Evaluation of Industrial Eco-Efficiency in Beijing-Tianjin-Hebei Urban Agglomeration

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Abstract. The study of industrial eco-efficiency of Beijing-Tianjin-Hebei urban agglomeration is of great significance for promoting the supply-side reform and green sustainable development. The DEA and Malmquist indexes were used to conduct an empirical study on the industrial eco-efficiency of 13 cities in Beijing-Tianjin-Hebei region from 2011 to 2016. The results show that the overall industrial eco-efficiency of Beijing-Tianjin-Hebei urban agglomeration is relatively high, but there are obvious regional differences; the overall total factor eco-efficiency of Beijing-Tianjin-Hebei urban agglomeration shows a good development trend, and the technological progress efficiency is the main driving force for the improvement of ecological efficiency.

1. Introduction
At present, Chinese economic development has entered a new normal state, with the development speed gradually slowing down, the development quality gradually improving, and the reasonable transformation of the industrial structure on the right track. However, in this process, substandard emissions of industrial wastes and pollutants still exist. Under the background of "two-oriented society" and "two-mountain concept", how to improve the eco-efficiency of industry so as to achieve the benign development of regional ecological environment to the greatest extent and how to improve the resources and environmental efficiency has always been the focus of political and academic circles.

2. Literature Review
At present, the research on the efficiency of Beijing-Tianjin-Hebei coordinated development mainly focuses on logistics, the allocation of scientific and technological resources, and the utilization of infrastructure and the input-output efficiency of certain industries. Tang Xin [1] used DEA-BCC model to make an empirical analysis on the logistics efficiency of the three provinces and cities in Beijing-Tianjin-Hebei, drew a conclusion that the synergic development was insufficient, and put forward corresponding improvement suggestions. Wang Cong [2] comprehensively evaluated the efficiency of resource allocation based on panel data of the allocation of science and technology resources in Beijing-Tianjin-Hebei from 2008 to 2014. Li Qi [3] analyzed the investment efficiency of the five major urban infrastructures in Beijing-Tianjin-Hebei region from 2003 to 2012, and found out the influencing factors affecting the overall development of the region. Li Jian [4] evaluated the input-output efficiency of the petrochemical industry in the Beijing-Tianjin-Hebei region from 2003 to 2014, and concluded that the input-output efficiency of the industry was low.

As for research on ecological efficiency, Schaltegger and Sturm [5] proposed that ecological
resources are efficient to meet human needs. In 1992, the world business council for sustainable development formally proposed the concept of eco-efficiency [6]. Subsequently, Kamiuto and Zaim [7, 8] constructed a global carbon cycle model and an environmental efficiency index for global eco-efficiency. Since then, research on maintaining the human ecological environment and focusing on the eco-efficiency of various industries has continued to be a research hotspot for scholars. In recent years, domestic scholars' research on eco-efficiency has mainly focused on efficiency measures at the industrial or regional level. The methods involved mainly include data envelopment analysis (DEA), economic and environmental ratio evaluation method, and factor analysis method. Gao Feng [9] analyzed the industrial eco-efficiency of 30 provinces in China in 2007 using data envelopment analysis (DEA); In addition, based on the study of regional eco-efficiency, it also studies its influencing factors. For example, Dai Zhi min [10] used the integrated super-efficiency DEA method to conduct an empirical analysis of panel data in relevant provinces and cities in East China in 2003-2013. Dynamic analysis of its eco-efficiency, and identification of the main influencing factors of eco-efficiency, and it is concluded that the inter-provincial differences in regional eco-efficiency are very obvious, but there is a conclusion of significant convergence. Similar research can also be seen in Tian Ze [11] research on the industrial eco-efficiency and influencing factors of provinces and cities along the “The Belt and Road” in China.

Based on the statistical description and analysis of the industrial input, output indicators and eco-efficiency of Beijing-Tianjin-Hebei urban agglomeration from 2011 to 2016, The DEA static model is used to study the industrial eco-efficiency of the Beijing-Tianjin-Hebei urban agglomeration, and the Malmquist index is used to dynamically analyze the changes in the industrial eco-efficiency of the Beijing-Tianjin-Hebei urban agglomeration, which provides a reference for the industrial-side reform and green development of the Beijing-Tianjin-Hebei urban agglomeration.

