study the improvement path and influencing factors of "2+26" urban ecological efficiency.

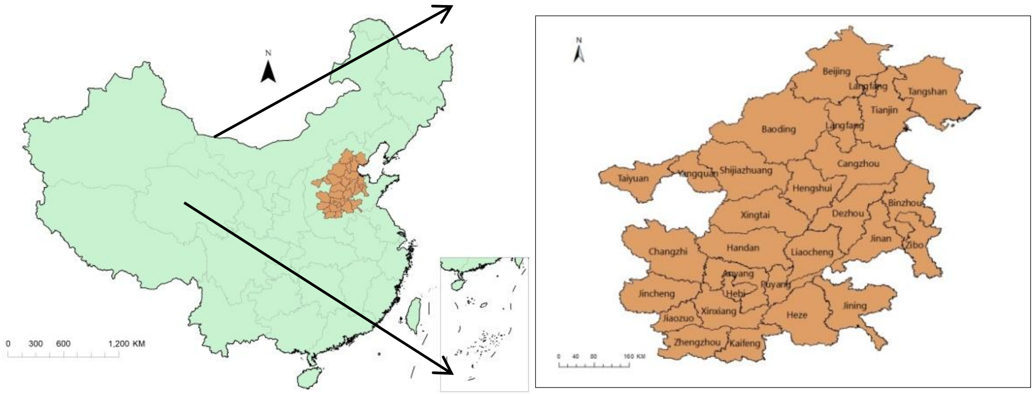

Fig.1. Study area"2+26" cities

3.2. Super-efficiency DEA-Malmquist Model

There are many methods to measure urban ecological efficiency, such as multiple index method, factor analysis method, stochastic frontier analysis method, etc. These measurement methods have a certain reference effect on revealing the relationship between urban ecological efficiency and resource environment, but the research on ecological efficiency only covers certain aspects of ecological efficiency. The multi-index analysis method is relatively subjective and random in the setting of index weights; factor analysis does not consider resource consumption and environmental impact in the evaluation process; stochastic frontier analysis needs to consider the influence of the dimensions of the index. But super-efficiency DEA [31] method can compare and analyze multiple decision-making units on the same frontier of production. In addition, the super-efficiency DEA model can also describe the dynamic change of the efficiency value of the decision-making unit in a continuous period of time, which helps to understand the cause of the efficiency change. The mathematical expression is as follows:

$$
\begin{aligned}
&\mathrm{Min}\,\theta \\
&s.t.\begin{cases}
\sum_{\mathrm{i}=1,\, j\neq i}^{n} A_j\lambda_j + S^- = \theta X_0 \\
\sum_{\mathrm{i}=1,\, j\neq i}^{n} Y_j\lambda_j - S^+ = Y_0 \\
\lambda_j \geq 0,\, j = 1, 2..., k-1, k, ..., n \\
S^- \geq 0, S^+ \geq 0
\end{cases}
\end{aligned}
\tag{1}
$$

θ represents ecological efficiency value of "2+26" city, X is input variable, Y is output variable, λ is combined ratio in the effective decision unit. This can be used to judge the scale of the decision unit($\Sigma\lambda<1$, $\Sigma\lambda=1$, $\Sigma\lambda>1$ represents increasing, constant, and decreasing returns to scale); S- and S+ are relaxation variables, which represent input excess and output deficit. When $\theta\geq1$, if S−≥0 and S+ ≥0, it means that input and output of the decision unit have achieved the optimal efficiency; When $\theta<1$, if S− ≠ 0 or S+ ≠ 0, it means that decision unit is not optimal, there is room for improvement.

The measurement results of super-efficiency DEA model are static. Malmquist index overcomes the shortcomings of current DEA model measurement results that cannot be compared across periods, and achieves a dynamic comparison of urban ecological efficiency.

Malmquist model is built on the basis of super-efficient DEA. The formula is as follows:

$$MI^{t,t+1} = \left[\frac{E^t\left(x^{t+1}, y^{t+1}\right)}{E^t\left(x^t, y^t\right)} \frac{E^{t+1}\left(x^{t+1}, y^{t+1}\right)}{E^{t+1}\left(x^t, y^t\right)} \right]^{1/2} \tag{2}$$

