Impact of Environmental Regulation on Industrial Green Efficiency——Based on Non-radial SBM Model

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Abstract. In this paper, the industrial green efficiency of each province is measured by the non-radial SBM model, and then makes a tobit regression of environmental regulations with green efficiency. Finally, the heterogeneity of the region and the heterogeneity of efficiency are analyzed.

Keywords: Environmental Regulation, Industrial Green Efficiency, Non-radial SBM Model

1. Introduction
China's economy is in a stage of rapid development, the quality of the environment it faces is deteriorating. Environmental pollution and resource shortage issues have become prominent and have become important factors restricting sustainable economic development. Designing and implementing scientific and reasonable environmental regulations has become an effective means of solving energy and environmental problems. The only way for sustainable development is to change China's industrial development model and achieve a win-win situation for intensive industrial development and green development. Industrial green efficiency is the key to achieving energy-saving emission reduction and industrial win-win development. Therefore, the continuous improvement of industrial green efficiency through reasonable environmental regulations and policies will naturally become the inevitable way of new industrialization. This article starts with the environmental reduction policy and discusses the heterogeneous effects of environmental regulation on industrial green efficiency. Test whether environmental regulation policies have really played a role in improving green efficiency [1-4].

2. Literature review
With the economic and social development, people pay more and more attention to environmental issues strengthens energy conservation and emission reduction, and vigorously build a green and clean society is an important task in China. However, as the main body of energy conservation and emission reduction, companies often fails to consciously fulfill their obligations to protect the environment, so environmental regulations are needed. Environmental regulation refers to the government's direct or indirect intervention in the environment. Zhao Yumin (2009) proposed that environmental regulation aims at environmental protection, takes individuals or organizations as the object, and takes tangible system or intangible consciousness as the binding force [5-8].
In studying the relationship between environmental regulation and regional environmental efficiency, Gao et al. (2018) found that there is a "U" relationship between the intensity of environmental regulation and the degree of green mining. Li Shanshan (2019) research found that environmental regulation has a threshold effect on carbon emission efficiency. The influence of different types of environmental regulations was studied on China's green productivity. Rong et al. (2016). Yan W et al. (2016) studied the influence of environmental regulations on polluting and clean industries, and found that the intensity of regulation was negatively related to polluting industries and positively related to clean industries. Xiongfen P et al. (2017) studied the effect of both command-and-control and market incentive regulations on energy efficiency [9-10].

With regard to the choice of research methods for efficiency, Lin Boqiang (2019) uses a non-radial direction distance function to construct a green economic efficiency index that can evaluate cities at the prefecture level and above in the framework of super-efficiency DEA. Jie W et al. Used a DEA model that takes into account undesired output to measure the industrial agglomeration and efficiency of various provinces in China. Meiting F et al. Used the GML index method to estimate and decompose the total factor CO2 emission efficiency. Nicholas Apergis et al. Used a non-radial SBM model to measure the energy efficiency of OECD member countries. Yiwen B et al. Used a non-radial DEA method to measure China's regional energy efficiency. Yan Z et al. Used a non-radial SBM model to evaluate the environmental efficiency of China's power industry. Peng Daiyan (2019) and others measured energy efficiency based on the super-efficiency DEA model and Malmquist index.

To sum up, in the previous studies, there have been many studies on the relationship between total factor productivity and environmental regulation. Radial DEA models with undesired outputs are often used to measure industrial green efficiency. This paper studies the relationship between environmental regulation and the industrial green efficiency of various provinces in China. The non-radial SBM model is used to measure the green efficiency of each province, and then the entropy method is used to calculate a comprehensive index for different kinds of environmental regulations. The environmental regulation index performs panel tobit regression on green efficiency, and finally analyzes the heterogeneity of the region and the heterogeneity of efficiency [11].

3. Methods and Data

We consider each province as an independent decision-making unit to consider its optimal production boundary. Fare et al. (2007) constructed a set of production possibilities that contains both "good" and "bad" outputs. That is, we assume that there are k provinces in environmental technology. The industrial production input of each province is x, and the "good" output is x, the expected output is x, and the "bad" output is the undesired output. Get a set of production possibilities:

The reason why SBM model is better than DEA model is that it depends on input and output data to obtain the corresponding technology frontier and the efficiency evaluation of each decision unit (DMU) relative to the reference technology, and does not need to set the best behavior goals of producers at the same time. Different from the traditional DEA model, it directly introduces the relaxation variable into the objective function. In this way, on the one hand, it solves the problem of poor input-output, on the other hand, it solves the problem of efficiency evaluation under unexpected output. At the same time, SBM model belongs to the non-radial and non-angle measurement methods in DEA model, so as to avoid the deviation and influence caused by the difference of radial and angular selection. Therefore, in this sense, it can better reflect the essence of efficiency evaluation than other models. We consider each province as an independent decision unit to consider its optimal production boundary, with inputs m, good output s1, bad output s2, x ∈ R^m, y^g ∈ R^y, y^b ∈ R_y^b. We get a set of production possibilities:

