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Original Research Paper

The Evaluation and Spatial Correlation Analysis of Chinese Industrial Environmental Efficiency

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ABSTRACT

Since the reform and opening up, with the progress of science and technology, China's economy developed rapidly, but the attendant environmental problems are becoming increasingly serious, environmental efficiency evaluation has been paid more and more attention in China. This paper used the SBM model to measure the environmental efficiency of the mainland of China's 30 provinces, autonomous regions and municipalities from 2000 to 2010 and analysed the overall situation of the industrial environment efficiency during the 10th and the 11th five-year plan in China. The results show that the overall industrial environmental efficiency of China is low, but it shows a rising trend, and there is a big gap between provinces and regions. At the same time, this paper used the Moran's I index to analyse the spatial correlation of the environmental efficiency. The results show that the industrial environmental efficiency agglomerate in the whole country and it has an obvious spatial autocorrelation. High-high environmental efficiency agglomeration area most distribute in the eastern zone, and low-low environmental efficiency agglomeration area is mainly distributed in the western zone, the location distribution showed significant differences.

INTRODUCTION

Nowadays, as the industry continues to develop, and the energy continues to consume, the environmental issues have become the focus of attention gradually. The shortage of resources and the fragile ecological environment has become a major problem which restricts the development of China. So how to effectively reduce pollution emissions and improve environmental efficiency, need to be resolved urgently in China. Environmental efficiency is an important indicator of the quality of the environment, as well as an important means to measure the status quo of industrial environment. Environmental efficiency evaluation is not only concerned with the economic value of the production process, but it also evaluates the impact of the production process on the environment, that is to say, environmental efficiency evaluation takes account of the economic and environmental effect (Peng Jun 2015).

The most widely used evaluation method is data envelopment analysis (DEA) method, which is a kind of non-parametric statistical method proposed by the American operational research experts, A. Charnes and W.W.Cooper on the basis of the concept of relative efficiency in 1978 (Charnes et al. 1978). Because in the actual industrial production activities, along with the desirable outputs or say "good" outputs, all kinds of industrial pollution (such as waste gas, wastewater and industrial solid wastes), which is also called undesirable outputs, or "bad" outputs is also increasing (Tu Zheng-ge et al. 2011). Therefore, this paper used SBM model which adds undesirable outputs (also known as SBM-Undesirable model) to measure the industrial environmental efficiency of the mainland of China's 30 provinces, autonomous regions and municipalities during the 10th and the 11th five-year plan in China and analyse the spatial correlation of the environmental efficiency.

COMPUTATIONAL MODELS AND RESEARCH METHODS

SBM model: DEA is a kind of analysis method that can evaluate the similarity decision unit effectively. The classical DEA model are CCR, BCC and ST model. CCR is one of the most widely used models, which is a kind of efficiency model that under the assumption that, the returns to scale of the decision making unit is unchanged. It is often referred to as a CCR model because it was proposed by Charnes, Cooper and Rhodes jointly (Li Jing 2008).

Assuming that there are n decision making units (DMU), the CCR model can be expressed as follows:

$$\min \theta$$

$$st.\begin{cases}\sum_{k=1}^{n} X\lambda_k \le \theta X_o \\ \sum_{k=1}^{n} Y\lambda_k \ge Y_o \\ \lambda_k \ge 0, k=1,...,n\end{cases} \quad ...(1)$$

