Evaluation of Air Pollution Control Efficiency in Hebei Province Based on DEA Method

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Abstract. In this paper, the operation cost, the total investment in environmental infrastructure construction, the exhaust gas treatment facilities are selected as the input variables and the industrial exhaust gas emission, the industrial SO\textsubscript{2} removal quantity, the industrial dust removal quantity and the industrial dust removal quantity as output variables of air pollution control. Besides, the efficiency of air pollution was controlled in Hebei province from static and dynamic aspects were measured from 2005 to 2015 by exploiting BC2 model. Finally, according to the analysis results, corresponding policy suggestions are given from different perspectives, including strengthening independent innovation capability, adjusting and optimizing industrial structure, increasing investment in pollution control, optimizing capital source and using structure of pollution control, and constructing reasonable and effective external supervision mechanism.

1. Introduction
Hebei province is an economically underdeveloped and ecologically sensitive region in the Beijing-Tianjin-Hebei urban agglomeration. At present, the number of motor vehicles in the province is increasing, the demand for coal and natural gas is growing, and the industrial exhaust emission treatment facilities are still improving. Although environmental protection has been gradually attracted more attention, the air pollution in the province is relatively serious. However, the input of human resources, material resources and financial resources to air govern in Hebei province has not reached the desired balance with the output variables of economic and environmental improvement.

Since the 1930s, the continuous occurrence of environmental pollution events has sounded an alarm for the blind pursuit of economic development. Poland's mismanagement of natural resources had caused serious environmental problems in recent decades (Wesolowski J J et al., 1992). [1] Through the research, it is concluded that environmental policies and risk reduction strategies can effectively guide the conclusions in environmental risk assessment and management procedures. According to Olivia Braspenning Radu et al. (2016), a comprehensive model of ten situations is suggested, including the development of an image framework, in order to assess the global environment and quantitatively analyze the impact of different assumptions and policies on future climate and air pollution, greenhouse gas and air pollutant emissions. [2] Grossman and Krueger (1995) studied the changes of 14 kinds of air pollution and water pollution substances in 66 countries including the United States and the United Kingdom in 12 years. [3] Furthermore, they built a cubic
function model by adding population, industrial structure, trade and other variables, and found an inverted u-shaped curve between environmental indicators and GDP per capita indicators.

Chinese research can be elaborated from two aspects. Firstly, it is related to the research on environmental and atmospheric pollution control in other countries. Zhou (1983) concluded that the degree of environmental damage is related to the level of production and consumption and the improvement and efficiency of waste gas treatment systems and facilities in various countries. [4] According to Li X et al. (1996), the research progress of nitrogen oxide gas treatment in foreign countries is showed, and they proposed that the treatment of nitrogen oxide pollutants has not yet had the advantages of wide application, high efficiency and low cost. [5] The other is the study of domestic air pollution. Xu (1994) used the method of fuzzy evaluation to quantitatively and comprehensively evaluate the three pollution factors of the atmosphere of Beilungang power plant: TSP, SO2 and NO. [7] The harm of air pollutants on human respiratory system from the concentration of airborne dust, sulfur dioxide and nitrogen oxides in the atmosphere and the related changes of disease spectrum in Hangzhou urban area, and concluded that the combined effect of these three pollutants was more harmful. (Chen C et al., 2011) [8]

2. Relevant theories and methods

2.1. Introduction to DEA basic model

Data envelope analysis was proposed by a.c. harenes, w. cooper and e. rhodes (1978), professors from the university of Texas, USA, in an article titled "Measuring the Efficiency of Decision Making Units" published in the journal of "European operations research". It showed a whole new field in operations research -- data envelopment analysis, or C²R for short. (data envelopment analysis is based on the non-return to scale premise, named after the initials of Charenes, Cooper, and Rhode.) Later, r.d.banker, a. cooper and w. cooper (1984) gave the BC² model.

