Measurement and Evaluation of Energy-Saving and Emission-Reducing Efficiency in Beijing-Tianjin-Hebei Urban Agglomeration

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Abstract. This paper used super-SBM model that considered undesired output, taking 13 cities in the Beijing-Tianjin-Hebei region as samples, and selecting panel data from 2008 to 2017 to measure the overall efficiency of energy-saving and emission-reducing in the Beijing-Tianjin-Hebei urban agglomeration. Decomposition and analysis of the comprehensive efficiency was performed through the Malmquist index model. The results showed that the overall efficiency of energy-saving and emission-reducing in the Beijing-Tianjin-Hebei urban agglomeration was generally low and fluctuating, showing the spatial pattern of the overall efficiency of energy-saving and emission-reducing has changed significantly, and the space radiation effect of high-efficiency cities was weak. TFPC fluctuated significantly, and TC was its main driving factor, PTEC and SEC jointly restricted the improvement of TEC.

1. Introduction
The Beijing-Tianjin-Hebei urban agglomeration is Chinese "capital circle". It is the third comprehensive regional unit in China after the Yangtze River Delta and the Pearl River Delta. It is the region with the strongest economic strength in northern China, and it is also one of the areas with the most potential for China's future economic development. In recent years, with the rapid economic development in the Beijing-Tianjin-Hebei region, industrialization and urbanization have continued to advance, accompanied by increasing energy consumption problems and environmental pollution pressures, especially the increasing haze problem, which seriously threatens people's health and affects their normal lives. By studying the energy efficiency of Beijing-Tianjin-Hebei urban agglomeration, we can not only solve the problem of how to use energy efficiently, but also improve the problem of poor environmental conditions in the Beijing-Tianjin-Hebei region, thereby ensuring the sustainable development of the economy in the Beijing-Tianjin-Hebei region.

2. Literature Review
At present, the research on energy-saving and emission-reducing in China has a wide scope and already has a certain research basis. On the research focus, some scholars focused on the discussion of energy-saving and emission-reducing policies [1], and other scholars focused on the evaluation of energy-saving and emission-reducing performance [2]. At the research level, some scholars have studied China's energy-saving and emission-reducing at the national level [3], and some scholars have conducted discussions at the provincial and municipal level [4]. In constructing an index system for
energy-saving and emission-reducing, some scholars have started to construct an index system for energy-saving and emission-reducing from the aspect of energy efficiency, and some scholars have designed an index system for energy-saving and emission-reducing for an industry from the industry level. In recent years, more and more scholars have begun to pay attention to undesired output when researching the efficiency of energy-saving and emission-reducing, but they have different choices of unexpected output indicators. Huang Qinghuang [5] examined the impact of environmental regulations on energy-saving and emission-reducing efficiency, and selected carbon dioxide and sulfur dioxide as undesired outputs. Wang Bing [6] studied the impact of energy-saving and emission-reducing on green total factor productivity, he chose chemical oxygen demand and sulfur dioxide as undesired outputs. Li Ke [7] chose carbon dioxide as the undesired output when studying the inter-provincial energy-saving and emission-reducing efficiency in China.

By combing the existing literature, it has been found that existing studies have conducted a more comprehensive discussion of energy-saving and emission-reducing efficiency. However, most researches only stay at the national, provincial or industry level, and there are few researches on the calculation of energy-saving and emission-reducing efficiency in a certain region. Therefore, this paper extends the research perspective to the Beijing-Tianjin-Hebei urban agglomeration. By selecting reasonable input-output indicators, using super-SBM model that takes into account undesired output, static analysis of the overall efficiency of energy-saving and emission-reducing in each city, and then uses the Malmquist index to perform a dynamic analysis of total factor productivity, with a view to providing relevant suggestions for the development of energy-saving and emission-reducing in the Beijing-Tianjin-Hebei urban agglomeration.

