Research on the Spatial-temporal Differences and Influencing Factors of Anhui Industrial Environmental Efficiency

Z Yao¹, H S Zhao¹, X Liu², Q Yu¹, H X Zhuang, N Y Shen³
¹School of Economics and Management, Anhui University of Science and Technology, Huai’nan 232001, China
²School of Energy and Security, Anhui University of Science and Technology, Huai’nan 232001, China
³Yangzhou city river management office, Yangzhou, China, 225000
E-mail: yaocvxv328@qq.com

Abstract. In order to improve the efficiency of industrial environment in Anhui Province and promote the coordinated development of industrial production and environmental protection, industrial waste water discharge, air particulate matter discharge and solid waste discharge are regarded as undesirable outputs. The model measures the industrial environmental efficiency of 16 prefecture-level cities in Anhui Province from 2013 to 2018, and fully considers the differences between regions; then, based on the analysis of the total factor productivity of the industrial environment, the impact of industrial environmental efficiency in each province is found factor. Finally, through the construction of the Malmquist index model, the spatial-temporal change trend of industrial environmental efficiency in Anhui Province was analyzed. Studies have shown that there is a clear difference in the efficiency of the industrial environment in Anhui Province. The change trend of TFP and TEC is basically the same. TEC is the main influencing factor of TFP. All regions should pay attention to technological innovation, adjust the existing industrial production model, coordinate the relationship between industrial development and resource environmental protection, and gradually improve their own industrial environmental efficiency.

1. Introduction
Anhui Province is an important energy and industrial production province in East China. Anhui Province is facing environmental problems such as water pollution and air pollution due to the large amount of coal and other energy used in the industrial industry. There are many researches on improving energy eco-efficiency. For example, Wang Teng et al. used the SBM model to analyze panel data from 2000 to 2014 in 30 provinces in China, and Yang Gangqiang used the directional distance function to analyze 257 cities in China. Panel data of each city were analyzed for energy efficiency [2]. However, existing studies focus on static studies of regional differences when measuring energy eco-efficiency, and rarely incorporate industry-related indicators into the analysis, so that the results of the calculation have certain errors. Taking into account the relevant indicators such as industrial pollution characteristics, Wang Jiqian analyzed the panel data of the Yangtze River Economic Belt from 2008 to 2017 using the SE-SBM model, and found that the efficiency of industrial environmental regulation in the Yangtze River Economic Belt showed a "U-shaped" change trend. Yuan He and others used the SBM model to study the industrial environmental efficiency of Jiangsu Province, and found that energy utilization rate, industrial structure, technological innovation and opening to the
outside world are important factors for the spatial difference of environmental efficiency in Jiangsu. Shen Chen and others used Super-SBM model to calculate the panel data of China’s industrial environment from 1997 to 2014, and found that the efficiency level of the country is on the rise. Yuan He and others used the SBM model to study the industrial environmental efficiency of Jiangsu Province from 2002 to 2014 from the perspective of the county, and found that the economic level had a promoting effect on its spatial differences. Su Weizhou and others used the SBM model to measure the industrial environmental efficiency of China’s “Belt and Road” node cities from 2006 to 2015, and found that the level of foreign trade and environmental regulations had a significant negative impact on industrial environmental efficiency. Although their research incorporates some indicators of industrial pollution into the measurement aspect, the research on the production efficiency of total factors in the industrial environment is in its infancy. Therefore, this article regards the relevant indicators of industrial environmental pollution (industrial wastewater discharge, industrial smoke and dust emissions and industrial solid waste generation) as undesirable outputs, and separately estimates the static efficiency and dynamics of the industrial environment in Anhui Province from 2013 to 2018 Efficiency and analysis of the differences between cities at different levels, in order to provide a basis for decision-making for the transformation and upgrading of Anhui industrial industry and the coordinated development of resource environmental protection.

2. Test method

2.1. On-radial SBM model

The DEA model proposed by Charnes and Cooper in 1978 is an input and output analysis method based on relative efficiency. The DEA model is deriving various improved models [8]. The classic BCC and CRR models do not need to consider the input and output relaxation variables, and are subject to certain restrictions when dealing with undesirable output. Tone proposed an SBM model in 2001. This model combines all relaxation variables with the objective function to effectively overcome the above shortcomings [9].