2.2. BC² model

Since the C²R model is based on the premise of constant return to scale, it is no longer applicable to study the case of variable return to scale. Therefore, the BC² model with variable return to scale is proposed, and its expression is as follows:

\[ \text{(P) } _{BC^2_R} \begin{cases} \max(\mu^TY_0 - \mu_0) \\ s.t. \sum_{j=1}^n x_jy_j - \mu^TY_0 + \mu_0 \geq 0, \quad (j = 1, 2, \ldots, n) \\ \sum_{j=1}^n x_j = 1 \\ \omega \geq 0, \mu \geq 0 \end{cases} \]

(1)

\[ \text{(D) } _{BC^2_R} \begin{cases} \min \delta \\ s.t. \sum_{j=1}^n x_j \lambda_j \leq \delta x_0 \\ \sum_{j=1}^n x_j \lambda_j \geq y_0 \\ \sum_{j=1}^n \lambda_j = 1 \\ \lambda_j \geq 0, \quad (j = 1, 2, \ldots, n). \end{cases} \]

(2)

In equation (1), it is explained as follows: when \( \mu_0 = 0 \), it means that the return on scale of production remains unchanged and the output increases in proportion to the input. When \( \mu_0 < 0 \), it indicates that the yield to scale is increasing, and the increase rate of output is greater than the input. When \( \mu_0 > 0 \), it indicates that the production is in diminishing returns to scale and the increase of output is less than the input.
3. Evaluation of air pollution control efficiency in Hebei province

3.1. Index selection and data sources

This paper studies the air pollution control efficiency in Hebei province, which involves multiple inputs and outputs, and DEA model itself has the advantage of complex analysis of multiple inputs and outputs. Based on the previous analysis of the current situation of air pollution control in Hebei province, the BC2 model was employed to analyze the relative efficiency of air pollution control in Hebei province in order to draw lessons from the existing research.

3.1.1. Index selection. When analyzing the current situation of air pollution, industrial exhaust emission, SO$_2$ emission, industrial SO$_2$ emission, smoke emission and dust emission are selected. When analyzing the situation of air pollution control, the two indexes of waste gas control investment and the completed investment of environmental control project in this year are selected to calculate the proportion of waste gas control investment in the whole environmental protection investment, which can well reflect the situation of air pollution control. The main input in air pollution control includes flowing elements and fixed assets. The input can be reflected by the input of human and material resources in the operation of air pollution control facilities and the input of air pollution control facilities. Considering the availability of data, the removal amount of air pollutants can be directly reflected as the effect of pollution control. The operating cost of waste gas treatment is the representative feature of air pollution control. The operating cost of waste gas treatment can reflect the input of various production factors such as energy and manpower for air pollution control. Therefore, the selected input and output indicators are shown in table 1.

| Input indicators | Output indicators |
|------------------|------------------|
| x1 Current operating expenses | y1 Industrial emission |
| x2 Total investment in environmental infrastructure construction | y2 Total industrial SO$_2$ emissions |
| x3 Waste treatment equipment | y3 Total industrial smoke emission |
|                 | y4 Total industrial dust exhaust emissions |

3.1.2. The data source. The data of this paper are from statistical yearbook of Hebei province, development yearbook of Hebei province and China environmental statistical yearbook from 2004 to 2015. Hebei province was selected as the DMU for investigation to conduct static and dynamic evaluation of air pollution control efficiency, and the original data of input and output indexes were selected. Since the original data in this paper comes from different almanacs, there are different decimal places, so it is required to keep three decimal places after all data.

3.2. Current situation of air pollution and control in Hebei province

3.2.1. The present situation and characteristics of air pollution in Hebei province. As can be seen from table 2 below, industrial exhaust emissions in Hebei province are divided into two stages. From 2012 to 2015, industrial emissions were basically stable, and the national policy gradually favored green economic development. As can be seen from figure 1, the SO$_2$ emission in Hebei province has only a small change and a trend of gradual reduction, indicating that the government is paying more and more attention to coal desulfurization and gasoline pretreatment. On the whole, 2011 was the worst year for environmental pollution in the past 11 years. After 2011, the provincial emergency plan for energy conservation and emission reduction was launched, so the emission fell.
Table 2. Air pollutant emission in Hebei Province 2005—2015

| Year | Industrial emission | Total industrial SO2 emissions | Total industrial smoke emission | Total industrial dust exhaust emissions |
|------|---------------------|---------------------------------|---------------------------------|---------------------------------------|
| 2005 | 26518               | 1281000                         | 560000                          | 26518                                 |
| 2006 | 39254               | 1326000                         | 553000                          | 39254                                 |
| 2007 | 48036               | 1294000                         | 464000                          | 48036                                 |
| 2008 | 37558               | 1159000                         | 396000                          | 37558                                 |
| 2009 | 50779               | 1043000                         | 330000                          | 50779                                 |
| 2010 | 56324               | 994000                          | 500000                          | 56324                                 |
| 2011 | 77185               | 1317099                         | 1223502                         | 77185                                 |
| 2012 | 67647               | 1238738                         | 1055732                         | 67647                                 |
| 2013 | 79121               | 1173147                         | 1187198                         | 79121                                 |
| 2014 | 72732               | 1047351                         | 1450723                         | 72732                                 |
| 2015 | 78570               | 829414                          | 1111046                         | 78570                                 |