3. Research Methods, Indicator Selection and Data Sources

3.1. Research methods

3.1.1. Super-SBM. Tone established super-SBM model considering undesired output [8]. With constant returns to scale, the specific calculation is shown in formula (1).

\[
\rho^* = \min \frac{1}{m} \sum_{i=1}^{m} x_i \left( 1 + \frac{1}{s_1 + s_2} \left( \frac{s_1}{y_{i0}^g} + \frac{s_1}{y_{i0}^b} \right) \right)
\]

s.t.

\[
\begin{align*}
\bar{x} & \geq \sum_{j=1, x \neq 0}^{n} x_{ij} \lambda_j, i = 1, \cdots, m \\
\bar{y}^g & \geq \sum_{j=1, x \neq 0}^{n} \bar{y}_{rj}^g \lambda_j, r = 1, \cdots, s_1 \\
\bar{y}^b & \geq \sum_{j=1, x \neq 0}^{n} \bar{y}_{tj}^b \lambda_j, t = 1, \cdots, s_2 \\
\bar{x} & \geq x_{0i}, i = 1, \cdots, m \\
\bar{y}^g & \geq y_{0r}^g, r = 1, \cdots, s_1 \\
\bar{y}^b & \geq y_{0t}^b, t = 1, \cdots, s_2, \lambda > 0, j = 1, \cdots, n, j \neq 0
\end{align*}
\]
\( \rho^* \) is the target efficiency value; \( n \) is the number of \( DMU \); \( m \) is the number of inputs of the \( DMU \); \( s_1 \) and \( s_2 \) are the number of expected outputs and the number of undesired outputs; \( y^g \) and \( y^b \) are the expected outputs and undesired output; \( \bar{x} \), \( \bar{y}^g \) and \( \bar{y}^b \) denote slack variables for input, expected output, and unexpected output, respectively.

3.1.2. Malmquist index model: Malmquist proposed the Malmquist index model [9], Caves introduced the Malmquist index to productivity, and constructed total factor productivity (TFP) [10]. On the basis of CRS, the specific calculation is shown in formula (2).

\[
TFPC = \frac{D_{c}^{(t+1)}(x,y)^{t+1}}{D_{c}^{(t)}(x,y)^{t}} \times \left[ \frac{D_{c}^{(t)}(x,y)^{t+1}}{D_{c}^{(t+1)}(x,y)^{t+1}} \times \frac{D_{c}^{(t)}(x,y)^{t}}{D_{c}^{(t+1)}(x,y)^{t+1}} \right]^{\frac{1}{2}} = TEC \times TC
\]  

\( TFPC \) is the total factor productivity change index; \( TEC \) is the technical efficiency change index between time \( t \) and \( t+1 \); \( TC \) is technical change index between time \( t \) and \( t+1 \); \( c \) represents CRS; \( D_{c}^{(t)} \) and \( D_{c}^{(t+1)} \) are the distance functions of CRS-based actual output and optimal output at time \( t \) and \( t+1 \), respectively; \( (x, y)^{t} \) and \( (x, y)^{t+1} \) are the input and output vectors at time \( t \) and \( t+1 \), respectively.

On the basis of VRS, \( TEC \) can be further decomposed into pure technical efficiency change (\( PTEC \)) and scale efficiency change (\( SEC \)) indices, the specific calculation is shown in formula (3).

\[
TEC = \frac{D_{v}^{(t+1)}(x,y)^{t+1}}{D_{v}^{(t)}(x,y)^{t}} \times \frac{D_{v}^{(t+1)}(x,y)^{t+1}/D_{v}^{(t)}(x,y)^{t}}{D_{c}^{(t+1)}(x,y)^{t+1}/D_{c}^{(t)}(x,y)^{t}} = PTEC \times SEC
\]  

\( v \) represents VRS, \( D_{v}^{(t)} \) and \( D_{v}^{(t+1)} \) are the distance functions of VRS-based actual output and optimal output at time \( t \) and \( t+1 \), respectively.

3.2. Indicator selection

The research period of this article is from 2008 to 2017. The research objects are 13 cities in Beijing-Tianjin-Hebei region, including Beijing, Tianjin, Baoding, Tangshan, Langfang, Shijiazhuang, Qinhuangdao, Zhangjiakou, Chengde, Cangzhou, Handan, Hengshui, Xingtai. Referring to the research results of existing literature and considering the availability of data, this paper chooses variables as input indicators from three angles of labor force, capital stock and energy, and chooses variables as output indicators from two perspectives of expected output and undesired output. The details are shown in Table 1.
Table 1. Setting of input-output indicators

| Input indicator | Variable | Variable name | Unit | Output indicator | Variable | Variable name | Unit |
|-----------------|----------|---------------|------|------------------|----------|---------------|------|
| Labor force     | $X_1$    | Social workers | 10,000 people | Expected output | $Y_1$    | GDP           | 100 million yuan |
| Capital stock   | $X_2$    | Investment in fixed assets | 100 million yuan | Unexpected output | $Y_2$, $Y_3$ | Industrial wastewater | 100 million tons |
| Energy          | $X_3$    | Annual investment | 10,000 tons of standard coal | | $Y_4$ | Industrial smoke and dust | 10,000 tons |