Malmquist index can be decomposed into technical progress (TC) and comprehensive technical efficiency (EC), and comprehensive technical efficiency can be decomposed into pure technical efficiency (PE) and scale efficiency (SE). The expression is as follows:

$$MI^{t,t+1} = EC^{t,t+1} \times TC^{t,t+1} \tag{3}$$

$$EC^{t,t+1} = \frac{E^{t+1}\left(x^{t+1}, y^{t+1}\right)}{E^t\left(x^t, y^t\right)} = \text{Pech} \times \text{Sech} \tag{4}$$

$$TC^{t,t+1} = \left[\frac{E^t\left(x^t, y^t\right)}{E^{t+1}\left(x^t, y^t\right)} \frac{E^t\left(x^{t+1}, y^{t+1}\right)}{E^{t+1}\left(x^{t+1}, y^{t+1}\right)} \right]^{1/2} \tag{5}$$

The value of the Malmquist index and its components can be greater than 1, equal to 1 or less than 1. These values respectively represent productivity growth, stagnation, or decline between period *t* and period *t+1*. Among them, comprehensive technical efficiency measures the impact of efficiency changes on productivity between two time periods, pure technical efficiency indicates the impact of changes in production management level on productivity, and scale efficiency indicates the efficiency changes caused by changes in scale returns; technological progress measures two Technical changes between time periods.

3.3. Regression Model

The panel data selected by this research is a measure of the influencing factors of "2+26" cities from 2010 to 2018. The Hausman statistical test results are used to determine whether to build a random effect model or a fixed-effect model. The basic measurement model which can be described as:

$$Y = \alpha_0 + \alpha_1 \left(IND\right)_{it} + \alpha_2 \left(FDI\right)_{it} + \alpha_3 \left(URB\right)_{it} + \alpha_4 \left(ER\right)_{it} + \varepsilon \tag{6}$$

In order to eliminate possible errors between variables, enhance the stability of panel data. All variables were logarithmically processed, and the final regression model was constructed as follows:

$$\ln Y = \alpha_0 + \alpha_1 \ln\left(IND\right)_{it} + \alpha_2 \ln\left(FDI\right)_{it} + \alpha_3 \ln\left(URB\right)_{it} + \alpha_4 \ln\left(ER\right)_{it} + \varepsilon \tag{7}$$

Y represents urban ecological efficiency, α_0 represents a constant term, *IND*, *FDI*, *URB* and *ER* represents four independent variables, α_1, α_2, α_3 and α_4 are regression coefficients of the respective variables. *i* represent city, *i*=1,2,…,28. *t* represent time, t=2009,2010,…,2017. ε is residual value.

3.4. Data Sources

The input and output indicators of the super-efficiency DEA-Malmquist model refer to the processing method of Wang [32]. This study selects the actual GDP of each city as the output variable. Wastewater, exhaust gas, and solid waste emissions as environmental input variables. Water resources, power consumption, and land resources were used as resource input variables. Human input and fixed asset input as variables of social input (see Table 1).The research sample is panel data from "2+26" cities. The original data of the indicators come from the 2010-2018 China City Statistical Yearbooks, China Energy Statistics Yearbook, China Environmental Statistics Yearbook, statistical yearbooks of various cities, and EPS databases.

Table 1 Evaluation index system of urban ecological efficiency

Index	Category	Specific indicator composition	Content
Input index	Environmental input	Wastewater discharge	Industrial wastewater discharge (10000 t)
		Exhaust emission	Industrial sulfur dioxide emissions (t)
			Industrial smoke (powder) dust emissions (t)
		Solid waste discharge	Untreated rate of general industrial solid waste (%)
	Resource consumption	Water resources consumption	City water consumption (10000 t)
		Power consumption	Electricity consumption of the whole society (10000 KWh)
		Land resource consumption	Urban construction land area (KM^2)
	Social investment	Manpower inputs	Unit employees at the end of the year (10000 persons)
		Fixed assets investment	Investment in fixed assets (10000 Yuan)
Output index		Total economic development	Regional GDP(10000 Yuan)

4. Results and Discussion

4.1 Characteristics of Static Changes in Urban Ecological Efficiency

Based on super-efficiency DEA model, we measured ecological efficiency of the "2+26" cities from 2010 to 2018. From a time perspective, the eco-efficiency of

"2+26" cities is relatively stable, showing an upward trend of fluctuations. The urban eco-efficiency value was 0.828 in 2010 and increased to 1.019 in 2018 (See Figure 2). Urban ecological efficiency of Beijing, Tianjin, Langfang, and Heze increased by more than 50%; the urban ecological efficiency of Hengshui, Yangquan, and Hebi remained unchanged; the urban ecological efficiency of Changzhi, Jining, Dezhou, Liaocheng, Binzhou, and Puyang showed a downward trend; the eco-efficiency of other cities has improved to varying degrees (See Table 2). The main reason is the continuous advancement of the Beijing-Tianjin-Hebei integration strategy and the continuous absorption of foreign capital, high-tech talents and other economic development factors.