Figure 1. Column chart of pollutant emission in Hebei province from 2005 to 2015

3.2.2. Air pollution control in Hebei province. The Chinese government's investment in environmental pollution control has been increasing year by year, and the amount of investment generally accounts for 1.2% to 1.4% of the GDP. From the perspective of pollution control in western countries, when the proportion of investment is 1%-2%, pollution can only be prevented from worsening, and only when the proportion of investment is 2%-3% can environmental quality be effectively changed. Therefore, China needs a large amount of financial input to improve environmental quality. As can be seen from figure 2 below, only in 2010, 2011 and 2012 did investment in waste gas treatment account for more than 2% of GDP in Hebei province, while in other years, investment accounted for less than 2% of GDP.
3.3. Analysis of air pollution control efficiency in Hebei province

Through the descriptive analysis of the original data of Hebei province, we can have a preliminary understanding of the input and effect of air pollution control in Hebei province. Although the investment in air pollution control in Hebei province has been increasing every year in the past 11 years, the control situation is not very optimistic. Therefore, it is necessary to understand the specific relationship between the input and output in Hebei province in the past 11 years. The following is a systematic analysis of air pollution control efficiency in Hebei province from the BC$^2$ model.

3.3.1. Efficiency analysis based on BC$^2$ model. As can be seen from table 3 below, the returns to scale in 2008, 2010 and 2012 were decreasing, while the technical efficiency was greater than the scale efficiency, indicating that the low scale efficiency was the main reason for the inefficiency of the comprehensive efficiency. Therefore, it is necessary not only to improve pollution control technology, but also to adjust the investment scale accordingly. Under the premise that the input factors increase in the same proportion, the output will increase in a larger proportion. Therefore, Hebei province only needs to adjust the investment in air pollution control to achieve the scale efficiency and then realize the comprehensive efficiency. The return to scale remained unchanged for the other eight years. Over the past 11 years, the trend of remuneration to scale in Hebei province has been unclear, and it is impossible to predict the future remuneration to scale. However, on the whole, the efficiency of air pollution control in Hebei province has achieved initial results. Although it cannot be compared with Shanghai and Zhejiang, there is some room for improvement to achieve comprehensive efficiency.
Table 3. Efficiency of air pollution control in Hebei Province from 2005 to 2015 (Cont)

| years | crste  | vrste  | scale | Scale reward |
|-------|--------|--------|-------|--------------|
| 2005  | 1.000  | 1.000  | 1.000 | -            |
| 2006  | 1.000  | 1.000  | 1.000 | -            |
| 2007  | 1.000  | 1.000  | 1.000 | -            |
| 2008  | 0.850  | 0.879  | 0.967 | drs          |
| 2009  | 1.000  | 1.000  | 1.000 | -            |
| 2010  | 0.960  | 0.961  | 0.999 | drs          |
| 2011  | 1.000  | 1.000  | 1.000 | -            |
| 2012  | 0.974  | 0.993  | 0.981 | drs          |
| 2013  | 1.000  | 1.000  | 1.000 | -            |
| 2014  | 1.000  | 1.000  | 1.000 | -            |
| 2015  | 1.000  | 1.000  | 1.000 | -            |

Refer to Table 3 (continued).

| Input relaxation variable | Output relaxation variable |
|---------------------------|---------------------------|
| s1            | s2         | s3         | s4         | s1         | s2     | s3     | s4     |
| 0.000         | 0.000      | 0.000      | 0.000      | 0.000      | 0.000  | 0.000  | 0.000  |
| 0.000         | 0.000      | 0.000      | 0.000      | 0.000      | 0.000  | 0.000  | 0.000  |
| 0.000         | 0.000      | 0.000      | 0.000      | 0.000      | 0.000  | 0.000  | 0.000  |
| 22878.042     | 0.000      | 48.231     | 0.000      | 0.000      | 0.000  | -108747.127 | 0.000  |
| 0.000         | 0.000      | 0.000      | 0.000      | 0.000      | 0.000  | 0.000  | 0.000  |
| 0.000         | 0.000      | 58.947     | 0.311      | 0.000      | 0.000  | -61172.417 | -60789.434 | 0.000  |
| 0.000         | 0.000      | 0.000      | 0.000      | 0.000      | 0.000  | 0.000  | 0.000  |
| 61133.501     | 441.575    | 43.869     | 0.000      | 0.000      | 0.000  | 0.000  | 0.000  |
| 0.000         | 0.000      | 0.000      | 0.000      | 0.000      | 0.000  | 0.000  | 0.000  |
| 0.000         | 0.000      | 0.000      | 0.000      | 0.000      | 0.000  | 0.000  | 0.000  |