Among them, X and Y express input and output vector, X_0 and Y_0 express a particular DMU_k's input and output value; λ_k is weight vector, θ is DMU_{k0}'s efficiency value. The decision making unit is effective when θ=1. In order to take into account the relationship between the input, output and pollution, Tone (2004) proposed the SBM model with undesirable output (Tone 2004). Assuming that there are n decision making units, for each DMU, define $X = (X_1,X_2,\ldots X_m)$ as a set of input resources and $Y = (Y_1,Y_2,\ldots Y_n)$ as a set of desirable output and $Z = (Z_1,Z_2,\ldots Z_t)$ as a set of undesirable output in the process of industrial production. Specific model is as follows:

$$\min EE = \frac{1-\frac{1}{m}\sum_{i=1}^{m}\frac{s_{io}^{-}}{x_{io}}}{1+\frac{1}{s+t}\left(\sum_{j=1}^{s}\frac{s_{jo}^{+}}{y_{ko}}+\sum_{j=1}^{t}\frac{s_{jo}^{b}}{z_{jo}}\right)}$$

$$st.\begin{cases} x_o = X\lambda + s^{-} \\ y_o = Y\lambda - s^{+} \\ z_o = Z\lambda + s^{b} \\ \lambda \geq 0, s^{-} \geq 0, s^{+} \geq 0, s^{b} \geq 0 \end{cases} \quad ...(2)$$

Here EE is the industrial environment efficiency. λ is weight vector, s^-, s^+ and s^b are the slack variable of input, desirable output and undesirable output. The index "0" indicates that the decision unit is evaluated. When and only when EE=1 that the corresponding DMU_0 is effective, and the value of the slack variable is 0.

Moran's I index: Spatial correlation analysis mainly establishes a relationship between spatial data through spatial location and describe the spatial distribution law and then find a spatial agglomeration or spatial anomaly of some phenomena. Spatial autocorrelation is a spatial statistical method, which shows that whether there is a special space form of a surface phenomenon (Liang Yan-ping et al. 2003).

Since the spatial autocorrelation is divided into the global auto correlation and the local auto correlation, the corresponding indexes are also divided into global and local indexes. Global index is used for detecting the spatial patterns of the entire study area and use a single value to reflect the cross-correlation of the region; local index calculated the degree of correlation of one property of each spatial unit and adjacent unit (Guo Ping-bo et al. 2009). We use the most commonly used indicators of spatial statistics, that is, the Moran's I index to test the spatial correlation of industrial environmental efficiency.

In the spatial correlation analysis, we need to determine the spatial weight matrix. It describes the spatial distribution of the spatial objects. Assuming there are n space units, the spatial weight matrix W is defined as follows. Among them, W_{ij} is the space weight of space unit i and space unit j.

$$W=\begin{bmatrix} w_{11} & w_{12} & \cdots & w_{1n} \\ w_{21} & w_{22} & \cdots & w_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ w_{n1} & w_{n2} & \cdots & w_{nn} \end{bmatrix} \quad ...(3)$$

This paper used the industrial environmental efficiency of each province as a research object. Because each province has the characteristics of adjacent or nonadjacent, this paper used the decision method based on spatial unit of simple adjacency to determine the spatial weight matrix. When the region i and j are adjacent, the spatial weight value of W_{ij} is 1, otherwise it is 0; when $i=j$, W_{ij} is 0. Specific forms are as follows.

$$w_{ij}=\begin{cases} 1, & \text{region } i \text{ is adjcent with region } j \\ 0, & \text{otherwise} \end{cases} \quad ...(4)$$

Global Moran's I index is defined as follows

$$Moran's\ I = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n}W_{ij}(Y_i-\bar{Y})(Y_j-\bar{Y})}{S^2\sum_{i=1}^{n}\sum_{j=1}^{n}W_{ij}} \quad ...(5)$$

Among them, $S^2=\frac{1}{n}\sum_{i=1}^{n}(Y_i-\bar{Y})^2$, $\bar{Y}=\frac{1}{n}\sum_{i=1}^{n}Y_i$, Y_i express the attribute value of region i, n is the total number of regions, W_{ij} is space weight matrix. Moran's I (hereinafter referred to as I) is in the range of -1 to 1. When 0 <I <1, it represents the attribute of the spatial object is spatial positive correlation; when -1<I<0, it represents the attribute of the spatial object is spatial negative correlation; when I=0, there is no correlation between the attribute of the space objects. The absolute value of I indicates the degree of spatial correlation, the greater the spatial correlation is, the greater is the absolute value of I.