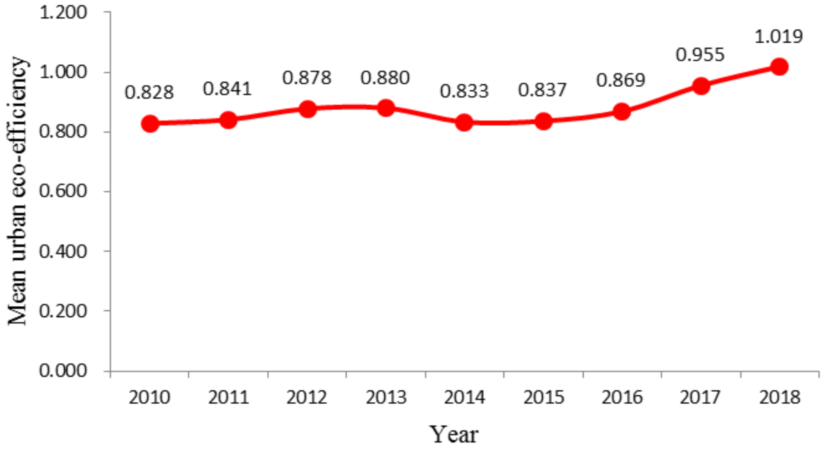

Fig.2. Average urban ecological efficiency from 2010 to 2018

Table 2 Eco-efficiency statistics of "2+26" cities from 2010 to 2018

	Beijing	**Tianjin**	**Shijiazhuang**	**Tangshan**	**Handan**	**Xingtai**	**Baoding**
2010	0.761	0.728	0.701	0.827	0.808	0.657	0.650
2013	0.843	0.945	0.966	1.018	0.766	0.683	0.897
2016	0.966	0.992	0.886	1.002	0.704	0.744	0.911
2018	1.532	1.175	0.903	1.151	0.871	0.834	0.774
	Cangzhou	Langfang	Hengshui	Taiyuan	Yangquan	Changzhi	Jincheng
2010	1.075	0.883	1.000	0.632	1.000	1.049	1.000
2013	1.027	0.885	1.000	0.608	0.884	0.662	0.927
2016	1.356	1.312	1.000	0.662	1.000	0.928	0.982
2018	1.457	2.158	1.000	0.751	1.000	0.751	1.275
	Jinan	Zibo	Jining	Dezhou	Liaocheng	Binzhou	Heze
2010	0.751	0.887	0.889	1.043	1.058	0.851	0.787
2013	0.887	0.798	0.887	1.049	0.922	0.863	1.002
2016	0.940	0.838	1.058	0.922	1.060	0.771	1.009
2018	1.043	0.899	0.884	1.026	1.021	0.819	1.231
	Zhengzhou	Kaifeng	Anyang	Hebi	Xinxiang	Jiaozuo	Puyang
2010	0.646	0.759	0.614	1.000	0.479	0.657	1.007
2013	0.718	0.735	0.680	0.831	0.573	0.637	0.642
2016	0.820	1.231	0.823	1.329	1.130	0.635	0.738
2018	0.880	1.000	0.889	1.000	0.683	0.718	0.804

From the perspective of spatial distribution (See Figure 3), urban ecological efficiency shows a trend of gradual increase from southwest to northeast. Cities with high eco-efficiency are mainly distributed in Beijing, Tianjin and Hebei Province (Langfang, Tangshan, etc.); cities with low eco-efficiency are mainly distributed in Shanxi Province (Taiyuan, Changzhi, etc.) and Henan Province (Jiaozuo, Xinxiang, etc.). In 2018, the "step-like" characteristics of the spatial distribution of urban ecological efficiency were more obvious, and these cities showed the "block-like" distribution characteristics. The main reason is that the level of economic development varies greatly among cities, the allocation of resources is not coordinated, and the factors of production are uneven.