3. Research Methods and Data Description

3.1. Research method

3.1.1. DEA model. DEA (Data Envelopment Analysis) was proposed in 1978 by the famous operational research experts A. Harnes, W.W. Cooper and E. Hodes, which is used to evaluate the relative effectiveness of the same department (also known as DEA effectiveness) [12]. This paper uses the DEA-BCC model proposed by Banker [13] to carry out a DEA analysis of the industrial eco-efficiency of cities in the Beijing-Tianjin-Hebei urban agglomeration to study its eco-efficiency under variable returns to scale (VRS). At this time, industrial eco-efficiency is decomposed into pure technical efficiency (vrste) and scale efficiency (scale). The specific model is as follows:

Suppose there are \( n \) decision units (DMUs), which have \( m \) kinds of inputs and \( s \) kinds of outputs, respectively. Note that the input and output of the \( j \)th decision unit are:

\[
X_j = (X_{1j}, X_{2j}, \ldots, X_{mj})
\]

\[
Y_j = (Y_{1j}, Y_{2j}, \ldots, Y_{sj})
\]

\[
\min \left[ \theta - \varepsilon \left( \sum_{i=1}^{m} S^-_i + \sum_{r=1}^{s} S^+_{r} \right) \right] = v_j(\varepsilon)
\]

s.t.
\[ \sum_{i=1}^{n} \lambda_i y_{ij} - S_r^+ = y_{0j} \]
\[ \sum_{i=1}^{n} x_{ij} - S_j^- = \theta x_{0j} \]
\[ \sum_{i=1}^{n} \lambda_i = 1 \]
\[ \theta, \lambda_i, S_j^-, S_r^+ \geq 0 \] (2)

3.1.2. Malmquist index. In 1953, Sten Malmquist first proposed the Malmquist model, which was subsequently refined by Fare and others and used in production operations. The Malmquist index can be decomposed into a technology progress index (TC) and a technology efficiency index (EC), while the technology progress rate can be broken down into scale efficiency (sech) and pure technology efficiency (pech). The expression of this index is as follows:

\[ \text{Techch} = \left[ \frac{D'(x_{t+1}, y_{t+1})}{D'^{t+1}(x_{t+1}, y_{t+1})} \times \frac{D'(x_t, y_t)}{D'^{t+1}(x_t, y_t)} \right]^{1/2} \]
\[ \text{Effch} = \frac{D'^{t+1}(x_{t+1}, y_{t+1})}{D'(x_t, y_t)} \] (3)

3.2. The evaluation index and data sources

3.2.1. The evaluation index. The determination of the industrial eco-efficiency evaluation index system is of great significance to the establishment and solution of the model. Combined with the characteristics of the DEA method, generally, income index is used as output index, and such index are expected outputs, which are characterized by a larger value and better; usually, cost indicators are used as input index and are characterized by a smaller value. Based on this principle, combined with domestic and foreign research on industrial eco-efficiency, the status quo of China's industrial ecology and the technical characteristics of the industry itself, an evaluation index for the industrial eco-efficiency of Beijing-Tianjin-Hebei was established.

| First-level index | Secondary index | Tertiary index |
|-------------------|-----------------|---------------|
| Input             | Resources invested | Industrial electricity consumption (10^4 kW·h) |
|                   | Environmental pollution | Wastewater discharge (10^4 tons) |
|                   |                   | Industrial SO_2 emissions (tons) |
|                   |                   | Industrial smoke (powder) dust emissions (tons) |
| Output            | Economic output | Comprehensive utilization rate of general solid waste (%) |
|                   |                   | Total industrial output value (above the scale) (10^7 yuan) |

3.2.2. Data sources. The data in this article are from the 2011-2016 China City Statistical Yearbook, China Statistical Yearbook, and statistical yearbooks of various cities.
4. Results and Analysis

