Measuring the Efficiency of Industrial Green Transformation in China

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Based on the three-stage data envelopment analysis (DEA) model, this paper measures the efficiency of industrial green transformation of 30 provinces (autonomy region, municipality) in China from 2006 to 2015. Furthermore, this paper analyzes the efficiency level and the differences of regional industrial green transformation. Finally, the study proposes some suggestions for improvement of the industrial green transformation.

Key words: Green Transformation, Three-Stage DEA, Efficiency

Introduction
Global climate change and international competition pose a challenge to industrial development. Under the increasing pressure of resources and environment, the green transformation of China's industry has become an important direction for future development¹. This paper intends to use the three-stage DEA model to evaluate the efficiency and discuss influencing factors of industrial green transformation in China.

Methodology and models
DEA is a non-parametric efficiency evaluation method that uses a mathematical planning model to calculate the efficient value of each decision making unit²-³. To eliminate the influence of environmental factors and statistical noises, Fried et al. proposed a three-stage DEA method⁴. The three-stage DEA method has been used widely in efficiency evaluation⁵-⁷. This study utilizes the three-stage DEA model to evaluate the efficiency of the decision making unit. The first stage: The traditional DEA model. BCC method is used to handle validity problem of decision making unit under the assumption of variable returns to scale. This paper adopts the input-oriented BCC model to assess the efficiency. The second stage: SFA model. The SFA model is established to eliminate the environmental factors and random errors. The SFA approach can be constructed as:

\[ S_{ni} = f(z_i; \beta_n) + v_{ni} + \mu_{ni} \]

\[ i = 1, 2, \ldots, I, n = 1, 2, \ldots, N \]

Where \( S_{ni} \) denotes the input slack variable, \( z_i \) represents the environmental variable. \( \beta_n \) is the parameter to be estimated for environmental variable. \( v_{ni} + \mu_{ni} \) is hybrid error. Further, this study adjusts the input items of decision making units using the regression result of SFA model. The adjusted value of input variable \( \hat{x}_{ni} \) is computed as:

\[ \hat{x}_{ni} = x_{ni} + \left[ \max \left( f(z_i; \hat{\beta}_n) - f(z_i; \beta_n) \right) + \max(\sigma_{ni} - \hat{\sigma}_{ni}) \right] \]

\[ i = 1, 2, \ldots, I, n = 1, 2, \ldots, N \]

Where \( \hat{x}_{ni} \) is the input after adjustment, \( x_{ni} \) is the original input. \( \hat{\beta}_n \) is estimated value of parameter of environmental variables, \( \hat{\sigma}_{ni} \) is estimated value of random disturbance term.

The third stage: Adjusted DEA model. The adjusted inputs and original outputs are used in BCC model again. The results would be more realistic.

Variable selection and data
Input and output variables
From the perspective of input variables, this paper evaluates the industrial green transformation efficiency from four fields: the net value of fixed assets in the industrial sector is selected as capital input; the number of industrial employees in each region as labor input; investment completed in the treatment of industrial pollution, and the energy consumption. Output variables are divided mainly
This paper selects the total industrial output value to measure the desirable output. For the measurement of undesirable output, to measure comprehensively the efficiency of China's industrial green transformation, this paper selects the total volume of industrial waste water discharged, total volume of industrial sulphur dioxide emission, and carbon dioxide emissions as undesirable outputs, and takes their reciprocal value as output indicators. This paper estimates carbon dioxide emissions based on the method provided in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

**Environmental variables**

The following factors are selected as environmental variables in this paper: First, the intensity of R&D investment. Promoting technological progress are important means to reduce energy expenditures and promote industrial transformation and upgrading. It is represented by the R&D expenditure input intensity by region. Second, the energy structure. This paper uses the ratio of natural gas consumption to total energy consumption to represent the energy structure. Third, the industrial structure, it is represented by the ratio of value-added by industry to Gross Regional Product.

**Data**


**Empirical results and analysis**

**The evaluation results of stage 1**

At this stage, through the relevant data obtained, the BCC model is selected to analyze the industrial green transformation efficiency of China's 30 provinces (autonomy region, municipality) in 2006–2015. Without considering external environmental variables and random factors, the average technical efficiency (TE) of China's industrial green transformation is 0.640, the average of pure technical efficiency (PTE) is 0.702, and the average value of scale efficiency (SE) is 0.915. The average of pure technical efficiency is lower than the average value of scale efficiency.

**The evaluation results of stage 2**

At this stage, the SFA model is applied to analyze the slack variables of capital input, labor input, energy consumption, and the investment completed in the treatment of industrial pollution. The three environmental variables are regarded as explanatory variables. The SFA regression results of the second stage can be obtained by using Frontier 4.1, as shown in Table 1 and Table 2. The negative coefficients suggest