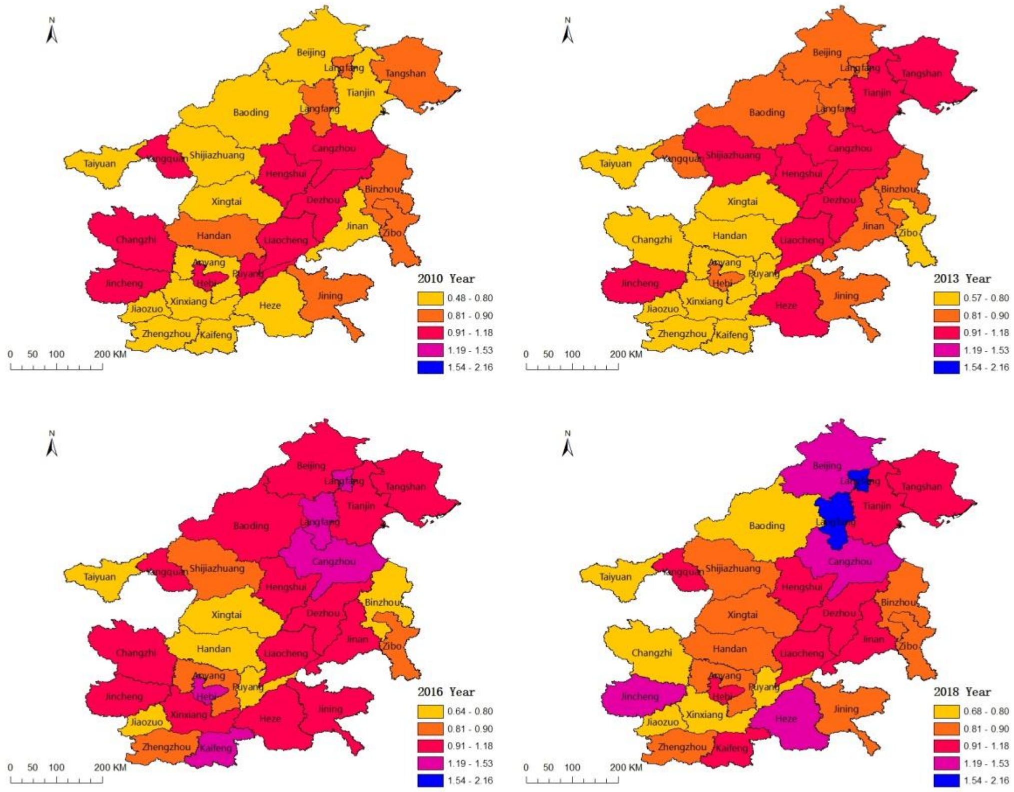

Fig.3. Changes in urban ecological efficiency from 2010 to 2018

4.2. Dynamic Characteristics of Urban Ecological Efficiency

4.2.1 Analysis of the overall changes in the "2+26" urban ecological efficiency

As shown in Figure 4, from 2010 to 2018, the average rate of change of urban ecological efficiency was 1.014, an annual increase of 1.4%. The overall ecological efficiency of "2+26" cities has improved, mainly because of technological progress. This shows that the development of the Beijing-Tianjin-Hebei region and its surrounding areas is still in the low-to-medium stage, relying only on technological progress in the region, and not taking full advantage of the impact of technological efficiency.

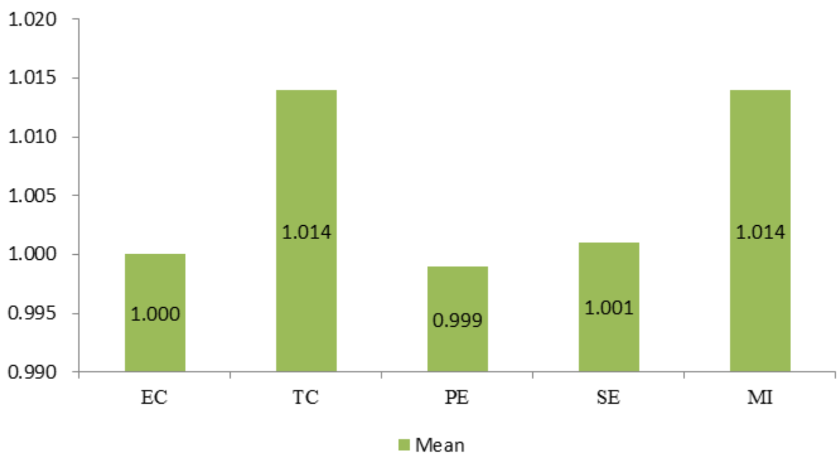

Fig.4. Mean Ecological Efficiency of "2 + 26" Cities

4.2.2 Time series analysis of "2+26" urban ecological efficiency

We calculated the eco-efficiency value of "2+26" cities from 2010 to 2018 and the results are shown in Table 3. The *MI* values in 2009, 2014 and 2017 were less than 1, while the *MI* values in the remaining years were greater than 1. This shows that the ecological efficiency of the city has been relatively stable in the past ten years, showing a fluctuating growth trend.