The formula of the SBM model is specifically explained as follows: Suppose the system has n decision units (DMUs), and each DMU contains m input variables, expected output and undesired output, which can be represented by three main variables:

\[ x \in \mathbb{R}^m, y^e \in \mathbb{R}^n, y^b \in \mathbb{R}^n \text{, and } y^g \in \mathbb{R}^n \text{, where } x, y^e \text{ and } y^b \text{ is expressed as: } X = [x_1, x_2, \ldots, x_n] \in \mathbb{R}^{m \times n}, Y^e = [y^e_1, y^e_2, \ldots, y^e_n] \in \mathbb{R}^{n \times n}, \text{ and } y^b = [y^b_1, y^b_2, \ldots, y^b_n] \in \mathbb{R}^{n \times n}, \]

\[ x_i > 0, y^e_i > 0 \text{ and } y^b_i > 0. \]

The SBM model of undesirable output can be expressed as follows:

\[ \rho^s = \min \rho = \min \left\{ \frac{1 - \sum_{i=1}^{n} \frac{y^e_i}{x_i}}{1 + \frac{\sum_{r=1}^{m} s^e_r}{y^e_m} + \frac{\sum_{r=1}^{m} s^b_r}{y^b_m}} \right\}, \]

\[ \begin{align*}
  s^e_i &= X \lambda + s^e, \\
  y^e_i &= Y^e \lambda - s^e, \\
  y^b_i &= Y^b + s^b, \\
  \lambda &\geq 0, s^e \geq 0, s^b \geq 0.
\end{align*} \]

Where, \( \lambda \) represents the weight vector, \( s^e \) and \( s^b \) respectively represent the input, expected and undesired relaxation variables, respectively. Both the objective function and the relaxation variable are strictly decreasing, \([0,1]\). If \( \rho = 1 \), the relaxation variables of, and are all zero, then this decision unit (DMU) is valid. If the relaxation variables of \(< 1\), and are not zero, the decision unit (DMU) is invalid.
2.2. Malmquist productivity index model
The Malmquist productivity index model was first proposed in 1953. In 1982, Christensen et al. were widely used in the measurement of dynamic production efficiency [10]. The Malmquist productivity index function can be expressed as follows:

\[
\frac{D_i'(h_t^+, k_t^+)}{D_i'(h_t^-, k_t^-)} \times \frac{D_j'(h_t^+, k_t^+)}{D_j'(h_t^-, k_t^-)}
\]

(2)

3. Select indicators and data sources
Anhui Province includes 16 prefecture-level cities including Hefei, Huaibei, Bozhou, Suzhou, Bengbu, and Fuyang. The data comes from the Anhui Statistical Yearbook from 2013 to 2018.
Anhui’s industrial environmental efficiency emphasizes the greatest reduction in pollutant emissions and energy consumption, and fully meets the needs of industrial production. Therefore, the pollutants generated in the industrial production process need to be selected as the research object. The input indicators selected in this paper include three aspects: input capital, labor capital and energy consumption, output indicators include expected output and undesired output, expected output includes: main business income, unexpected output includes: industrial wastewater emissions and industrial smoke emissions.

Table 1. Input and output indicators and their specific meanings

| Indicator type       | Indicator category         | Specific instructions                  | Index unit          |
|---------------------|----------------------------|---------------------------------------|--------------------|
| Input indicators    | Expected investment        | Number of secondary industries        | Ten thousand yuan  |
|                     |                            | Power consumption in the secondary industry | GWh               |
| Output index        | Expected output            | Main business income                   | Ten thousand yuan  |
|                     |                            | Total industrial wastewater discharge | Ton                |
|                     | Unexpected output          | Industrial smoke and dust emissions   | Ton                |
|                     |                            | Industrial solid waste generation     | Ten thousand tons  |