P = \{(x, y^g, y^b)| \lambda x \geq Y^g, y^g \leq Y^g, y^b \geq Y^b, \lambda \geq 0\}

Tone (2004) proposed an SBM model with undesired outputs:
\[
\begin{align*}
\min \rho &= \frac{1 - \left( \frac{1}{m} \right) \sum_{i=1}^{m} s_i / x_0}{1 + \left( \frac{1}{s_1 + s_2} \right) \left( \sum_{r=1}^{s_1} \frac{s_r^{g_a}}{y_0^{b_a}} + \sum_{r=1}^{s_2} \frac{s_r^{b}}{y_0^{b}} \right)} \\
 x_0 &= \lambda X + \bar{s}, y_0^{a} = Y_0^{a} - s_0^{a}, y_0^{b} = Y_0^{b} + s_0^{b}, \bar{s} \geq 0, s_0^{a} \geq 0, s_0^{b} \geq 0
\end{align*}
\]

This paper uses \( s_i \in R_m, s_0^{a} \in R_{y_0}, s_0^{b} \in R_{y_0} \) to respectively the slack of input, expected output and undesired output, \( \lambda \) is the weight variable, \( \lambda \geq 0 \).

When \( \rho = 1 \), the corresponding DMU is valid, it means \( \bar{s}_i = 0, s_0^{a} = 0, s_0^{b} = 0 \), if \( 0 < \rho < 1 \), the DMU is not valid. When \( \rho = 1 \), the corresponding decision unit is effective (SBM-efficient), which is equivalent to \( \bar{s}_i = 0 \), it means, in the optimal state, no input-output relaxation occurs.

\( 1 - \left( \frac{1}{m} \right) \sum_{i=1}^{m} s_i / x_0 \) represents the average reduction of factor input, and represents the inefficiency of input, and \( [1 + \left( \frac{1}{s_1 + s_2} \right) \left( \sum_{r=1}^{s_1} \frac{s_r^{g_a}}{y_0^{b_a}} + \sum_{r=1}^{s_2} \frac{s_r^{b}}{y_0^{b}} \right)]^{-1} \) represents the inefficiency of output. Multiplying this two parts is the overall inefficiency.

This article selects the data of 30 provinces in China from 2005 to 2015. The data mainly come from the 2006-2016 China Industrial Statistical Yearbook, China Environmental Statistics Yearbook, China Energy Statistics Yearbook, China Labour Statistics Yearbook, and the EPS database Data on.

Table 1. Index and data selection

| index                                      | Data selection                                                                 |
|--------------------------------------------|-------------------------------------------------------------------------------|
| Labor input                                | Average annual number of all employees in industrial enterprises above designated size |
| Energy input                               | Industrial energy consumption (equivalent to 10,000 tons of standard coal)    |
| Capital investment                         | The increase in industrial fixed assets above designated size is used as an approximate estimate of the capital stock (decrease with 2005 as the base period) |
| Expected output                            | The total industrial output value (industrial ex-factory product price index is deflated). Because some provinces lack data for 2013 and beyond, the total industrial output value in 2012 is calculated by using the ratio of 2012 and 2011 "industrial sales output value" |
| Unexpected output                          | Use the entropy method to give weight to industrial waste water, waste gas and solid waste and calculate a comprehensive indicator; industrial CO2 emissions Volume was estimated) |
| Investment-based environmental regulation  | Government environmental protection acceptance investment                      |
| Cost-based environmental regulation         | Ratio of sewage charges to GDP                                                |
| Conscious environmental regulation          | Total letters on environmental issues                                         |
| Command-and-control regulations regulation  | Actual number of environmental protection departments at the end of the year   |

Because the four types of environmental regulations have different units of measurement, we first normalize these four indicators, and then combine them into one indicator using the entropy method, and return the indicator with a lag of one period. At the same time, select \( x_1: \) GDP per capita, \( x_2: \) industrial structure (proportion of value added of the secondary industry to GDP), \( x_3: \) foreign investment (lnFDI), \( x_4: \) degree of innovation (number of patent applications), \( x_5: \) energy structure (coal
consumption accounts for total proportion of energy consumption, $x_0$: six variables of the urbanization rate of each province as control variables.

4. Result

1) Result of SBM efficiency.