Table 3 Calculation and Decomposition of Ecological Efficiency in "2 + 26" Cities

Year	EC	TC	PE	SE	MI
2009~2010	1.001	0.933	1.008	0.993	0.934
2010~2011	1.005	1.029	1.003	1.003	1.035
2011~2012	0.992	1.078	0.991	1.001	1.070
2012~2013	1.012	1.006	0.978	1.034	1.017
2013~2014	0.999	1.045	1.013	0.986	1.044
2014~2015	0.972	1.018	0.980	0.992	0.989
2015~2016	0.977	1.063	0.993	0.984	1.038
2016~2017	1.039	1.032	1.034	1.005	1.071
2017~2018	1.002	0.930	0.998	1.003	0.931

As shown in Figure 5, ecological efficiency index of the "2+26" city shows the characteristics of two rising peaks and one falling valley. Risings peaks appeared in 2011~2012 (1.07) and 2016~2017 (1.071), falling valley appeared in 2014~2015 (0.989). We also found that the trend of the *TE* value is basically consistent with the trend of *MI* value. This further verifies that the main reason for the change in the ecological efficiency of the "2+26" city is the impact of technological progress.

From 2009 to 2012, urban ecological efficiency index continued to rise, from 0.934 to 1.07. This is closely related to the 2008 international financial crisis. Affected by the international financial crisis, the ecological efficiency of "2+26" cities has experienced a trough. After the financial crisis, the Chinese economy began to recover, and the urban ecological efficiency index began to rise continuously. During this period, the technical efficiency fluctuated slightly, and the technical change increased from 0.933 to 1.078.

From 2012 to 2014, urban eco-efficiency index still showed an increasing trend, but the growth rate decreased, and the average growth rate was 3.05%. Although technological progress has been improved from 2013 to 2014; technical efficiency has dropped significantly. Therefore, the growth rate of the *MI* value has decreased, which is related to the economic development model of "2+26" cities in the middle and low levels. From 2014 to 2015, due to the influence of government laws and regulations, urban ecological efficiency decreased slightly.

From 2015 to 2017, ecological efficiency index of "2+26" cities began to rise, and the growth rate gradually accelerated. At this stage, the urban ecological efficiency is influenced by both technological progress and technological efficiency, so the *MI* value grows rapidly. The reason for this phenomenon may be that the "2+26" city became a national strategy in 2014. The government began to focus on tapping the technical efficiency of Beijing-Tianjin-Hebei and surrounding areas, so as to enhance the regional competitiveness and comprehensive strength, and achieve rapid economic development.

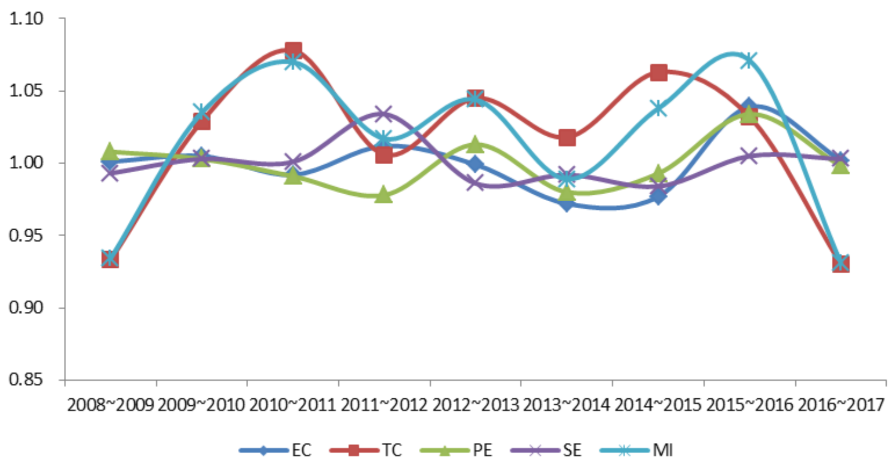

Fig.5.Decomposition indicators and trends of "2 + 26" urban ecological efficiency each year

4.2.3 Analysis of the spatial difference of "2+26" urban ecological efficiency

Calculate the urban ecological efficiency of "2+26" cities from 2010 to 2018 (See Table 4). According to Table 4, Xingtai, Baoding, Changzhi, Jincheng, Zibo, Jining, Liaocheng, Binzhou, Kaifeng, Xinxiang, and Puyang of eco-efficiency index less than 1. The change rates of Xingtai, Zibo, Binzhou, Kaifeng, and Xinxiang are less than 1%. The ecological efficiency of other cities is greater than 1.