4.1. Industrial eco-efficiency of Beijing-Tianjin-Hebei urban agglomeration

Table 2. Statistical description of Beijing-Tianjin-Hebei input, output index and eco-efficiency from 2011 to 2016

| Item               | IEC (10^4 kW·h) | WWD (10^4 tons) | ISE (tons) | ISDE (tons) | CURGSW (%) | TIOV (10^7 yuan) | Eco-efficiency |
|--------------------|-----------------|-----------------|------------|-------------|------------|-----------------|---------------|
| The maximum        | 559,072.70      | 310,580.00      | 331,863.00 | 185,986.60  | 100.00     | 28,242.13       | 1.00          |
| The minimum        | 178,968.00      | 1,373.00        | 9,563.00   | 7,133.00    | 4.74       | 440.84          | 0.25          |
| The average        | 142,130.87      | 10,006.50       | 94,864.73  | 11,890.30   | 76.72      | 638.46          | 0.63          |
| The standard       | 1,668,260.94    | 64,799.94       | 73,349.16  | 23,250.18   | 27.05      | 709.87          | 0.29          |
| deviation          |                 |                 |            |             |            |                 |               |

IEC: Industrial electricity consumption
WWD: Waste water discharge
ISE: Industrial SO₂ emissions
ISDE: Industrial smoke (powder) dust emissions
CURGSW: Comprehensive utilization rate of general solid waste
TIOV: Total industrial output value (above the scale)

From Table 2 above: (1) from 2011 to 2016, there was a large gap in resource consumption represented by industrial electricity consumption among cities in Beijing-Tianjin-Hebei. Among them, the largest resource consumption was in Tianjin in 2014, whose industrial electricity consumption reached 559,072.7(10^4 kW·h). The smallest was Hengshui in 2013, which used 178,968(10^4 kW·h) of industrial electricity. The standard deviation is 1,668,260.94(10^4 kW·h), which shows that the resource consumption fluctuates greatly from 2011 to 2016.

(2) The environmental pollution caused by Beijing-Tianjin-Hebei urban agglomeration during the development process from 2011 to 2016 is also very different. Among them, the difference between the industrial smoke (powder) dust emissions in exhaust gas pollution and the general solid waste utilization rate among solid wastes is the largest. The largest industrial smoke (powder) dust emission was Qinhuangdao in 2015, with an emission of 185,986.6(tons); the smallest emission was in Hengshui in 2016, with an emission of 7,133(tons) and a standard deviation of 23,250.18(tons). The largest comprehensive utilization rate of general solid waste was Cangzhou in 2015 with a utilization rate of 100%; the lowest comprehensive utilization rate was in Chengde in 2012 with a utilization rate of 4.74% and a standard deviation of 27.05.

(3) Between 2011 and 2016, the level of industrial development of cities in Beijing-Tianjin-Hebei varied greatly. The largest industrial output value was in Tianjin in 2015, with a total output value of 2,824,213(10^7 yuan). The smallest industrial output value was in Hengshui in 2011, with a total output value of 44,084(10^7 yuan). The standard deviation of the 13 cities is 709.887(10^7 yuan), which is close to the average value of 638.468(10^7 yuan) in Beijing-Tianjin-Hebei.

4.2. Industrial eco-efficiency analysis based on DEA-BCC model

Taking the input-output data of 13 cities in Beijing-Tianjin-Hebei into the DEA-BCC model for analysis, we can get the industrial eco-efficiency (represented by VRS value) for each year from 2011 to 2016. The results are shown in table 3.
Table 3. Industrial eco-efficiency value of Beijing-Tianjin-Hebei from 2011 to 2016

| City       | 2011  | 2012  | 2013  | 2014  | 2015  | 2016  | The average |
|------------|-------|-------|-------|-------|-------|-------|-------------|
| Beijing    | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000       |
| Tianjin    | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000       |
| Shijiazhuang| 0.249 | 1.000 | 1.000 | 0.913 | 0.974 | 0.997 | 0.856       |
| Tangshan   | 0.312 | 0.840 | 0.569 | 0.520 | 0.512 | 0.666 | 0.570       |
| Qinhuangdao| 0.620 | 0.563 | 0.421 | 0.600 | 0.292 | 0.279 | 0.463       |
| Handan     | 0.723 | 1.000 | 0.598 | 0.621 | 0.541 | 0.564 | 0.675       |
| Xingtai    | 0.338 | 0.752 | 0.663 | 0.946 | 0.642 | 0.500 | 0.640       |
| Baoding    | 0.554 | 1.000 | 0.930 | 0.996 | 0.998 | 0.827 | 0.884       |
| Zhangjiakou| 0.265 | 0.364 | 0.350 | 1.000 | 0.499 | 1.000 | 0.580       |
| Chengde    | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000       |
| Cangzhou   | 0.716 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 0.953       |
| Langfang   | 0.397 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 0.900       |
| Hengshui   | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000       |
| The average| 0.629 | 0.886 | 0.810 | 0.892 | 0.804 | 0.833 | 0.809       |

