DEA-based Ecological Efficiency Evaluation during the Process of Industrial Transformation in the Pearl River Delta Urban Cluster

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Abstract. In order to comprehensively evaluate the effect of industrial transformation, the concept of ecological efficiency was introduced in this paper due to its merit of integrating social, economic, and environmental factors. The indicator system and model of ecological efficiency evaluation was subsequently established, while the model based on data envelopment analysis is hopeful to reduce the subjectivity of evaluation. The case study on the Pearl River Delta Urban Cluster shows the generally increased ecological efficiency during the process of industrial transformation. However, the declined returns to scale implies the lack of satisfactory harmony among different cities in the Pearl River Delta Urban Cluster. Certain suggestions to improve ecological efficiency was put forward based on the results.

1. Introduction

Industrial transformation is undoubtedly a hopeful option of socio-economic development especially in the regions where the traditional economy has caused certain eco-environmental problems. In the past decades, many cities and regions in China has experienced the industrial transformation, the remained question is that whether the industrial transformation is effective, i.e., realizes the desired goal of harmonious socio-economic and eco-environmental development.

In order to comprehensively evaluate the effect of industrial transformation, the concept of ecological efficiency is introduced in this paper regarding its integration and linkage among social, economic, and environmental factors [1]. Although ecological efficiency has been widely studied on such scales as nation, region, and enterprise [2–6], there is few attempt from the viewpoint of industrial transformation. And more effective evaluation method is still necessary to resolve the existent problems, e.g., reducing the subjectivity of the evaluation.

Focusing on these demands, the evaluation method of ecological efficiency based on data envelopment analysis is constructed in this paper, attempting to evaluate the overall effect of industrial transformation. The case study is conducted for the Pearl River Delta Urban Cluster, the representative of industrial transformation in China with relatively long history and remarkable

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outcome. Certain suggestions to improve ecological efficiency is finally proposed based on the results.

2. Methodology

2.1. Concept of ecological efficiency

Although there are various understandings of ecological efficiency among different organizations and scholars [2, 4, 6–8], its essential point is always the efficiency, i.e., the ratio of the output to input for a system. Differing from the general efficiency, ecological efficiency also considers the resource and environmental factors besides the traditional economic factor, e.g., it investigates such undesired output as waste gas and wastewater besides economic output along with the resource and environmental input.

2.2. Evaluation indicators of ecological efficiency

According to the essential point of ecological efficiency, the evaluation indicator system were confirmed, when referring to indicators established in the traditional German economic account [1], the data availability and the correlation among different indicators. As indicated in Table 1, it mainly includes three aspects, i.e., resource, environment, and economy, in which the first two aspects mainly reflect the input dimension while the last one represents the output dimension. And it should be pointed out that the undesired output (i.e., environmental discharge) was regarded as the input indicator rather than output in this paper, when considering the following two facts. The first one is that it is difficult to collect accurate data of investment for dispose of undesired output, while the undesired output is an alternative. Another one is that the undesired output can be regarded as a kind of input per se for the environment since it needs absorption and dispose by the environment.

Table 1. The evaluation indicator system of ecological efficiency.

Dimension	Aspect	Item	Indicator
Input	Resource	Labor	Amount of employment at the end of the year
		Land	Area of cultivated land at the end of the year
			Area of built-up parts
		Water resource	Amount of non-residential water consumption
		Energy	Amount of non-residential electricity consumption
	Environment	Water environment	Amount of industrial wastewater discharge
		Atmospheric environment	Amount of industrial waste gas emission
Output	Economy		Gross domestic product

2.3. Evaluation model of ecological efficiency based on data envelopment analysis

The weights of different indicators are always an open question which may influence the results of comprehensive assessment. With the ability of conducting assessment without confirming weights of indicators, the method named as data envelopment analysis was selected to implement evaluation of ecological efficiency. To better satisfy the demand of dynamic evaluation of ecological efficiency during the process of industrial transformation, the BCC (Banker, Charnes, Cooper) model was applied in which the returns to scale is variable.

In the BCC model, it is assumed that there are n decision making unit and each unit has s input and t output. When x_j represents the input of the jth decision making unit, and y_j means the output of the jth decision making unit, then the efficiency of the jth unit can be converted into a problem of linear programming solution, when θ means the efficiency.

$$\min \theta$$

$$\mathrm{s.t.} \sum_{j \in n} \lambda_j y_j \leq \theta x_0 \quad (1)$$

$$\sum_{j \in n} \lambda_j y_j \geq y_0 \quad (2)$$

$$\sum \lambda_j = 1 \quad (3)$$

$$\lambda_j \geq 0, \quad j \in n$$

Concretely speaking, the decision making unit is the Pearl River Delta Urban Cluster and the nine typical cities, the input is that from resource and environment, while the output is the economic outcome.

In order to analyze the change of ecological efficiency during the process of industrial transformation, the Malmquist index was combined with the merit of time series analysis. The calculation is given in Eq. (4):

$$M(X^{t+1}, Y^{t+1}, X^t, Y^t) = [\frac{D^{t+1}(X^{t+1}, Y^{t+1}|CRS)}{D^{t+1}(X^t, Y^t|CRS)} * \frac{D^t(X^{t+1}, Y^{t+1}|CRS)}{D^t(X^t, Y^t|CRS)}]^{\frac{1}{2}} \quad (4)$$

where $D^t(X^t, Y^t)$ and $D^{t+1}(X^{t+1}, Y^{t+1})$ is the single stage distance function with fixed returns to scale, while $D^{t+1}(X^t, Y^t)$ and $D^t(X^{t+1}, Y^{t+1})$ is the inter-temporal distance function with fixed returns to scale.