4. Empirical analysis

4.1. Static industrial environment efficiency analysis
This article uses the Super-SBM model to measure the efficiency of Anhui’s industrial environment. The results of the calculation are shown in Table 2. It can be seen from Table 2 that from 2013 to 2018, the average value of industrial environmental efficiency in Anhui Province is 0.94, and there is a certain potential for improvement in promoting industrial production and protecting the ecological environment. The industrial environmental efficiency values of Huangshan City, Xuancheng City, Tongling City, Suzhou City, Chizhou City, Huaibei City, Huainan City and Ma'anshan City are between 1.00 and 1.42, which are at a relatively high level. The efficiency values of the industrial environment in Anqing City, Wuhu City and Fuyang City are low, ranging from 0.54 to 0.63, which shows that there is a significant difference in the industrial environmental efficiency in Anhui Province, and some cities have huge industrial environmental efficiency improvements. potential. Bengbu City, Hefei City, Chuzhou City, Lu'an City and Bozhou City have higher industrial environmental efficiency values, ranging from 0.76 to 0.99, indicating that these cities have a good coordination between industrial production and ecological environmental protection. The average efficiency values of Maanshan City and Huainan City are both 1, which indicates that Maanshan City and Huainan City are at the forefront of industrial environmental efficiency, and the two cities have reached harmonization in the development of industrial production and ecological environmental protection.
Table 2. Anhui Province Industrial Environmental Efficiency Value from 2013 to 2018

| Area    | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | Mean | Rank |
|---------|------|------|------|------|------|------|------|------|
| Huangshan | 1.71 | 1.83 | 1.00 | 1.98 | 1.00 | 1.00 | 1.42 | 1    |
| Xuancheng | 1.00 | 3.94 | 1.00 | 1.07 | 0.55 | 0.62 | 1.36 | 2    |
| tongling  | 1.48 | 1.61 | 1.00 | 1.10 | 1.00 | 1.00 | 1.20 | 3    |
| Suzhou   | 1.24 | 1.07 | 1.00 | 1.44 | 1.00 | 1.00 | 1.12 | 4    |
| Chizhou  | 1.16 | 1.14 | 1.00 | 1.03 | 1.00 | 1.00 | 1.06 | 5    |
| Huaipei  | 1.06 | 1.06 | 1.00 | 1.11 | 1.00 | 1.00 | 1.04 | 6    |
| Huainan  | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 7    |
| Ma'anshan | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 8    |
| Bozhou   | 1.06 | 1.00 | 1.00 | 1.05 | 0.86 | 1.00 | 0.99 | 9    |
| Lu'an    | 0.64 | 0.59 | 1.00 | 1.20 | 0.69 | 1.00 | 0.85 | 10   |
| Chuzhou  | 1.09 | 1.09 | 0.78 | 0.75 | 0.60 | 0.37 | 0.78 | 11   |
| Hefei    | 1.00 | 1.00 | 1.00 | 1.00 | 0.37 | 0.27 | 0.77 | 12   |
| Bengbu   | 1.00 | 0.87 | 0.71 | 0.79 | 0.61 | 0.59 | 0.76 | 13   |
| Anqing   | 0.64 | 0.60 | 0.59 | 0.65 | 0.79 | 0.53 | 0.63 | 14   |
| Wuhu     | 1.00 | 0.54 | 0.52 | 0.52 | 0.44 | 0.41 | 0.57 | 15   |
| Fuyang   | 0.55 | 0.54 | 0.55 | 0.51 | 0.54 | 0.52 | 0.54 | 16   |
| Mean     | 1.04 | 1.18 | 0.88 | 1.01 | 0.78 | 0.77 | 0.94 |