The results show: (1) from the perspective of time scale, the average industrial eco-efficiency of Beijing-Tianjin-Hebei has shown a good development trend of fluctuation and increase for 6 consecutive years. In 2011, the average industrial eco-efficiency of cities in the Beijing-Tianjin-Hebei was 0.629, 0.886 in 2012, 0.810 in 2013, 0.892 in 2014, 0.804 in 2015 and 0.833 in 2016. In 2016, there were 9 cities whose industrial eco-efficiency value was greater than or equal to the average eco-efficiency value of corresponding urban areas, and 11 cities whose industrial eco-efficiency value in 2016 was greater than or equal to the corresponding industrial eco-efficiency value in 2011. It can be seen that the overall development of each city is in a good direction.

(2) From the perspective of space, the average industrial eco-efficiency in Beijing-Tianjin-Hebei is not low. The average value of industrial eco-efficiency is 0.809, which still has a lot of room for improvement. Among them, Beijing, Tianjin, Chengde and Hengshui are ranked first, with average industrial eco-efficiency of 1, indicating that the four cities have been in the forefront of industrial eco-efficiency for 6 consecutive years. The average industrial eco-efficiency of Cangzhou and Langfang is weak and invalid between 0.9 and 1, while the average industrial eco-efficiency of Shijiazhuang and Baoding is generally invalid between 0.8 and 0.9, and the average industrial eco-efficiency of other cities is below 0.7, which is strong and invalid, leading to a large degree of resource waste and environmental pollution.

4.3. Dynamic analysis of industrial eco-efficiency based on Malmquist index

The DEA-BCC model conduct a static analysis of the industrial eco-efficiency of each city based on cross-section data, while the Malmquist index analysis model is based on the time-integrated panel data to study the dynamic trend of industrial ecological efficiency in each city. Table 4 shows the decomposition of Malmquist index of industrial eco-efficiency in Beijing-Tianjin-Hebei from 2011 to 2016. Table 5 shows the average Malmquist index and decomposition results of the Beijing-Tianjin-Hebei from 2011 to 2016.
Table 4. Malmquist index decomposition of industrial eco-efficiency in Beijing-Tianjin-Hebei from 2011 to 2016

| City         | effch | techch | pech  | sech  | tfpch |
|--------------|-------|--------|-------|-------|-------|
| Beijing      | 1.000 | 1.228  | 1.000 | 1.000 | 1.228 |
| Tianjin      | 1.024 | 1.069  | 1.000 | 1.024 | 1.095 |
| Shijiazhuang | 1.301 | 1.114  | 1.320 | 0.986 | 1.449 |
| Tangshan     | 1.186 | 1.062  | 1.164 | 1.019 | 1.259 |
| Qinhuangdao  | 0.894 | 1.157  | 0.853 | 1.049 | 1.035 |
| Handan       | 0.981 | 1.147  | 0.952 | 1.031 | 1.125 |
| Xingtai      | 1.115 | 1.168  | 1.081 | 1.031 | 1.303 |
| Baoding      | 1.119 | 1.193  | 1.083 | 1.033 | 1.336 |
| Zhangjiakou  | 1.020 | 1.103  | 1.304 | 0.782 | 1.125 |
| Chengde      | 1.225 | 1.068  | 1.000 | 1.225 | 1.308 |
| Langfang     | 1.274 | 1.164  | 1.203 | 1.059 | 1.482 |
| Hengshui     | 1.044 | 1.218  | 1.000 | 1.044 | 1.271 |
| The average  | 1.095 | 1.144  | 1.071 | 1.022 | 1.252 |