Local Moran's I index is defined as follows

$$I_i = \frac{(x_i-\bar{x})}{S^2}\sum_{j=1}^{n}w_{ij}(x_j-\bar{x}) \quad ...(6)$$

When I_i is positive, it indicates that region i has similar spatial concentration (high-high association or low-low association) with the area around i. When I_i is negative, it indicates that region i has dissimilar spatial concentration (high-low association or low-high association) with the area around i.

Moran's I scatter diagram

Moran's I scatter diagram is used to represent the spatial agglomeration degree of the region and the surrounding area, which can clearly describe the spatial correlation of a phenomenon. Moran's I scatter diagram is a two-dimensional graph, consisted of intersected vertical and horizontal axes and the four quadrants represent the spatial relationship between the inspection unit and the neighbouring unit. The first quadrant represents the high-high correlation (HH), which indicates that a region with a high property value whose surrounding area's property value is also high. The second quadrant represents the low-high correlation (LH), which indicates that a region with a low property value whose surrounding area's property value is high. The third quadrant represents the low-low correlation (LL), which indicates that a region with a low property value whose surrounding area's property value is also low. The fourth quadrant represents the high-low correlation (HL), which indicates that a region with a high property value whose surrounding area's property value is low (Lu Feng 2004). Among them, the first quadrant and the third quadrant represents space positive correlation and the second quadrant and the fourth quadrant represents space negative correlation.

EMPIRICAL ANALYSIS

This paper used the panel data of the mainland 30 provinces and autonomous regions and municipalities directly under the central government (hereinafter referred to as the provinces, because the index data of the Tibet autonomous region is consecutive years of absence, the research of this paper is to remove the Tibet autonomous region), during the 10th and the 11th five-year plan in China as sample data to calculate the industrial environmental efficiency and analyse the spatial correlation of the environmental efficiency.

Index system and data source: The evaluation index system of this paper is shown in Table 1.

Among them, the pollution emission (PE) output used "the total discharge of industrial waste water", "the total emission of industrial waste gas", "industrial solid waste generation" as a basic index data and recalculated the result by entropy method. The resulting pollution emission composite index is the index value of undesirable production expenses.

The data source is sorting data of China Environmental Statistics Yearbook, Statistical Yearbook of China's Industrial Economy, China Energy Statistical Yearbook and China Statistical Yearbook.

Calculation results and analysis of industrial environmental efficiency: According to the establishment of the input-output index system, using the model and R2009b MATLAB programming to calculate the industrial environmental efficiency during the 10th and the 11th five-year plan in China, we can get the results which are given in Table 2. And the national industrial environmental efficiency change trend is shown in Fig. 1. The mean value contrast analysis chart of each province is shown in Fig. 2.

According to the ranking of the average industrial environmental efficiency of the provinces during the 10th and the 11th five-year plan, using the industrial environmental efficiency average values plus or minus 0.1 range as a dividing line, we divide the provinces into high environmental efficiency area, medium environment efficiency area and low environment efficiency area. The specific data are shown in Table 3. At the same time, the trend of the average industrial environmental efficiency of the three major regions in our country during the 10th and the 11th five-year plan is shown in Fig. 3. The following conclusions can be obtained from the above.

1. According to Table 2, the industrial environmental efficiency of Shanghai, Jiangsu and Guangdong province are always effective during the period of the 10th and the 11th five-year plan. The industrial environmental efficiency of Tianjin province is always effective during the period of the 11th five-year plan. The industrial environmental efficiency of Shandong province is effective in some years during the period of the 11th five-year plan. The industrial environmental efficiency of our country is overall low and the top three of the average industrial environmental efficiency are Shanghai, Jiangsu and Guangdong province. Among them, the average industrial environmental efficiency of Beijing, Tianjin, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong and Guangdong are higher than the whole country. These provinces and cities are coastal areas so we can say that the environmental efficiency in the coastal area is higher than the inland region.
2. According to Fig. 1, the average industrial environmen-

Table 1: Evaluation index system.