3.3. Data sources

The data in this article mainly come from China Statistical Yearbook, China Energy Statistical Yearbook, China City Statistical Yearbook, National Bureau of Statistics and provincial and municipal statistical yearbooks. Due to space limitations, the panel data of 13 cities in Beijing-Tianjin-Hebei are no longer listed one by one, and the descriptive statistics of the samples are shown in Table 2.

Table 2. Descriptive statistics of Beijing-Tianjin-Hebei urban agglomeration samples

| Variable | 2008 | 2017 |
|----------|------|------|
|          | Maximu m | Minimu m | Mean | Standard deviation | Maximu m | Minimu m | Mean | Standard deviation |
| $X_1$    | 980.9 | 160.6 | 427.359 | 236.973 | 1246.8 | 184.985 | 456.236 | 330.755 |
| $X_2$    | 3848.5 | 241.06 | 1208.986 | 1147.984 | 11274.69 | 873.39 | 4003.34 | 3088.848 |
| $X_3$    | 7775.68 | 624.08 | 2767.592 | 2344.747 | 8722.27 | 988.221 | 3966.11 | 2908.86 |
| $Y_1$    | 11392 | 603.81 | 2816.6 | 3132.766 | 28000.4 | 1506.01 | 6722.53 | 7976.368 |
| $Y_2$    | 2.937 | 0.479 | 1.155 | 0.744 | 1.811 | 0.062 | 0.546 | 0.484 |
| $Y_3$    | 27.208 | 2.564 | 10.975 | 7.622 | 11.981 | 0.380 | 6.085 | 5.803 |
| $Y_4$    | 16.354 | 2.964 | 6.006 | 5.202 | 50.772 | 1.938 | 10.533 | 13.450 |

4. Results and Analysis

4.1. Static analysis of comprehensive efficiency of energy-saving and emission-reducing

The panel data of the input-output indicators of 13 cities from 2008 to 2017 were substituted into MAXDEA software, and the comprehensive efficiency of energy-saving and emission-reducing in the Beijing-Tianjin-Hebei urban agglomeration was calculated. The evaluation results are shown in Table 3. The greater the efficiency value, the more ideal the energy-saving and emission-reducing capabilities. Figure 1 shows the average change of the overall efficiency of the Beijing-Tianjin-Hebei urban agglomeration during the study period.
Table 3. Comprehensive efficiency value of energy-saving and emission-reducing in Beijing-Tianjin-Hebei urban agglomeration from 2008 to 2017.

| City       | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | Mean |
|------------|------|------|------|------|------|------|------|------|------|------|------|
| Beijing    | 1.118| 1.095| 1.110| 1.137| 1.126| 1.119| 1.117| 1.179| 1.183| 1.175| 1.136|
| Tianjin    | 0.460| 0.445| 0.430| 0.380| 0.364| 0.392| 0.346| 0.352| 0.376| 0.362| 0.386|
| Shijiazhuang| 0.262| 0.254| 0.221| 0.194| 0.182| 0.175| 0.162| 0.158| 0.154| 0.148| 0.193|
| Baoding    | 0.253| 0.238| 0.203| 0.172| 0.151| 0.138| 0.152| 0.156| 0.162| 0.158| 0.178|
| Cangzhou   | 0.285| 0.266| 0.234| 0.211| 0.178| 0.169| 0.167| 0.175| 0.168| 0.171| 0.202|
| Chengde    | 0.247| 0.228| 0.195| 0.186| 0.165| 0.153| 0.151| 0.162| 0.158| 0.161| 0.181|
| Handan     | 0.236| 0.217| 0.191| 0.173| 0.151| 0.141| 0.131| 0.137| 0.131| 0.135| 0.162|
| Hengshui   | 0.253| 0.224| 0.186| 0.162| 0.141| 0.131| 0.137| 0.131| 0.135| 0.128| 0.163|
| Langfang   | 0.237| 0.225| 0.223| 0.195| 0.176| 0.171| 0.184| 0.195| 0.186| 0.191| 0.198|
| Qinhuangdao| 0.319| 0.287| 0.251| 0.212| 0.183| 0.173| 0.169| 0.173| 0.172| 0.168| 0.211|
| Tangshan   | 0.328| 0.308| 0.287| 0.285| 0.258| 0.255| 0.239| 0.225| 0.224| 0.228| 0.264|
| Xingtai    | 0.192| 0.183| 0.156| 0.138| 0.123| 0.112| 0.113| 0.109| 0.111| 0.107| 0.134|
| Zhangjiakou| 0.223| 0.197| 0.168| 0.147| 0.133| 0.127| 0.125| 0.117| 0.115| 0.118| 0.147|
| Mean       | 0.339| 0.317| 0.298| 0.277| 0.256| 0.251| 0.247| 0.250| 0.251| 0.248| 0.273|