From the analysis of overall industrial eco-efficiency: The average value of the industrial eco-efficiency decomposition index of Beijing-Tianjin-Hebei is greater than 1, and the total factor productivity of each city is greater than 1, with an average total factor productivity of 25.2%, indicating that the overall industrial eco-efficiency is showing a good improvement trend. As can be seen from Table 4, technological progress, management improvement, and scale adjustment are the keys to the improvement of total factor productivity, and the main driving force for the improvement of Beijing-Tianjin-Hebei's industrial eco-efficiency is technological progress, with an average growth rate of 14.4%. There are 8 cities in Beijing-Tianjin-Hebei urban agglomeration where the total factor productivity is greater than the average. The other five cities have lower total factor productivity, with Tianjin and Qinhuangdao having the lowest total factor productivity. The main reason for the poor growth rate is the decline in technical efficiency or pure technical efficiency.

Table 5. Decomposition of the average annual Malmquist index of cities in the Beijing-Tianjin-Hebei

| Year         | effch | techch | pech  | sech  | tfpch |
|--------------|-------|--------|-------|-------|-------|
| 2011—2012    | 2.007 | 1.446  | 1.535 | 1.307 | 2.903 |
| 2012—2013    | 0.903 | 1.071  | 0.896 | 1.008 | 0.967 |
| 2013—2014    | 0.961 | 1.009  | 1.138 | 0.845 | 0.970 |
| 2014—2015    | 0.962 | 1.065  | 0.865 | 1.112 | 1.025 |
| 2015—2016    | 0.938 | 1.176  | 1.042 | 0.900 | 1.103 |
| The average  | 1.095 | 1.144  | 1.071 | 1.022 | 1.252 |

From 2011 to 2016 development dynamic analysis: On average, the total factor productivity of Beijing-Tianjin-Hebei urban agglomeration is 1.252, which belongs to the stage of increasing returns to scale. The comprehensive technical efficiency, technological progress, pure technical efficiency and scale efficiency are 1.095, 1.144, 1.071 and 1.022, respectively. Thus it can be seen that the total factor productivity of Beijing-Tianjin-Hebei urban agglomeration is mainly driven by technological progress, while the pure technical efficiency and scale efficiency are relatively insignificant. From the perspective of the dynamic evolution trend of TFP, TFP shows a better trend of decreasing and then rising, and the average value of 1.252 is greater than 1, indicating that the industrial eco-efficiency of
Beijing-Tianjin-Hebei urban agglomeration has gone through a change process of decreasing and then rising. From the decomposition index, the technical progress is consistent with the change of total factor productivity, which also shows a trend of decreasing and then rising, but the overall level is higher than 1. But the pure technical efficiency and the scale efficiency both present the trend of fluctuation to rise. According to the dynamic change trend of each decomposition index, technological progress is always the main driving force of total factor productivity, which is consistent with the conclusion in table 4.

5. Conclusion
In this paper, the DEA model was used to calculate the industrial eco-efficiency values of 13 cities in Beijing-Tianjin-Hebei from 2011 to 2016, and Malmquist index was used to analyze the dynamic change trend. The following conclusions are drawn:

(1) In the past 6 years, the industrial eco-efficiency of Beijing-Tianjin-Hebei shows a trend of fluctuation and increase, and the overall level is not low, which is 0.806. Among them, only Beijing, Tianjin, Chengde and Hengshui have been in the forefront of production for 6 consecutive years. Thus it can be seen that most urban areas in Hebei province still achieve the transformation of industry from extensive to intensive and sustainable at the cost of huge resource consumption and environmental pollution.

(2) The overall total factor industrial eco-efficiency of Beijing-Tianjin-Hebei urban agglomeration shows a good development trend. The total factor eco-efficiency of all cities is greater than 1, with an annual growth rate of 25.2%. The rate of technological progress is the main driving force for the improvement of total factor productivity. Judging from the decomposition of the Malmquist index in Beijing-Tianjin-Hebei urban agglomeration in various years, the better development trend of total factor eco-efficiency first decreasing and then rising is caused by the first rising and then decreasing of technological advancement efficiency, which shows that technology promotion in 6 years brings industrial eco-efficiency has become the main source of efficiency improvement. Therefore, in Beijing-Tianjin-Hebei, if they want to continue to improve industrial ecological efficiency, they still need to continuously strengthen technology investment and promote technology research and development.

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