		Index name	Unit
Industrial environmental efficiency evaluation	Input	Average annual balance of fixed assets	Billion yuan
		Total energy consumption	Million tons of standard coal
		Average number of employees	Million
	Desirable output	Gross industrial output value	Billion yuan
	Undesirable output	Pollution emission	

Table 2: The industrial environmental efficiency during the 10th and the 11th five-year plan in China.

Province	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Beijing	0.700	0.716	0.684	0.748	0.824	0.802	0.764	0.778	0.858	0.876
Tianjin	0.754	0.814	0.756	0.940	0.819	1.000	1.000	1.000	1.000	1.000
Hebei	0.331	0.352	0.344	0.379	0.427	0.418	0.442	0.500	0.499	0.470
Shanxi	0.176	0.193	0.201	0.225	0.251	0.234	0.254	0.272	0.265	0.267
InnerMongolia	0.201	0.226	0.229	0.268	0.283	0.289	0.314	0.357	0.427	0.375
Liaoning	0.357	0.364	0.375	0.425	0.460	0.497	0.519	0.562	0.639	0.614
Jilin	0.376	0.407	0.398	0.408	0.408	0.421	0.469	0.490	0.562	0.547
Heilongjiang	0.315	0.320	0.314	0.324	0.391	0.386	0.361	0.394	0.380	0.378
Shanghai	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Jiangsu	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Zhejiang	1.000	1.000	0.711	1.000	0.783	0.790	0.785	0.766	0.744	0.724
Anhui	0.312	0.337	0.320	0.367	0.400	0.419	0.433	0.462	0.511	0.520
Fujian	0.521	0.561	0.571	0.630	0.581	0.586	0.569	0.591	0.589	0.640
Jiangxi	0.283	0.293	0.278	0.335	0.365	0.399	0.452	0.433	0.523	0.576
Shandong	0.602	0.615	0.612	0.649	0.736	0.735	0.762	1.000	1.000	1.000
Henan	0.348	0.357	0.347	0.368	0.413	0.437	0.524	0.538	0.541	0.508
Hubei	0.400	0.412	0.305	0.302	0.327	0.337	0.346	0.400	0.408	0.433
Hunan	0.307	0.324	0.306	0.316	0.364	0.369	0.402	0.434	0.477	0.458
Guangdong	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Guangxi	0.273	0.296	0.273	0.286	0.320	0.339	0.350	0.356	0.387	0.374
Hainan	0.379	0.398	0.413	0.435	0.349	0.385	1.000	0.504	0.490	0.494
Chongqing	0.306	0.338	0.381	0.371	0.331	0.337	0.360	0.361	0.409	0.410
Sichuan	0.274	0.303	0.271	0.290	0.338	0.347	0.377	0.417	0.487	0.429
Guizhou	0.211	0.236	0.211	0.223	0.240	0.239	0.240	0.247	0.255	0.229
Yunnan	0.315	0.324	0.297	0.337	0.345	0.359	0.351	0.351	0.348	0.313
Shanxi	0.284	0.282	0.262	0.263	0.294	0.308	0.355	0.341	0.392	0.376
Gansu	0.276	0.273	0.226	0.249	0.310	0.309	0.339	0.332	0.332	0.304
Qinghai	0.199	0.197	0.176	0.221	0.233	0.241	0.241	0.258	0.248	0.233
Ningxia	0.244	0.224	0.190	0.249	0.244	0.245	0.238	0.242	0.241	0.222
Xinjiang	1.000	0.296	0.269	0.333	0.328	0.348	0.330	0.386	0.319	0.298

tal efficiency of our country showed an increasing trend on the whole, and after a brief decrease in 2003, it has been in a steady rise and reached the highest value 0.544 in the year of 2009. It can be concluded that although the industrial environmental efficiency in various provinces of China is generally low, on the whole it shows a steady upward trend.