Table 2. Industrial green efficiency values of provinces in China from 2005 to 2015

| Year   | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | Mean |
|--------|------|------|------|------|------|------|------|------|------|------|------|------|
| Beijing     | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Tianjin     | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.77 | 1.00 | 1.00 | 1.00 |
| Hebei       | 0.35 | 0.33 | 0.33 | 0.33 | 0.33 | 0.34 | 0.40 | 0.39 | 0.45 | 0.36 | 0.46 | 0.37 |
| Shanxi      | 0.22 | 0.21 | 0.20 | 0.23 | 0.24 | 0.23 | 0.21 | 0.27 | 0.20 | 0.19 | 0.23 | 0.23 |
| Inner Mongolia | 0.21 | 0.30 | 0.30 | 0.36 | 1.00 | 0.37 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.69 |
| Liaoning    | 0.37 | 0.39 | 0.39 | 0.41 | 0.51 | 0.51 | 0.60 | 0.76 | 0.60 | 1.00 | 0.58 | 0.55 |
| Jilin       | 0.27 | 0.28 | 0.28 | 0.30 | 0.30 | 0.29 | 0.29 | 0.33 | 0.31 | 0.33 | 0.34 | 0.33 |
| Heilongjiang | 0.46 | 0.36 | 0.27 | 0.33 | 0.26 | 0.29 | 0.29 | 0.33 | 0.31 | 0.33 | 0.34 | 0.33 |
| Shanghai    | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Jiangsu     | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Zhejiang    | 0.67 | 0.69 | 0.70 | 0.72 | 1.00 | 1.00 | 0.74 | 0.71 | 0.72 | 0.62 | 0.69 | 0.75 |
| Anhui       | 0.30 | 0.29 | 0.26 | 0.30 | 0.30 | 0.28 | 0.29 | 0.35 | 0.35 | 0.41 | 0.47 | 0.45 |
| Fujian      | 0.31 | 0.28 | 0.28 | 0.29 | 0.35 | 0.35 | 0.37 | 0.36 | 0.46 | 0.45 | 0.68 | 0.42 |
| Jiangxi     | 0.36 | 0.39 | 0.32 | 0.29 | 1.00 | 1.00 | 0.36 | 0.36 | 0.40 | 0.40 | 0.45 | 0.41 |
| Shandong    | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Henan       | 0.36 | 0.36 | 0.36 | 0.36 | 0.36 | 0.36 | 0.36 | 0.36 | 0.36 | 0.36 | 0.36 | 0.36 |
| Hubei       | 0.24 | 0.28 | 0.23 | 0.28 | 0.27 | 0.31 | 0.34 | 0.39 | 0.45 | 0.49 | 0.35 | 0.35 |
| Hunan       | 0.31 | 0.28 | 0.26 | 0.30 | 0.29 | 0.32 | 0.35 | 0.47 | 0.43 | 0.51 | 0.30 | 0.33 |
| Guangdong   | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Guangxi     | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 |
| Hainan      | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Chongqing   | 0.46 | 0.34 | 0.29 | 0.29 | 0.32 | 0.27 | 0.32 | 0.32 | 0.29 | 0.33 | 0.32 | 0.32 |
| Sichuan     | 0.29 | 0.31 | 0.26 | 0.31 | 0.26 | 0.26 | 0.26 | 0.26 | 0.26 | 0.26 | 0.32 | 0.30 |
| Guizhou     | 0.33 | 0.26 | 0.26 | 0.32 | 0.26 | 0.26 | 0.26 | 0.26 | 0.26 | 0.26 | 0.32 | 0.32 |
| Yunnan      | 0.33 | 0.34 | 0.27 | 0.39 | 0.26 | 0.26 | 0.26 | 0.26 | 0.26 | 0.26 | 0.34 | 0.31 |
| Shanxi      | 0.30 | 0.28 | 0.28 | 0.29 | 0.29 | 0.28 | 0.29 | 0.29 | 0.29 | 0.29 | 0.29 | 0.29 |
| Guan       | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Guangxi     | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 |
| Ningxia     | 0.40 | 1.00 | 0.29 | 0.31 | 0.27 | 0.29 | 0.29 | 0.29 | 0.34 | 0.43 | 0.34 | 0.40 |
| Xinjiang    | 0.40 | 0.39 | 0.31 | 0.42 | 0.37 | 0.32 | 0.32 | 0.31 | 0.29 | 0.30 | 0.29 | 0.33 |

As can be seen from the above table, Beijing, Tianjin, Shanghai, Jiangsu, Shandong, and Hainan provinces remain at the forefront of efficiency, that is, high levels of industrial green development. The industrial green efficiency of Sichuan, Chongqing and Guangxi is relatively low. Generally speaking, the level of industrial green efficiency in regions with good economic development is significantly higher.