Table 4 "2 + 26" urban ecological efficiency index and its decomposition mean value from 2010 to 2018

	Beijing	**Tianjin**	**Shijiazhuang**	**Tangshan**	**Handan**	**Xingtai**	**Baoding**
EC	1.000	1.000	1.003	1.000	0.978	1.006	0.996
TC	1.113	1.080	1.048	1.043	1.053	0.993	0.955
PE	1.000	1.000	0.990	1.000	0.985	1.005	0.992
SE	1.000	1.000	1.013	1.000	0.993	1.001	1.003
MI	1.113	1.080	1.051	1.043	1.030	0.999	0.950
	Cangzhou	Langfang	Hengshui	Taiyuan	Yangquan	Changzhi	Jincheng
EC	1.000	1.000	1.000	0.986	0.998	0.984	0.987
TC	1.001	1.013	1.004	1.044	1.102	0.959	0.957
PE	1.000	1.000	1.000	0.984	1.000	1.000	1.000
SE	1.000	1.000	1.000	1.002	0.984	0.984	0.987
MI	1.001	1.013	1.004	1.029	1.100	0.944	0.945
	Jinan	Zibo	Jining	Dezhou	Liaocheng	Binzhou	Heze
EC	1.000	0.988	0.994	1.000	1.000	0.986	1.015
TC	1.047	1.010	0.975	1.002	0.964	1.012	1.001
PE	1.000	0.989	0.997	1.000	1.000	0.987	1.014
SE	1.000	0.999	0.998	1.000	1.000	0.999	1.001
MI	1.047	0.998	0.970	1.002	0.964	0.998	1.016
	Zhengzhou	Kaifeng	Anyang	Hebi	Xinxiang	Jiaozuo	Puyang
EC	1.001	0.986	1.013	1.021	1.027	0.997	1.022
TC	1.037	1.008	1.051	0.989	0.967	1.024	0.953
PE	1.004	1.000	1.022	1.000	1.030	0.992	1.000
SE	0.997	0.986	0.992	1.021	0.997	1.006	1.022
MI	1.038	0.994	1.065	1.010	0.993	1.021	0.974

We ranked the *MI* values of the "2+26" cities (see Table 5) and found that *MI* value ranked first in Beijing (1.113) and lowest in Changzhi (0.944). Urban ecological efficiency value of Beijing is 16.9 percentage points higher than that of Changzhi City, and the gap is relatively large. Tianjin's urban eco-efficiency value ranks third with 1.08, which is relatively high in the ranking of these 28 cities. This shows that there is a certain gap between the urban ecological efficiency of the other four provinces and that of Beijing and Tianjin. We also found that the order of *MI* value ranking and *TC* value ranking of the "2+26" cities are roughly the same. It is further confirmed that the ecological efficiency of the "2+26" city is greatly affected by technological changes. For the lower ranking cities, the phenomenon of double reduction of *TC* value and *EC* value has occurred, resulting in the average ecological efficiency of the entire city being much lower than other cities. This type of city is the focus of attention in the future development process, and it has a huge room for improvement.

The top three cities with *EC* values are Xinxiang City (1.027), Puyang City (1.022), and Hebi City (1.021), which are 4.9 percentage points higher than the lowest-ranked Handan City (0.978). Although *EC* value of Xinxiang and Puyang ranked higher, *MI* value ranked lower. The reason is that the technical change indicators (0.967 and 0.953 respectively) of these two cities are relatively poor. This shows that Xinxiang City and Puyang City have neglected the role of technological progress, have not updated the technology in a timely manner, and still stay at a lower technological level for production.

Table 5 "2+26" urban ecological efficiency index calculation and its decomposition mean ranking

City name	**EC**	**Ranking**	**TC**	**Ranking**	**MI**	**Ranking**
Beijing	1.000	9	1.113	1	1.113	1
Yangquan	0.998	18	1.102	2	1.100	2
Tianjin	1.000	10	1.080	3	1.080	3
Anyang	1.013	5	1.051	5	1.065	4
Shijiazhuang	1.003	7	1.048	6	1.051	5
Jinan	1.000	11	1.047	7	1.047	6
Tangshan	1.000	12	1.043	9	1.043	7
Zhengzhou	1.001	8	1.037	10	1.038	8
Handan	0.978	28	1.053	4	1.030	9
Taiyuan	0.986	24	1.044	8	1.029	10
Jiaozuo	0.997	19	1.024	11	1.021	11
Heze	1.015	4	1.001	18	1.016	12
Langfang	1.000	13	1.013	12	1.013	13
Hebi	1.021	3	0.989	21	1.010	14
Hengshui	1.000	14	1.004	16	1.004	15
Dezhou	1.000	15	1.002	17	1.002	16
Cangzhou	1.000	16	1.001	19	1.001	17