3. What we can see from Fig. 2 is that in addition to Zhejiang and the Xinjiang Uygur Autonomous Region, the average industrial environmental efficiency of the remaining 28 provinces is higher in the 11th five-year plan than in the 10th five-year plan. It can be seen that after the implementation of the 11th five-year plan, the industrial environmental efficiency in most provinces of the country has improved.
4. According to Fig. 3, the provinces of high environmental efficiency are distributed in the eastern region, and most of the provinces of the medium environmental efficiency are distributed in the central region, while the provinces of low efficiency are mostly located in the western region. It is can be seen that the environmental efficiency of the eastern region is generally high while the environmental efficiency of the western region is generally low.
5. Fig. 3 reflects that the average environmental efficiency values are showing a growing trend of steady "m" and in 2007 rose to a higher level, then tended to be stable. And the average environmental efficiency of three large areas fluctuates roughly the same with the whole country. The industrial environmental efficiency of the eastern provinces is far ahead, and the central region is after the national level and in the western region it is always in backward position. We can say that there is a big difference in the industrial environmental efficiency between the provinces and regions.

In this paper, we use GeoDa 1.4.6 software to detect the global Moran's I index of the industrial environmental efficiency of the 10th and the 11th five-year plan in the country. The results are shown in Table 4.

Spatial correlation analysis: Previous empirical results reflect that the industrial environmental efficiency of our country has a certain degree of spatial agglomeration phenom-

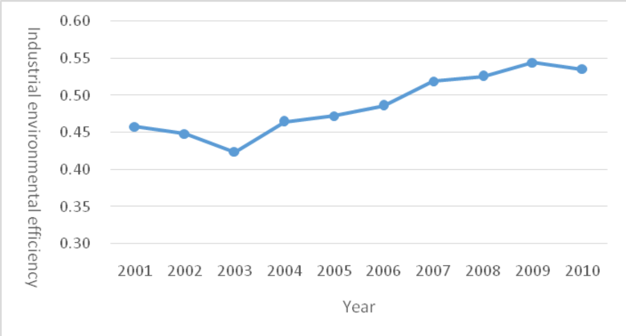

Fig. 1: The industrial environmental efficiency change trend during the 10th and the 11th five-year plan in China.

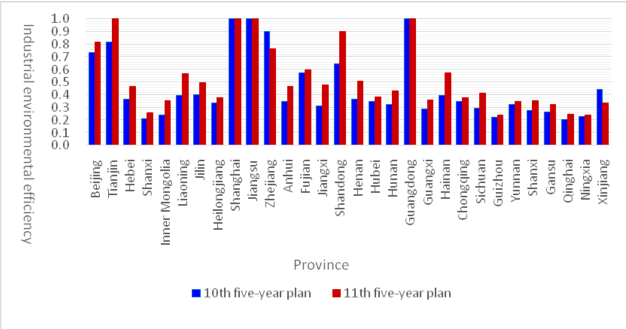

Fig. 2: Industrial environmental efficiency during the 10th and the 11th five-year plan.

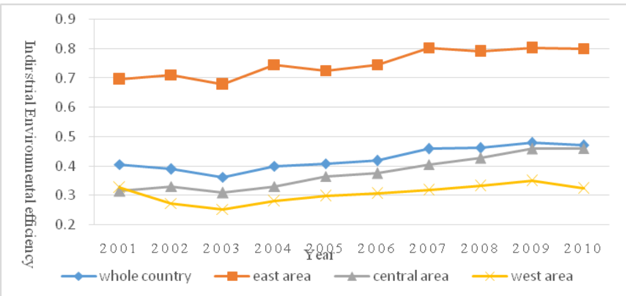

Fig. 3: Trends of industrial environmental efficiency in three major areas.