4.2. Dynamic analysis of industrial environmental efficiency in Anhui province

In order to further study the dynamic change trend of industrial environmental efficiency in Anhui Province, this paper uses DEAP2.1 software to decompose and calculate Malmquist index of 16 prefecture-level cities in Anhui Province. The results of the calculation are shown in Table 3, in which TEC, EFC, SEC, PEC and TFP respectively represent technological progress, technical efficiency, scale efficiency, pure technical efficiency and total factor productivity. It can be seen from Table 3 that the average value of the Malmquist index of industrial environmental efficiency in Anhui Province from 2013 to 2018 is 0.97, indicating that the industrial environmental efficiency of Anhui Province is at a relatively high level. During this period, the mean values of EFC and TEC decomposed by TFP were 1.00 and 0.97, respectively, and PEC increased from 1.00 in 2013-2014 to 1.02 in 2014-2015, an increase of 2.00%. EFC increased from 1.00 in 2013-2014 to 1.04 in 2014-2015, an increase of 4.00%. This shows that during the “Twelfth Five-Year Plan” period of 16 prefecture-level cities in Anhui Province, they focused on economic development. Many high-energy-consuming enterprises began to pay attention to the protection of resources and the environment, reducing the discharge of industrial wastewater and exhaust gas and improving the efficiency of Anhui’s industrial environment. After decomposing TFP into PEC and TEC, it can be found that both PEC and TEC play a certain inhibitory effect, and the inhibitory effect of TEC is more obvious. From 2013 to 2018, the average TFP rose from 0.99 to 1.09, then fell to 0.86 in 2016-2017, and finally rose to 1.00 in 2017-2018. During the same period, PEC and SEC decomposed by TFP remained stable, with the smallest change in PEC, and TEC increased significantly in 2016-2018, which shows that TEC is the main reason for the promotion of TFP. It shows that during this period, 16 prefecture-level cities in Anhui Province attached great importance to technological innovation in the industrial industry, and actively implemented the "Intelligent Manufacturing Development Plan (2016-2020)" issued by the Ministry of Industry and Information Technology during the 13th Five-Year Plan period to stimulate advanced intelligent manufacturing in enterprises. At the same time, it also attaches great importance to the protection of the ecological environment, and the efficiency of the industrial environment has been significantly improved.
Table 3. The average Malmquist index and its decomposition of Anhui industrial environmental efficiency in 2013-2018

| Period     | Efc  | Tec  | Pec  | Sec  | Tfp  |
|------------|------|------|------|------|------|
| 2013-2014  | 1.00 | 0.99 | 1.00 | 1.00 | 0.99 |
| 2014-2015  | 1.04 | 1.05 | 1.02 | 1.02 | 1.09 |
| 2015-2016  | 0.97 | 0.95 | 0.99 | 0.98 | 0.92 |
| 2016-2017  | 1.00 | 0.86 | 0.99 | 1.02 | 0.86 |
| 2017-2018  | 0.99 | 1.01 | 0.99 | 1.01 | 1.00 |
| Average    | 1.00 | 0.97 | 1.00 | 1.00 | 0.97 |

Figure 1. 2013-2018 Anhui Province Industrial Environmental Efficiency Average Malmquist Index Dynamic Change Graph

5. Conclusions and recommendations

5.1. In conclusion
This article uses the Super-SBM model to statically analyze the panel data of 16 cities in Anhui Province from 2013 to 2018, and then uses the Malmquist index model to dynamically analyze the efficiency of the industrial environment in Anhui Province.

①The regional difference of industrial environmental efficiency in Anhui Province is obvious. The average TFP of industrial environmental efficiency in 2013-2018 is 0.97. Overall, the industrial environmental efficiency value of the whole province is higher, but there is still some room for improvement. The spatial and temporal differences in industrial environmental efficiency in different regions are relatively obvious. The average value of industrial environmental efficiency in Huainan City and Ma'anshan City is 1, while the efficiency value of the industrial environment in Anqing City, Wuhu City, and Fuyang City is low, which range from 0.54 to 0.63. The industrialization degree of Ma'anshan City and Huainan City is relatively low, but their industrial environmental efficiency ranks first among all cities in Anhui Province and is at the forefront of efficiency. This shows that the level of social and economic development is not necessarily related to the efficiency of the industrial environment.

②From the perspective of time, the efficiency of Anhui's industrial environment in 2013-2018 experienced a state of slowly rising first, then rapidly declining, and finally rapidly rising. The change trend of TFP curve and TEC curve of industrial environmental efficiency in the whole province is
basically the same, while the change trend of TFP curve and EFC, SEC, PEC curve is obviously different.

5.2. Specific recommendations

① The local government should conserve energy resources and pay attention to environmental protection, and coordinate the relationship between industrial development and resource protection. Government departments in various regions should formulate some strict environmental protection policies and strictly prohibit industrial enterprises that do not meet the requirements of environmental protection from carrying out industrial production operations. Industrial enterprises should increase investment in research and development of energy-saving technologies, accelerate the transformation of high-pollution and high-energy-consuming enterprises, optimize the industrial structure of high-energy consumption, and take the road of green and low-carbon development.

② The regional differences in industrial environmental efficiency in various regions of Anhui Province are relatively star-like. Each region should coordinate the relationship between industrial development and energy conservation and emission reduction, strengthen technological innovation to improve the level of TEC, and promote the improvement of industrial environmental efficiency.

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