Evaluation of Environmental Efficiency in Beijing-Tianjin-Hebei Region Based on DEA

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Abstract. Data Envelopment Analysis (DEA) is a new category explored in operations research, management, applied mathematics, and finance. Beijing-Tianjin-Hebei coordinated development has become the focus of current national society. In this paper, a total of 13 cities above the prefecture level in Beijing-Tianjin-Hebei region are selected as sample units for decision-making. The total population at the end of the year, regional fixed asset investment, industrial dust emissions, industrial wastewater emissions, and industrial sulfur dioxide emissions were selected as input indicators. The actual GDP is used as the output indicator. Two linear programming models included in the DEA method are adopted: Model and The model, through the collection, screening and use of a large amount of data, uses Matlab programming to calculate the comprehensive technical efficiency, pure technical efficiency and scale efficiency of 13 cities, and evaluates and analyzes the effectiveness of the three efficiency values to correctly judge Beijing and Tianjin.

1. Introduction

As the "third pole" that is expected to lead the Chinese economy in the future, as a regional economic spatial structure adjustment According to the development experience since China's reform and opening up, the economic development of each period and stage cannot be separated from the driving role of a certain region as an engine. For example, Guangzhou and Shenzhen have started the vigorous development of the "Pearl River Delta" region; the dazzling stars of Shanghai and Pudong illuminate the progress of the "Yangtze River Delta" region. The coordinated development of the Beijing-Tianjin-Hebei region will carry the drive for North China Even China's important task for sustainable development in the future.

However, at the same time, the area of Beijing-Tianjin-Hebei is facing huge environmental pressures, the side effects brought by rapid economic development are becoming more prominent, and the rate of economic growth has continued to decline. Air pollution as an example. According to the air quality status of key regions and 74 cities announced by the Ministry of Environmental Protection, 11 cities in the Beijing-Tianjin-Hebei region are listed among the top 20 most polluted cities, of which 8 This city ranks in the top 10. The “ten-face haze” and “dense fog surrounding city” brought about by air pollution are becoming more and more serious, which has seriously affected the daily travel and physical health of the people. Under such a severe environmental situation, for Beijing The Tianjin and Hebei area still uses traditional economic efficiency to measure its economic development achievements, and it can no longer be objective and accurate. Instead, it introduces environmental
factors into the evaluation system, and uses the economic efficiency of environmental factors, that is, environmental efficiency, to measure the impact on Beijing and Tianjin. The development of Hebei has become a necessity.

### 2. DEA model establishment

The DEA method does not need to be designed in advance to have a functional form the model with self-defined weight vectors is very suitable for the efficiency evaluation of solving multiple input and multiple output situations. So it is feasible to evaluate environmental efficiency through DEA, and has the following two advantages: The method is a model that does not need to assume the values of the weight parameters. The input and output data of the decision unit does not need to be dimensionless and can be used directly. It does not need to guess the weights in advance, and all rely on the collected data for evaluation. This can prevent human interference from causing excessive weight errors.

In real life evaluating environmental efficiency, expected and undesired outputs often appear together. In the analysis results of the DEA method, \(R^2\) the obtained comprehensive technical efficiency can be decomposed into two parts: pure technical efficiency and scale efficiency. The pure technical efficiency of the decision unit can be obtained, and then the characteristics of scale returns can be analyzed [1, 2].

**Theorem 1.1** (1) \(DMU_{j0}\) A necessary and sufficient condition for weakly effective DEA is a linear programming model \((D_1)\) Optimal solution \(V_{D_1} = 1\) ; (2) \(DMU_{j0}\) the necessary and sufficient conditions for effective DEA are not only to meet the planning problem \((D_1)\) Optimal value \(V_{D_1} = 1\), and \((D_1)\) all solutions obtained \(\lambda^0 = [\lambda_1^0 \cdots \lambda_n^0]^T, S^0, S^{+0}, \theta^0\) Must meet \(S^{-0} = S^{-+0} = 0\).

\[
\begin{align*}
(F_{j0}) \quad \min & \quad F(X, Y) \\
\text{s.t.} & \quad (X, Y) \in T_{CCR}
\end{align*}
\]

among them: \(X = [x_1, \cdots, x_n]^T, Y = [y_1, \cdots, y_n]^T; F(X, Y) = [X^T, -Y^T]^T;\)

Scholars Charnes and Cooper introduced non-Archimedean infinitesimal quantities into the planning model, and studied them in depth, and they have been widely used in real life. This method has become a calculation. \(DMU_{j0}\) is it a more practical method of effectiveness.