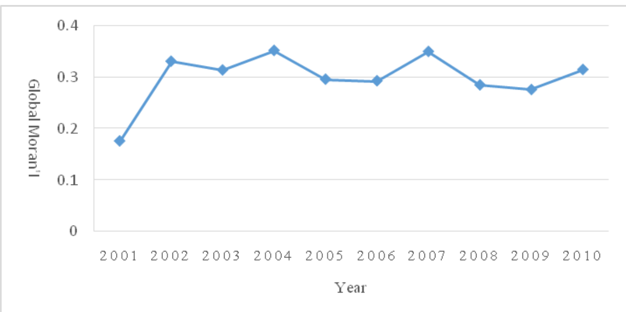

Fig. 4: Trends of global Moran's I of industrial environmental efficiency during the 10th and the 11th five-year plan.

ena, in order to test that the spatial agglomeration is not a random occurrence, but has regularities of distribution, we must test the spatial correlation of the industrial environmental efficiency.

In this paper, we used GeoDa 1.4.6 software to detect the global Moran's I index of the industrial environmental efficiency of the 10th and the 11th five-year plan in the country. The results are shown in Fig. 4.

Global Moran's I index has shown that the global spatial autocorrelation of the environmental efficiency, the use of Moran's I scatter diagram can further analyse the spatial distribution of environmental efficiency in the local situation. 2005 and 2010 s' Moran's I scatter diagram is shown in Fig. 5.

Specific provinces and their spatial association patterns corresponding to the Moran's I scatter diagram is shown in Table 4. In order to display the spatial agglomeration degree more directly, this paper used the GeoDa 1.4.6 to make the Moran's I cluster maps which is corresponding to the Table 4. They are shown in Fig. 6. Among them, 0 expresses meaningless area, 1 expresses high-high correlation zone, 2 expresses low-high correlation zone, 3 expresses low-low correlation zone, 4 expresses high-low correlation zone. The following conclusions can be obtained from the above.

1. We can see from Fig. 4 that the global Moran's I index of the national environmental efficiency has no obvious change trend and it is at a relatively stable level on the whole. But in 2005, 2006 and 2008, 2009 there were two significant decline, indicating that, in this 4 years the space correlation degree of environmental efficiency is overall lower, and the mutual influence of regional environmental efficiency is small, and the spatial agglomeration of environmental efficiency is not obvious.
2. From Fig. 5 and Table 4, we can see the number of provinces in the first and third quadrant in 2005 accounted for 30% and 50% of the total number of provinces in the country and the number of provinces in the first and third quadrant in 2010 accounted for 40% and 40%. The above shows that the environmental efficiency showed obvious "polarization" in the space distribution.
3. From Fig. 6 we can see that provinces which present high-high association distributed in the eastern zone, provinces which presents low-high association mainly concentrated in the central zone, provinces which present low-low association mainly distributed in the western zone. This is consistent with the previous section of this paper's conclusion. But the individual province do not conform to this law of distribution. For example, Liaoning Province is geographically located in the east-