Xingtai	1.006	6	0.993	20	0.999	18
Binzhou	0.986	25	1.012	13	0.998	20
Zibo	0.988	22	1.010	14	0.998	19
Kaifeng	0.986	26	1.008	15	0.994	21
Xinxiang	1.027	1	0.967	23	0.993	22
Puyang	1.022	2	0.953	28	0.974	23
Jining	0.994	21	0.975	22	0.970	24
Liaocheng	1.000	17	0.964	24	0.964	25
Baoding	0.996	20	0.955	27	0.950	26
Jincheng	0.987	23	0.957	26	0.945	27
Changzhi	0.984	27	0.959	25	0.944	28

4.3. Analysis of Influencing Factors of Urban Ecological Efficiency

For the data used in the panel data model, based on the principles of data availability, practicability, and completeness, we have borrowed most scholars' selection methods for influencing factors of urban ecological efficiency and combined with the reality of this article. This study selected four factors such as regional industrial structure (IND), foreign direct investment (FDI), urbanization level (URB) and environmental governance level (ER) as external factors. Industrial structure (IND) is expressed as the proportion of the output value of the secondary industry to GDP. Foreign direct investment (FDI) is expressed by the direct investment of foreign investors in the region. Urbanization level (URB) is expressed as the proportion of urban population to total population. In order to comprehensively measure the impact of environmental governance (ER) on urban ecological efficiency, this study selected domestic waste treatment rate, industrial sulfur dioxide removal rate, industrial smoke (dust) removal rate, industrial solid waste comprehensive utilization rate, and domestic sewage treatment rate. Five indicators, and use the entropy method to calculate the level of environmental governance (see table 6). The specific steps of entropy method to calculate the level of environmental regulation are as follows: (1) Data standardization: $x'_{kij}=\frac{x_{kij}}{x_{\max}}$, $x'_{kij}=\frac{x_{\min}}{x_{kij}}$, If the indicator is a positive indicator, choose the former; if the indicator is a negative indicator, choose the latter; (2) Calculate the proportion of the *j* index in the *i* year of the *k* city: $y_{kij}=\frac{x'_{kij}}{\sum_{k=1}^{r}\sum_{i=1}^{m}x'_{kij}}$; (3) Calculate the information entropy of the *j* indicator: $e_j=-k\sum_{k=1}^{r}\sum_{i=1}^{m}\left(y_{kij}\times\ln y_{kij}\right)$, $k=\frac{1}{\ln(rm)}$; (4) Calculate information entropy redundancy: $d_j=1-e_j$; (5) Calculate indicator weight: $w_j=\frac{d_j}{\sum_{j=1}^{m}d_j}$; (6) Calculate individual indicator scores: $F_j=\sum_{j=1}^{n}\left(w_j\times x'_{kij}\right)$.

Table 6 Influencing factor index

Index	Content
Industrial structure	Output value of secondary industry/total output value (%)
Foreign direct investment	Total foreign investment/GDP (%)
Urbanization level	Urban population/total population (%)
Environmental governance level	Industrial sulfur dioxide removal rate (%)
	Industrial smoke (dust) dust removal rate (%)
	Domestic sewage treatment rate (%)
	Harmless treatment rate of domestic garbage (%)
	Comprehensive utilization rate of industrial solid waste (%)

Based on the super-efficient DEA-Malmquist index method, the static and dynamic characteristics and evolution trends of the "2+26" urban ecological efficiency are analyzed. In order to further explore the influence mechanism of related influencing factors on urban ecological efficiency, a regression model is adopted in this paper. The result of the Hausman test negates the random effect hypothesis. We use a fixed effect regression model, and the results are shown in Table 7:

Table 7 Regression results of influencing factors

	Regression coefficient	t-value
LnIND	-0.466 **	-2.35
LnFDI	-0.005	-0.22
LnURB	-0.283**	-1.85
LnER	0.118***	1.70
Sigma_u	0.2938	
Sigma_e	0.1328	
rho	0.8304	

Note:*, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

Industrial structure (IND) has a significant inhibitory effect on the improvement of the ecological efficiency of the “2+26” city. In other words, the increase in the output value of the secondary industry has a negative impact on the improvement of urban ecological efficiency. This may be because the secondary industry has always been the most important industry in the national economy, and the demand for energy is huge. Therefore, in the process of developing the secondary industry, the government should accelerate the elimination of backward production capacity, and actively cultivate and develop new industries with high technological content and good economic benefits. In addition, the local government should also optimize the industrial structure, and gradually shift from heavy industry-based industries to service industries and other tertiary industry-based industries.