The sign of non-Archimedean infinitesimals is \(\varepsilon\) in the field of generalized real numbers, \(\varepsilon\) is an "abstract number" less than any positive number and greater than zero, we will \(\varepsilon\) Bring in in \(C^2 R\) Medium, available \((P_{\varepsilon})\) :

\[
\begin{align*}
(P_{\varepsilon}) \quad \max & \quad V_{n, \varepsilon} = \mu^T y_a \\
\text{s.t.} & \quad w^T x_j - \mu^T y_j \geq 0 \quad (j = 1, 2, \cdots, n) \\
& \quad w^T x_a = 1 \\
& \quad w^T \geq \varepsilon [e^-]^T, \mu^T \geq \varepsilon [e^+]^T
\end{align*}
\]

\((P_{\varepsilon})\) the dual programming problem is:

\[
\begin{align*}
(D_{\varepsilon}) \quad \min & \quad V_{n, \varepsilon} = [\theta - \varepsilon ([|e^-|^T S^- + [e^+|^T S^+) \\
\text{s.t.} & \quad \sum_{j=1}^n x_j \lambda_j + S^- = \theta x_a \\
& \quad \sum_{j=1}^n y_j \lambda_j - S^+ = Y_a \\
& \quad \lambda_j \geq 0 \quad (j = 1, 2, \cdots, n); S^+ \geq 0; S^- \geq 0
\end{align*}
\]
among them \([e^-]^T = [1,1,\cdots,1] \in E_m, [e^+]^T = [1,1,\cdots,1] \in E_e\).

Theorem 1.2 if set \(\theta^0\), \(S^{-0}\), \(S^{+0}\), \(\theta^0\) is with \(\varepsilon\) linear programming model \((D_{\varepsilon})\) optimal solution:

1. If \(\theta^0 = 1\), then \(DMU_{j_0}\) effective for weak DEA;
2. If \(\theta^0 = 1\), and \(S^- = 0, S^+ = 0\), then \(DMU_{j_0}\) effective for DEA.

The basic form of the model \([1, 2, 4]\) will bring in \(BC^2\) in the model, available \((P_{2\varepsilon})\):

\[
\begin{align*}
\text{(P}_{2\varepsilon}\text{)}: \quad \max & \quad v_{\lambda} = (\mu^T y_\theta - \mu_0) \\
\text{s.t.} & \quad w^T x_j - \mu^T y_j + \mu_0 \geq 0 \quad (j = 1, 2, \cdots, n) \\
& \quad w^T x_0 = 1 \\
& \quad w^T \varepsilon [e^-]^T, \mu^T \geq [e^+]^T
\end{align*}
\]

\((P_{2\varepsilon})\) the dual programming problem is:

\[
\begin{align*}
\text{(D}_{2\varepsilon}\text{)}: \quad \min & \quad \lambda_0 + [\rho - \varepsilon ([e^-]^T S^- + [e^+]^T S^+)] \\
\text{s.t.} & \quad \sum_{j=1}^n y_j \lambda_j + S^- = \rho x_0 \\
& \quad \sum_{j=1}^n y_j \lambda_j - S^+ = y_0 \\
& \quad \lambda_j \geq 0 \quad (j = 1, 2, \cdots, n); S^- \geq 0; S^+ \geq 0 \\
& \quad \sum_{j=1}^n \lambda_j = 1 \quad (j = 1, 2, \cdots, n)
\end{align*}
\]

among them \([e^-]^T = [1,1,\cdots,1] \in E_m, [e^+]^T = [1,1,\cdots,1] \in E_e\). It is necessary here for the \(\mu_0\) be explained: \(\mu_0\) is the variable of return on scale \([1]\).

Theorem 1.3 if set \(\lambda^0\), \(S^{-0}\), \(S^{+0}\), \(\rho^0\) is with \(\varepsilon\) linear programming model \((D_{2\varepsilon})\) optimal solution:

1. If \(\rho^0 = 1\), then \(DMU_{j_0}\) effective for DEA weak; (2) If \(\rho^0 = 1\) and \(S^- = 0, S^+ = 0\), when \(DMU_{j_0}\) effective for DEA; (3) If \(\rho^0 < 1\), then \(DMU_{j_0}\) invalid for DEA.