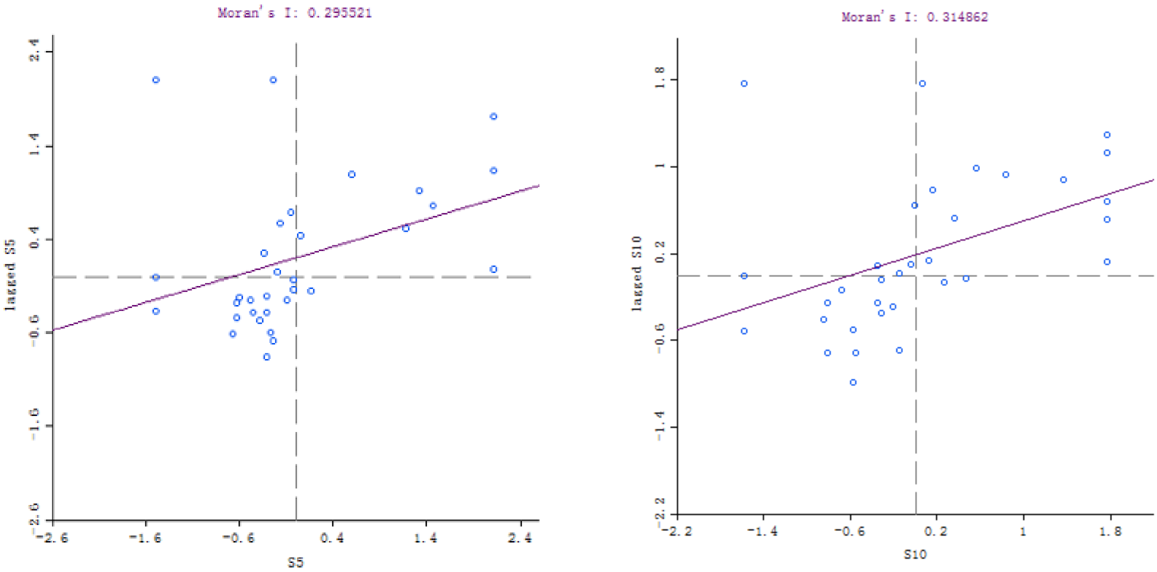

Fig. 5: Moran's I scatter plot of industrial environmental efficiency in 2005 and 2010.

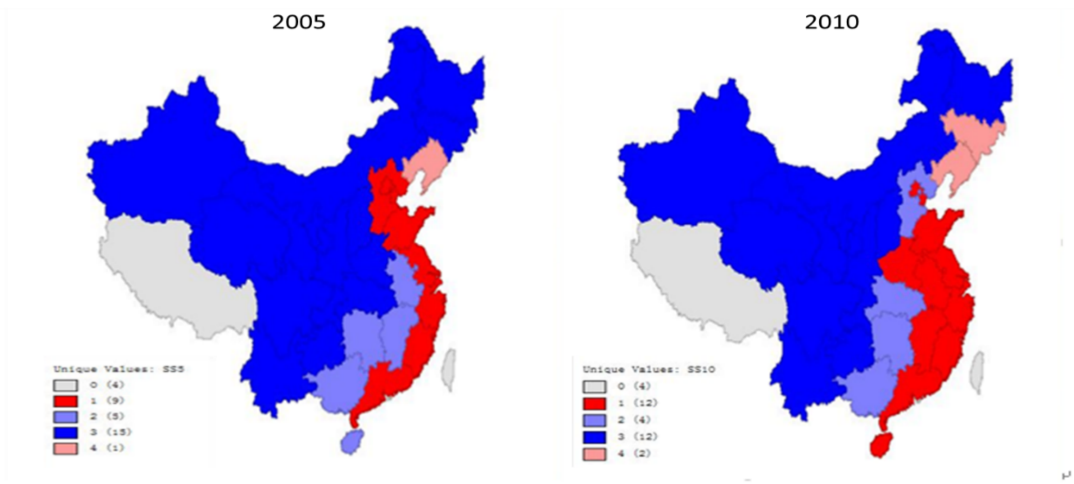

Fig. 6: Moran's I cluster map of industrial environmental efficiency in 2005 and 2010.

ern zone, but its adjacent provinces such as Heilongjiang Province, Jilin Province and Inner Mongolia Autonomous Region, whose industrial environmental efficiency is low, so the spatial association form in Liaoning Province is high-low correlation.

CONCLUSIONS AND RECOMMENDATIONS

This paper used the panel data of the mainland 30 provinces and autonomous regions and municipalities directly under the central government during the 10th and the 11th five-year plan in China and apply the SBM model to estimate the environmental efficiency and used the Moran's I index to analyse the spatial correlation of the environmental efficiency, then get the following conclusions and recommendations.