2) Empirical result

The results of tobit regression using Stata are as follows:

Table 3. Basic regression results

| y       | Coef. | Std. Err. |
|---------|-------|-----------|
| X       | 1.4826*** | 0.2597 |
| x1      | 0.1044*  | 0.0592 |
| x2      | -0.0134*** | 0.0028 |
| x3      | 0.0357*** | 0.0168 |
| x4      | -0.0937*** | 0.0196 |
| x5      | -0.1326*** | 0.0487 |
From the regression results of all provinces across the country, there is a significant positive correlation between the intensity of environmental regulation and industrial green efficiency, indicating that increasing the intensity of environmental regulation can effectively improve the level of green efficiency of industrial enterprises. In terms of control variables, there is a positive correlation between GDP per capita and industrial green efficiency, indicating that economic development can effectively promote the improvement of green efficiency. The higher the proportion of the secondary industry, the lower the industrial green efficiency, indicates that the concentration of industrial industries can promote the improvement of green efficiency. There is a significant positive correlation between foreign investment and green efficiency. The possible reason is that foreign investment can promote industrial technological progress and improve efficiency. Coal consumption accounts for areas with high total energy consumption, and excessive use of non-clean energy leads to relatively low green efficiency. Areas with high urbanization rates have higher green efficiency, and it can be concluded that the development of cities will increase the green efficiency of industry. However, there is a negative correlation between innovation and industrial green efficiency. This article speculates that it may be due to the excessive investment in patent research and development by industrial enterprises, which reduces the reduction of green efficiency caused by the reduction of investment in pollution reduction and pollution control.

Then divides the country into two parts, the east and the midwest, and introduces dummy variables for regression:

\[ y = \beta_0 + \beta_1 x + \beta_2 x \text{region} + \beta_3 x \text{region} + X_i + \epsilon \]

Among them, \( y \) is the green efficiency value, \( x \) is the strength of environmental regulations, \( \text{region} \) is the dummy variable, the central and western regions are set to 1, \( X_i \) is the control variable, and \( \epsilon \) is the error term. The results are shown in column (1) in Table 3.

Then, the industrial green efficiency is divided into high and low efficiency regions according to the average value over the years, and dummy variables are also introduced for regression:

\[ y = \beta_0 + \beta_1 x + \beta_2 x \text{eff} + \beta_3 x \text{eff} + X_i + \epsilon \]

Among them, \( \text{eff} \) is a dummy variable in high and low efficiency areas, making the low efficiency area to be 1. The results are shown in column (2) in Table 3.

**Table 4. Regional heterogeneity and efficiency heterogeneity**

|        | (1)       | (2)       |
|--------|-----------|-----------|
| \( y \) | 1.192***  | 2.1214*** |
| \( x \) |           |           |
| \( x \text{region} \) | -1.041*** |           |
| \( \text{region} \) | 0.0021    |           |
| \( x \text{eff} \) |           | -1.6445***|
| \( \text{eff} \) |           | 0.1008    |
| \( x_1 \) | 0.0998*   | 0.0957*   |
| \( x_2 \) | -0.0118***| -0.0152   |
| \( x_3 \) | 0.0378**  | 0.0239    |
The results show that, compared with the eastern and central and western regions, the effect of environmental regulation in the eastern region is significantly stronger than that in the central or in the western regions; compared with the areas with higher efficiency and lower efficiency, the effect of environmental regulation in the high efficiency area is also significantly stronger than that in the low efficiency area. From this, we can conclude that in regions with better economic development, environmental regulations can better promote the improvement of industrial green efficiency.

5. Conclusion

Encouraging green technological innovation to promote industrial green development by formulating reasonable and effective environmental regulations is an urgent and important task of practical significance. Whether it's in the east or the Midwest, environmental regulation has a significant positive effect on industrial green efficiency in high-efficiency or low-efficiency regions. At the same time, the effects of environmental regulations have a time lag. Therefore, in response to different stages of industrial development and different regions, setting different types and intensity of environmental regulations can better promote industrial green development. This article gives the following policy recommendations:

1. Speed up the establishment of a low-carbon, green growth model for the industrial economy in the Midwest, and avoid the old path of pollution first and governance later.

2. Strengthen environmental supervision and law enforcement, control the pollution emission of enterprises from the source, and restrict industrial enterprises to choose more efficient production processes or management modes through a series of policies and regulations, and promote their green productivity.

3. Further improve the environmental regulatory system. On the basis of strengthening the existing level of regulation, more attention should be paid to the innovation of environmental regulatory tools in order to achieve the supporting and combined use of multiple regulatory tools.

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