Pure technical efficiency for \(n\) decision units \(\rho\) for evaluation and analysis, pure technical efficiency refers to the effect of economies of scale. The ability of a decision unit to give the maximum output under a given input reflects the impact of the system and management level of the decision unit on the overall efficiency.

3. Related concepts and evaluation methods of Beijing-Tianjin-Hebei environmental efficiency

3.1. Influencing factors of environmental efficiency

The size of the per capita GDP value can objectively reflect the true level and difference of the economy in each region. In addition, there is also an industrial structure. At the current stage, the level of technology is limited, so a large amount of energy consumption and pollution emissions cannot be avoided. The speed of resource regeneration cannot make up for the consumption of resources, and loopholes with reduced environmental efficiency will eventually emerge \([1]\).

Due to the incompleteness of some legal systems, the location choice of foreign direct investment has not been affected by environmental regulations, and the final result is that these countries have more and more dirty industries and environmental pressure is increasing day by day. Therefore, the impact of the degree of opening up on the environmental efficiency of a country is uncertain \([1]\).
Regional differences are reflected in many aspects, such as geographical location, population density, and cultural differences. Due to the existence of these differences, each city also has different aspects such as the degree of infrastructure improvement. And environmental efficiency is also very different, so the impact on environmental efficiency will be ambiguous [1].

3.2. Decision unit and index system

In this paper, a total of 13 cities in Beijing, Tianjin, and Hebei are used as samples for decision-making units. Due to the limitation of the model's degree of freedom, that is, based on 13 decision-making units, it is determined to introduce 6 indicators, 1 output indicator, and 5 input indicators [1].

Under the above criteria, select the input and output indicators. Input indicators: year-end total population, fixed asset investment, industrial wastewater emissions, industrial sulfur dioxide emissions, industrial dust emissions. Due to restrictions on data availability, all cities the labor population data is unavailable, so the total population at the end of the year is used to represent it; it is also limited by the availability of data, so it is expressed using the total regional fixed asset investment; sulfur dioxide is selected to take into account its most serious environmental harm, which is fog one of the main components of haze; the other two environmental variables are selected mainly because of the comprehensiveness of environmental factors. Output indicators: regional GDP is the actual regional GDP, which is the true level of economic development of a city. These indicators are now divided into input indicators and output indicators. In order to concisely and completely reflect the characteristics of the data, data from the three years of 2018, 2017, and 2016 were selected.

3.3. Data processing

According to the selected input-output indicator data for 2016-2018, bring the data into \( \varepsilon \) of \( R_2^C \) and \( BC^1 \) model, and calculating the comprehensive technical efficiency of 13 cities in 2016-2018. \( \theta^0, \rho^0 \) with \( S^0 \). and \( S^0 \) by \( S^0 = \theta^0 / \rho^0 \) the calculation yields pure scale efficiency. The results of the calculation of the DEA effectiveness of the environmental efficiency are shown in Table 1.

| City            | \( \theta^0 \) | \( \rho^0 \) | \( S^0 \) | \( \theta^0 \) | \( \rho^0 \) | \( S^0 \) | \( \theta^0 \) | \( \rho^0 \) | \( S^0 \) |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Beijing         | 1.000           | 1.000           | 1.000           | 1.000           | 1.000           | 1.000           | 1.000           | 1.000           | 1.000           |
| Tianjin         | 0.995           | 1.000           | 0.995           | 1.000           | 1.000           | 1.000           | 1.000           | 1.000           | 1.000           |
| Shijiazhuang    | 0.989           | 0.994           | 0.995           | 1.000           | 1.000           | 1.000           | 1.000           | 1.000           | 1.000           |
| Tangshan        | 0.990           | 1.000           | 0.990           | 1.000           | 1.000           | 1.000           | 1.000           | 1.000           | 1.000           |
| Qinhuangdao     | 0.984           | 0.990           | 0.994           | 0.995           | 1.000           | 0.995           | 1.000           | 1.000           | 1.000           |
| Handan          | 0.974           | 0.981           | 0.993           | 0.982           | 0.989           | 0.993           | 0.990           | 1.000           | 0.990           |
| Xingtai         | 0.940           | 0.946           | 0.994           | 0.945           | 0.956           | 0.988           | 0.960           | 0.963           | 0.996           |
| Baoding         | 0.957           | 0.961           | 0.996           | 0.973           | 0.975           | 0.997           | 0.978           | 0.985           | 0.993           |
| Zhangjiakou     | 0.971           | 0.973           | 0.998           | 0.979           | 0.980           | 0.999           | 0.985           | 0.987           | 0.997           |
| Chengde         | 0.977           | 0.983           | 0.994           | 0.986           | 0.999           | 0.987           | 1.000           | 1.000           | 1.000           |
| Cangzhou        | 0.986           | 0.992           | 0.994           | 1.000           | 1.000           | 1.000           | 1.000           | 1.000           | 1.000           |
| Langfang        | 0.988           | 1.000           | 0.988           | 1.000           | 1.000           | 1.000           | 1.000           | 1.000           | 1.000           |
| Hengshui        | 0.943           | 0.953           | 0.989           | 0.958           | 0.967           | 0.991           | 0.979           | 0.989           | 0.990           |
| average         | 0.976           | 0.983           | 0.994           | 0.986           | 0.990           | 0.996           | 0.992           | 0.994           | 0.997           |