In general, from 2008 to 2017, the comprehensive efficiency values of energy-saving and emission-reducing in the Beijing-Tianjin-Hebei region were not high. Most cities did not reach the production frontier and were in a non-DEA effective state. From 2008 to 2017, the average efficiency of energy-saving and emission-reducing in 13 cities was 0.273, which was only 27.3% of the optimal level, indicating that the Beijing-Tianjin-Hebei urban agglomeration still has large energy-saving and emission-reducing space and potential. From the perspective of the city, there was a large difference in the efficiency of energy-saving and emission-reducing between cities. During the study period, among the 13 cities, except for Beijing, the average efficiency of the other cities in the sample interval was less than 1. And the average energy-saving and emission-reducing efficiency of 11 cities in Hebei province were all lower than 0.3. This means that the Beijing-Tianjin-Hebei region has a lot of space and potential for energy conservation and emission reduction, and it also reflected from the side that the efficiency of energy-saving and emission-reducing may also be related to urban development.

Looking at Figure 1, the overall efficiency of energy-saving and emission-reducing in the Beijing-Tianjin-Hebei region was declining. In 2014, the overall efficiency of energy-saving and emission-reducing reached the lowest point, with an average value of only 0.247. Compared with the optimal...
level of data envelope analysis efficiency, there was room for improvement of 75.3%. This may be due to the long-term rapid economic growth of China at the expense of the environment. Especially since the beginning of the 21st century, the sustained growth of the economy has mainly depended on large projects and projects, which has led to rising energy consumption. Eventually, large-scale haze weather appeared in many places in China, especially the pollution emissions in the Beijing-Tianjin-Hebei region centered on the capital Beijing exceeded the environmental carrying capacity. Because we are not mature enough in environmental pollution control, the overall efficiency of energy-saving and emission-reducing has been declining. However, in recent years, with the government's emphasis on environmental governance and the issuance of environmental governance measures, the average efficiency of energy-saving and emission-reducing in 2015 and 2016 has improved, but the increase was not large. In 2017, there was a slight decline, which also illustrates the arduous task of energy-saving and emission-reducing in China.

4.2. Spatial differentiation of comprehensive efficiency of energy-saving and emission-reducing

Figure 2. Distribution diagram of comprehensive efficiency of energy-saving and emission-reducing in Beijing-Tianjin-Hebei urban agglomeration
In order to further study the spatial differences in the comprehensive efficiency of energy-saving and emission-reducing in the Beijing-Tianjin-Hebei urban agglomeration, this paper used ArcGis 10.2 software to classify the comprehensive efficiency of energy-saving and emission-reducing in 13 cities in odd years, the distribution diagram of the overall efficiency of energy-saving and emission-reducing is shown in Figure 2. The high efficiency zone was defined as the comprehensive efficiency of energy-saving and emission-reducing above 0.597, the medium efficiency zone between 0.276 and 0.597, and the low efficiency zone below 0.276. It can be seen from Figure 2 that from 2008 to 2017, the spatial pattern of comprehensive emission reduction efficiency in the Beijing-Tianjin-Hebei urban agglomeration has changed significantly, and the overall efficiency of energy-saving and emission-reducing has shown a trend of high in the east and low in the west, and the number of high-efficiency cities has been decreasing year by year. During the study period, the comprehensive efficiency of energy-saving and emission-reducing in Beijing and Tianjin has been at a relatively high level, while Qinhuangdao and Tangshan have gradually transitioned from the medium efficiency area to the low efficiency area, and the overall change is large.