Foreign direct investment (FDI) has a small impact on the ecological efficiency of the “2+26” city and has not passed the significance test. On the one hand, it is because foreign-invested industries account for a small proportion of the overall industry and have a limited impact on cities. On the other hand, although foreign-invested industries have advanced management models and certain advantages in improving urban ecological efficiency, they are often accompanied by high energy consumption and high pollution projects.

Urbanization level (URB) has a significant inhibitory effect on the improvement of the ecological efficiency of the “2+26” city. This is because the rapid progress of urbanization in the Beijing-Tianjin-Hebei economic circle in recent years has prompted a large number of population and economic activities to gather. With the rapid development of industrialization, increased energy demand, accelerated consumption of resources and energy, and increased environmental pollution, which has reduced urban ecological efficiency.

Environmental governance level (ER) plays a role in promoting the ecological efficiency of the “2+26” city. In other words, the increase in environmental governance level has a positive impact on improving urban ecological efficiency. Mainly because China has begun to attach importance to environmental pollution in recent years, Beijing, Tianjin and Hebei and surrounding areas, as the "severe disaster areas" of environmental pollution, have increased their access to environmental protection technology and pollution control, which has fundamentally improved the urban ecological efficiency.

5. Conclusions and Suggestions

We conclude through the above empirical analysis: 1) The ecological efficiency of “2+26” cities have been increasing for the past ten years, with an average annual increase of 1.4%. The ecological efficiency value of most cities in 2018 has been greatly improved compared to 2010. Beijing, Tianjin, Langfang, and Heze increased by more than 50 %. 2) The urban ecological efficiency shows a trend of gradually increasing from the southwest to the northeast, and form the distribution characteristics of “stepped” and “blocked”. 3)From 2010 to 2018, the rankings of the ecological efficiency index of the “2+26” cities are as follows: Beijing, Yangquan, Tianjin, Anyang, Shijiazhuang, Jinan, Tangshan, Zhengzhou, Handan, Taiyuan, Jiaozuo, Heze, Langfang, Hebi, Hengshui, Texas, Cangzhou, Xingtai, Binzhou, Zibo, Kaifeng, Xinxiang, Puyang, Jining, Liaocheng, Baoding, Jinyang, Changzhi. 4) The increase in the output value of the secondary industry and the increase in the level of urbanization will lead to a decline in urban ecological efficiency. The improvement of environmental governance level will promote the improvement of urban ecological efficiency. Foreign direct investment has little effect on urban ecological efficiency.

Based on the above conclusions, we find that “2+26” cities are distributed in different stages of industrialization. Beijing, as a high-end technology innovation center, is in a post-industrial period. Provincial capitals such as Shijiazhuang, Zhengzhou, and Jinan have formed their own unique scales in terms of industrial manufacturing and technology research. They are in the late stage of industrialization. Other cities remain in the middle of industrialization. The root cause of this phenomenon is the unbalanced economic development of “2+26” cities. In order to comprehensively improve the ecological efficiency of the “2+26” city, we made a few suggestions to the local government. (1) The government should formulate a joint action plan, and only by improving the technical level of a single city cannot achieve the long-term improvement of urban ecological efficiency. Each city should further strengthen technological innovation and coordinated regional development. (2) Traditional enterprises focus on high-input, high-consumption, and low-tech extensive production, and cannot really take advantage of the industrial advantages of ecological civilization construction. The government should encourage the development of an ecological economy, increase the technical investment in the secondary and tertiary industries, adjust the industrial structure, and accelerate the transformation of the economic growth pattern. For example, Baoding, Kaifeng, and Handan should give full play to the advantages of historical cities, explore the cultural heritage of the city in depth, and focus on the development of the cultural tourism industry. Jinan, Tianjin, Zhengzhou, and other cities should focus on the development of the leisure tourism industry. (3) The establishment of the Xiongan New District has brought opportunities for the development of “2+26” cities and its construction height has risen to the national strategic level. Beijing-Tianjin-Hebei and surrounding cities should take the opportunity to focus on introducing new-generation information technology and Internet industries, new materials, energy-saving and environmental protection industries, and other high-tech industries.

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