4. Conclusion

As can be seen from Table 1, the average comprehensive technical efficiency of the 13 cities in the
three years from 2016 to 2018 was 0.976, 0.986, and 0.992, reflecting the steady development of the urban environment in the Beijing-Tianjin-Hebei region. Significantly improved.

Based on the data from the above three years, we can see that the environmental improvement in the Beijing-Tianjin-Hebei region has a gap with the standards of developed countries. During the three years, only Beijing was effective. Therefore, the urban environmental efficiency of the Tianjin-Hebei region is still not good. Cities need to continue to explore and optimize the favorable factors and improve the disadvantages to improve the overall technical efficiency and continue to stimulate the Beijing-Tianjin-Hebei region integrated development.

The average overall efficiency was 0.983, 0.990, and 0.994, reflecting the steady improvement in the technical conditions for maintaining the urban environment in the Beijing-Tianjin-Hebei region. In the past years, Beijing, Tianjin, Tangshan, The pure technical efficiency of Langfang is 1. This is due to the impact of the reform and development of these cities in recent years, which have led all aspects of society to a new stage. In addition, the shortcomings of pure technical efficiency in other cities are mainly due to industrial production. Caused by unscientific management and investment ratio.

It can be seen that the average overall efficiency of the 13 cities in the three years is 0.994, 0.996, and 0.997, reflecting that most cities in the Beijing-Tianjin-Hebei region have medium-to-upper-level efficiency. Only Beijing, Tianjin, Shijiazhuang, Tangshan, Cangzhou, and Langfang have been effective for the last two years. The reasons for the inefficiency of scale in other cities may be the level of environmental governance or the development of industrial production structures.

4.1. Suggestion

According to the verification of the above data, it can be obtained that Hebei Province is the most serious, but its GDP is more than the sum of Beijing and Tianjin. In addition, Beijing, Tianjin and Hebei have relevant documents and systems for ecological environment compensation, and they are not based on the integration of the three regions. It is also one of the main reasons for the unfair development of the Beijing-Tianjin-Hebei region and the uneven overall environmental efficiency.

First, increase the proportion of cutting-edge manufacturing. Make Beijing comprehensively promote the coordinated development of the Beijing-Tianjin-Hebei region. Tianjin, as a port and gateway for the three regions to open to the outside world, must continue to adhere to the development of industry. We must spare no effort to raise the standard of the modern service industry and strive to quickly build an international metropolis with advanced and developed logistics ports. At the same time, we need to further improve financial services. Hebei Province should continue to adhere to "agricultural security, industrial connotation, the service industry will expand in size. Geographically adjacent to Beijing and Tianjin, in order to meet the supply and demand of the agricultural and sideline markets in the three regions, ecological modern agriculture should be developed; followed by the transformation and upgrading of the industrial structure, scientific and rational production, and avoiding waste. The phenomenon of resources meets the requirements of a low-carbon environmentally-friendly circular economy; in addition, it expands the green tourism industry and turns it into a leisure and entertainment destination in Hebei.

Second, improve the related efficiency of technology: transfer large-scale technologies from technology sources to the Beijing-Tianjin-Hebei region. In the Beijing-Tianjin-Hebei region and the country as a whole, Beijing is a center of academic achievements in scientific and technological resources, the proportion of these achievements into actual and applied to life is not high. Although there are many enterprises in Hebei Province, their innovation capacity is the biggest deficiency, so Beijing's innovative technology can be applied to enterprises in Hebei Province to maximize knowledge. Turn it into production capacity and solve practical problems.

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