1. During the period of 10th and 11th five-year plan, the industrial environmental efficiency of most provinces in our country are low, but overall the national industrial environmental efficiency showed a steady upward trend. The industrial environmental efficiency of each province

Table 3: Geographical distribution of industrial environmental efficiency.

Classification	Province
High environmental efficiency area	Beijing, Tianjin, Shanghai, Jiangsu, Zhejiang, Shandong, Guangdong
Medium environment efficiency area	Hebei, Liaoning, Jilin, Anhui, Fujian, Jiangxi, Henan, Hainan, Xinjiang
Low environment efficiency area	Shanxi, Inner Mongolia, Heilongjiang, Hubei, Hunan, Guangxi, Chongqing, Qinghai, Sichuan, Guizhou, Yunnan, Shanxi, Gansu, Ningxia

Table 4: Spatial association of industrial environmental efficiency in 2005 and 2010.

Year	Provinces	Quadrant	Spatial relation
2005	Beijing, Tianjin, Shanghai, Jiangsu, Zhejiang, Shandong, Hebei, Fujian, Guangdong	First Quadrant	High-high correlation
	Anhui, Jiangxi, Hunan, Guangxi, Hainan	Second Quadrant	Low-high correlation
	Henan, Jilin, Heilongjiang, Hubei, Gansu, Guizhou, Shanxi, Shaanxi, Xinjiang, Yunna, Sichuan, Ningxia, Inner Mongolia, Qinghai, Chongqing	Third Quadrant	Low-low correlation
	Liaoning	Fourth Quadrant	High-low correlation
2010	Beijing, Tianjin, Shanghai, Jiangsu, Zhejiang, Shandong, Anhui, Henan, Jiangxi, Fujian, Guangdong, Hainan	First Quadrant	High-high correlation
	Hebei, Hunan, Hubei, Guangxi	Second Quadrant	Low-high correlation
	Shanxi, Inner Mongolia, Heilongjiang, Gansu, Guizhou, Shaanxi, Xinjiang, Yunnan, Qinghai, Chongqing, Ningxia, Sichuan	Third Quadrant	Low-low correlation
	Liaoning, Jilin	Fourth Quadrant	High-low correlation

has a big difference, and the industrial environmental efficiency of provinces of the eastern part is generally higher than the provinces of central and western regions. Therefore, we should formulate different emission reduction policy aiming at different development level regions, in particular, we should make central and western region whose industrial environmental efficiency is low but has a large room for improvement, a key object of energy-saving and emission-reduction.

2. The industrial environmental efficiency of most provinces in 11th five-year plan is higher than in 10th five-year plan. This suggests that in the year launched the energy-saving emission reduction policies, such as the Olympic Games period, the environmental efficiency can be effectively improved, while in the year without the introduction of relevant policies, the environmental efficiency will decline. So the fluctuation of the industrial environmental efficiency has direct correlation with the formulation of the corresponding environmental protection policy. Therefore, the government should take the form of legislation to promote energy-saving emission reduction and to build up a strict energy-saving emission reduction incentive and restraint mechanisms.
3. From the overall perspective, during the period of 10th and 11th five-year plan, the industrial environmental efficiency has a agglomeration phenomenon nationwide and presents an obvious spatial autocorrelation. The high-high environmental efficiency and low-low environmental efficiency agglomeration area showed significant differences in the location distribution. For the high-high environmental efficiency agglomeration area, the government should encourage it to continue to maintain this state. And as mentioned above, the high-low environmental efficiency agglomeration area similar to the Liaoning Province and the surrounding area, it should give full play to its spatial spillover effect and radiation leading role as a core area, and actively improve the environmental efficiency of the adjacent area. For low-low environmental efficiency agglomeration area, the government should intensify the implementation of cleaner production, taking a new road of industrialization of green manufacturing, circular economy and cleaner production, perfect the relevant mechanism and therefore improve the environmental efficiency.

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