4.3. Dynamic analysis of comprehensive efficiency of energy-saving and emission-reducing

The measurement of the energy-saving and emission-reducing efficiency of 13 cities in the Beijing-Tianjin-Hebei region used the super-SBM method considering undesired output is just a static analysis. In order to better study its dynamic change trend, this paper used MAXDEA software to calculate the Malmquist index and decomposition index of comprehensive efficiency (Table 4). Analyze the dynamic characteristics of energy-saving and emission-reducing efficiency from TEC, TC, PTEC, and SEC.

Table 4. Changes and decomposition of Malmquist index of energy-saving and emission-reducing in Beijing-Tianjin-Hebei urban agglomeration

| City        | TEC  | TC    | PTEC | SEC  | TFPC |
|-------------|------|-------|------|------|------|
| Beijing     | 1.006| 1.011 | 1.006| 1.000| 1.017|
| Tianjin     | 0.960| 1.164 | 0.959| 1.001| 1.117|
| Shijiazhuang| 0.943| 1.106 | 0.959| 0.983| 1.042|
| Tangshan    | 0.952| 1.093 | 0.966| 0.985| 1.040|
| Qinhuangdao | 0.930| 1.108 | 0.978| 0.951| 1.031|
| Handan      | 0.924| 1.103 | 0.956| 0.967| 1.020|
| Xingtai     | 0.924| 1.102 | 0.975| 0.948| 1.018|
| Baoding     | 0.937| 1.117 | 0.969| 0.967| 1.047|
| Zhangjiakou | 0.919| 1.102 | 0.967| 0.950| 1.012|
| Chengde     | 0.955| 1.100 | 1.110| 0.860| 1.049|
| Cangzhou    | 0.915| 1.136 | 0.933| 0.981| 1.040|
| Langfang    | 0.971| 1.111 | 1.004| 0.967| 1.049|
| Hengshui    | 0.934| 1.107 | 0.998| 0.936| 1.035|
| Mean        | 0.944| 1.104 | 0.982| 0.961| 1.042|

As can be seen from Table 4, overall, the TFPC of the Beijing-Tianjin-Hebei urban agglomeration was growing at an average annual rate of 4.2%, of which TC contributed 10.4%. However, TEC decreased by 5.6%, while both PTEC and SEC were less than 1, indicating that the main reason for the increase in the TFPC lies in TC, while PTEC and SEC were its limiting factors. From the perspective of the city, from 2008 to 2017, the TFPC of each city was greater than 1, indicating that the overall development trend of urban energy-saving and emission-reducing efficiency was relatively stable. According to the analysis of the decomposition index of TFPC, cities with improved PTEC include Beijing, Chengde, and Langfang. Cities with improved SEC include Beijing and Tianjin. TC in all cities was greater than 1, which further illustrated the degree to which TC contributed to TFPC. In
general, TC was the dominant factor affecting the TFPC of the sample cities, while PTEC and SEC jointly restricted TEC.

5. Conclusions and Recommendations
From 2008 to 2017, the overall efficiency of energy-saving and emission-reducing in the Beijing-Tianjin-Hebei region was generally low, and it showed a downward trend in fluctuations. There were significant differences in the efficiency of energy-saving and emission-reducing between cities. Of the 13 cities, only Beijing has been at the forefront of efficiency during the study period. Therefore, during the formulation and implementation of energy-saving and emission-reducing policies, the government should adapt measures to local conditions and cities, and fully consider the differences between cities.

The spatial pattern of comprehensive efficiency of energy-saving and emission-reducing was obviously different, and the space radiation effect of high-efficiency cities was weak. In order to solve the energy-saving and emission-reducing problems in the Beijing-Tianjin-Hebei region, the government should not only strive to improve the management level of technologies related to energy-saving and emission-reducing, but also fully consider the space spillover effects between cities, and set advanced energy-saving and emission-reducing technologies and policies for high-efficiency cities in a timely manner spread to inefficient cities, and strengthen the coordinated development of cities.

The TFPC of Beijing-Tianjin-Hebei cities showed significant fluctuation characteristics. TC has significantly improved TFPC, while PTEC and SEC have a more significant inhibitory effect on TFPC. Therefore, the government should strengthen the impact of technological progress in the field of energy-saving and emission-reducing in urban energy conservation and emission reduction, and increase support for technological innovation in energy conservation and emission reduction.

Acknowledgments
This work was financially supported by “Tianjin Science and Technology Project Plan” fund.

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