Data source: calculated by DEAP

4. Conclusion and Thinking

4.1. Conclusion

The efficiency of air pollution control in Hebei province is analyzed from static and dynamic perspectives. It can be seen from the static analysis that the increasing and decreasing trend of returns to scale in Hebei province from 2005 to 2015 is unknown, and the returns to scale in 2008, 2010 and 2012 are decreasing, while the remaining returns to scale remain unchanged. Later, the input-output analysis showed that there was insufficient output, among which the third output was as high as 108747 in 2008, and there was also input redundancy. The input factors in 2010 and 2012 were relatively high, indicating that the waste of resources was particularly serious in the process of environmental pollution control in Hebei province in these two years. It can be seen from the dynamic analysis that the comprehensive efficiency of environmental pollution control in Hebei province is at a very high level, while the pure technical efficiency and scale efficiency are relatively effective. From the perspective of a single year, there is a trend of diminishing returns to scale in Hebei province in recent years, which indicates that in the process of environmental pollution control investment in Hebei province, there is too much emphasis on investment scale, but no improvement of technical efficiency. The root cause may be the problem of both pure technical efficiency and scale efficiency.
4.2. Thinking
Air pollution follows the development of industrialization and urbanization, and air pollution has hindered the development of social economy. Based on a preliminary understanding of the current situation of air pollution and its treatment in Hebei province, the efficiency of air pollution treatment in Hebei province is analyzed with DEA model, and based on the actual situation in Hebei province, some Suggestions are proposed:

4.2.1. Increasing the utilization of capital makes the input redundant into effective investment. From 2005 to 2015, Hebei province continuously strengthened its investment in air pollution control. In 2008, 2010 and 2012, the investment in air pollution control appeared to be redundant, indicating that there was a disproportionate proportion between the control investment and the control effect, and the utilization rate of the fund for air pollution control was low. Therefore, it is necessary to improve the utilization of capital to turn redundancy into effective investment. Specific measures: the redundancy will be used to improve the management level of environmental protection departments and strengthen supervision, so as to control the emission of air pollutants from the source; Use redundancy in the development and use of energy saving and emission reduction technologies; Using redundancy to promote clean energy; Use redundancy to guide low-carbon travel.

4.2.2. We will increase investment in environmental protection and raise the level of governance technology. According to the analysis, the mean value of comprehensive air pollution control efficiency in Hebei province in the past 11 years was less than 1, while the technical efficiency showed no significant positive growth. This shows that at present, Hebei province is more dependent on energy, capital and manpower, and less dependent on knowledge and technology investment. Therefore, the government should increase the funds for air pollution control, so as to increase the investment in science and technology and improve the control technology. The government can work with relevant local research institutions to develop technical solutions appropriate to the local environment. Specific technologies may contain emission reduction technologies for pollution sources PM10 and PM2.5; Desulfurization, dust removal and other technologies of coal-fired plants; Waste recycling technology.

4.2.3. Construction of ecological compensation system. In order to ensure the coordinated development of the 14 prefectures in Hebei province and improve the overall environmental efficiency, a complete provincial ecological compensation system should be established. The establishment of the system is based on the ecological protection and economic development, and the balance of various interests in the development process is considered. In addition to government compensation, market mechanism can also be introduced, and supply channels of ecological compensation funds can be increased. Only in this way can the principle of ecological compensation system of "who pollutes, who governs" be met. The compensation standard can be determined by the combination of top-down and bottom-up. Reasonable determination of compensation objects can ensure the efficient use of compensation funds; Compensation can be diversified, not limited to cash compensation; Passive compensation will be transformed into development compensation and blood transfusion compensation into blood type compensation, so as to ensure the sustainability of environmental protection compensation in Hebei province.

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