<table>
<thead>
<tr>
<th>Variables</th>
<th>Capital input</th>
<th>Labor input</th>
<th>Energy consumption</th>
<th>Investment completed in the treatment of industrial pollution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant term</td>
<td>46.40</td>
<td>-112.87</td>
<td>1716.89</td>
<td>-47187.92***</td>
</tr>
<tr>
<td>(0.06)</td>
<td>(-1.41)</td>
<td>(0.93)</td>
<td>(-7719.70)</td>
<td></td>
</tr>
<tr>
<td>The intensity of R&amp;D investment</td>
<td>8.70</td>
<td>-7.66</td>
<td>-1081.94***</td>
<td>-8679.70***</td>
</tr>
<tr>
<td>(0.07)</td>
<td>(-0.52)</td>
<td>(-3.08)</td>
<td>(-861.84)</td>
<td></td>
</tr>
<tr>
<td>The energy structure</td>
<td>-468.87**</td>
<td>-18.76</td>
<td>-2075.22***</td>
<td>-21755.23***</td>
</tr>
<tr>
<td>(-2.22)</td>
<td>(-0.73)</td>
<td>(-3.70)</td>
<td>(-4966.49)</td>
<td></td>
</tr>
<tr>
<td>The industrial structure</td>
<td>22.82</td>
<td>3.20*</td>
<td>43.73</td>
<td>2677.45***</td>
</tr>
<tr>
<td>(1.31)</td>
<td>(1.83)</td>
<td>(1.17)</td>
<td>(12.31)</td>
<td></td>
</tr>
<tr>
<td>σ²</td>
<td>6.89E+06***</td>
<td>3.87E+04***</td>
<td>4.69E+07***</td>
<td>1.68E+10***</td>
</tr>
<tr>
<td>(3.45E+06)</td>
<td>(3.10E+04)</td>
<td>(4.41E+07)</td>
<td>(1.68E+10)</td>
<td></td>
</tr>
<tr>
<td>Γ</td>
<td>0.74***</td>
<td>0.64***</td>
<td>0.91***</td>
<td>0.56***</td>
</tr>
<tr>
<td>(33.66)</td>
<td>(20.35)</td>
<td>(114.74)</td>
<td>(15.79)</td>
<td></td>
</tr>
<tr>
<td>LR test</td>
<td>176.31***</td>
<td>102.39***</td>
<td>363.54***</td>
<td>77.00***</td>
</tr>
</tbody>
</table>

Note: ***, ** and * indicate the significance level at 1%, 5%, and 10% respectively.
that the increase of the environmental variables’ value is beneficial to reduce input slacks. Conversely, the positive coefficients mean that environmental variables are unfavorable to the efficiency improvement. Specifically, the impacts of each environment variable are as follows:

- The intensity of R&D investment. The coefficients of the intensity of R&D investment are significant and negative to the slack variables of energy consumption and the investment completed in the treatment of industrial pollution, which indicates that the improvement of R&D investment intensity can save energy consumption and investment completed in the treatment of industrial pollution, and promote efficiency of industrial green transformation.

- The energy structure. There is a significant negative correlation between the proportion of natural gas consumption and the slack variables of capital input, energy consumption, and the investment completed in the treatment of industrial pollution. It is said that the increase of proportion of natural gas consumption is conducive to reducing the input of capital, energy consumption, and investment completed in the treatment of industrial pollution, which is conducive to improving the efficiency of industrial green transformation.

- The industrial structure. The coefficients of the industrial structure are significant and positive to the slack variables of labor input, and the investment completed in the treatment of industrial pollution, indicating that the increase of the ratio of value-added by industry to Gross Regional Product will bring about the increase of labor input, and investment completed in the treatment of industrial pollution.

The evaluation results of stage 3

Through comparison of the BCC model results of the first stage and the third stage, it can be found that the DEA efficiency score after eliminating the influence of environmental and random factors differs significantly from the DEA efficiency score in the first stage. After adjustment, the average value of technical efficiency increased in 22 provinces (autonomy region, municipality) This indicates that exterior environmental factors and random factors have an important impact on the efficiency value and should be taken into account in the analysis to restore a more authentic efficiency score. On the whole, eliminating environmental values and random factors, the average technical efficiency of China's industrial green transformation is 0.704, the national average pure technical efficiency is 0.980, and the national average scale efficiency is 0.718. The national average technical efficiency shows greater overall improvement than before adjustment. The adjusted national average scale efficiency value is lower than the average pure technical efficiency value. From the perspective of the regions, there are significant differences in average efficiency among different regions in China. The East China has a high level of comprehensive technical efficiency and scale efficiency. The technical efficiency of the North-east China, the Central South China, the South-west China and the North-west China is lower than the national average.

Conclusions and Recommendations

With the three-stage DEA model, this paper measure and analysis the efficiency of China's industrial green transformation from 2006 to 2015, and the results show that: (1) The industrial green transformation efficiency score eliminating the influence of environmental and random factors differs significantly from the efficiency score in the first stage. The exterior environmental factors and random factors have an important impact on the efficiency value and should be taken into account in the analysis to restore a more authentic efficiency score. (2) The increase of the intensity of R&D investment and the
proportion of natural gas consumption are conducive to the improvement of the efficiency of industrial green transformation. The increase of the ratio of value-added by industry to Gross Regional Product has unfavorable influences on the improvement of the efficiency of industrial green transformation. (3) There is a significant imbalance in the efficiency of industrial green transformation between regions in China. Based on this, to improve the efficiency of China’s industrial green transformation, this paper puts forward the following suggestions: (1) Improve the external environment for the efficiency of industrial green transformation. We should increase input intensity in research and development, and allocate scientific research funds in a reasonable way. In addition, we should promote industrial structure adjustment and upgrading, further improve the structure of energy consumption and increase the proportion of clean energy. (2) We should strengthen regional exchanges and cooperation to improve the efficiency of green industrial transformation. According to the objective reality of different regions, differentiated industrial green transformation policies are formulated to achieve coordinated development among the different regions.

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