The result parameter obtained from data envelopment analysis and Malmquist index can be mainly divided into three types, including the overall efficiency, the input slackness degree, and the change of efficiency.

(1) The overall efficiency

Pure technological efficiency: the efficiency influenced by management and technology,

Scale efficiency: the efficiency influenced by industrial scale,

Comprehensive efficiency: the integrated efficiency influenced by both technology and industrial scale.

(2) The input slackness degree

The input is redundant when the value of input slackness degree > 0, and the input is insufficient when the value < 0, and the input is suitable when the value = 0.

(3) The change of efficiency

Change of technological efficiency: the technological efficiency increases when the value ≥ 1, and the efficiency decreases when the value < 1,

Change of technological progress: the technological level improves when the value ≥ 1, and the technological level declines when the value < 1,

Change of pure technological efficiency: the pure technological efficiency increases when the value ≥ 1, and the efficiency decreases when the value < 1, Change of scale efficiency: the scale efficiency increases when the value ≥ 1, and the efficiency decreases when the value < 1,

Change of total factor productivity: it means the ratio of total production to total factor input. The total factor productivity increases when the value ≥ 1, and the efficiency decreases when the value < 1.

2.4. Data sources

Required data during 1997–2015 were mainly collected from various statistical yearbook, e.g., Guangdong Statistical Yearbook, China City Statistical Yearbook, Yangtze River Delta & Pearl River Delta and Hong Kong & Macao SAR & Tai Wan Statistical Yearbook, as well as the statistical yearbooks of the nine typical cities in the Pearl River Delta. Moreover, some data were acquired from the online resources, e.g., the website of municipal water authority and Guangdong statistical information.

3. Results and discussion

3.1. Overall ecological efficiency of the Pearl River Delta Urban Cluster

Based on the BCC model, the overall ecological efficiency of the Pearl River Delta Urban Cluster and nine cities were obtained, as shown in Table 2. Three findings are investigated from the results. (1) Except for Dongguan and Zhongshan, the comprehensive efficiency of other seven cities was higher than that of the Pearl River Delta Urban Cluster during the study period. It means that the usage of input was efficient in these seven cities when using that of the Pearl River Delta Urban Cluster as the baseline. (2) Although with relatively low comprehensive efficiency, Dongguan and Zhongshan had increased returns to scale during the study period, which implies that the ecological efficiency was gradually improved during the process of industrial transformation. (3) The Pearl River Delta Urban Cluster showed decreased returns to scale, although none city showed the same trend during the study period. It reflects that the coordination among different cities in the Pearl River Delta Urban Cluster was unsatisfactory.

Table 2. The ecological efficiency obtained from BCC model.

Area	Comprehensive efficiency	Pure technological efficiency	Scale efficiency	Change of scale efficiency
Guangzhou	1.000	1.000	1.000	-
Shenzhen	1.000	1.000	1.000	-
Zhuhai	1.000	1.000	1.000	-
Huizhou	1.000	1.000	1.000	-
Dongguan	0.749	0.861	0.870	irs
Zhongshan	0.848	1.000	0.848	irs
Jiangmen	1.000	1.000	1.000	-
Foshan	1.000	1.000	1.000	-
Zhaoqing	1.000	1.000	1.000	-
The Pearl River Delta	0.897	1.000	0.897	drs

Note: 'irs' means the returns to scale increase, 'drs' means the returns to scale decrease, and '-' means the returns to scale remain unchanged.

3.2. The input slackness degree of ecological efficiency for the Pearl River Delta Urban Cluster

The input slackness degree of ecological efficiency for the Pearl River Delta Urban Cluster were also calculated based on the BCC model. It is denoted in Table 3 that the input of employment and non-residential water were non-redundant, whereas that of industrial waste gas, non-residential electricity, cultivated land, and built-up area showed obvious redundancy during the study period. It implies that the ecological efficiency during the process of industrial transformation is closely related with resource and environmental input, and the influence of industrial transformation on resource and environment should be paid attention to.

Table 3. The input slackness degree based on BCC model.

Aspect	Indicator	Input slackness degree
Resource	Amount of employment at the end of the year	0
	Area of cultivated land at the end of the year	1.365
	Area of built-up parts	0.718
	Amount of non-residential water consumption	0
	Amount of non-residential electricity consumption	3.124
Environment	Amount of industrial wastewater discharge	0.053
	Amount of industrial waste gas emission	49.376

3.3. The dynamic analysis of ecological efficiency for the Pearl River Delta Urban Cluster

The dynamics of ecological efficiency for the Pearl River Delta Urban Cluster was analyzed based on the Malmquist index method. As shown in Figure 1, the change value of total factor productivity was bigger than one in most of years during 1997–2015, representing the ecological efficiency of the Pearl River Delta Urban Cluster generally improved during the process of industrial transformation. However, it is also found out that the change value of total factor productivity was smaller than one during 2012–2015, showing the declined trend of ecological efficiency in recent years which was mainly caused by the decrease of scale efficiency. Due to the big industrial scale in the Pearl River Delta Urban Cluster, the harmony among various aspects of different industries and cities has not been achieved, thus affects the ecological efficiency.

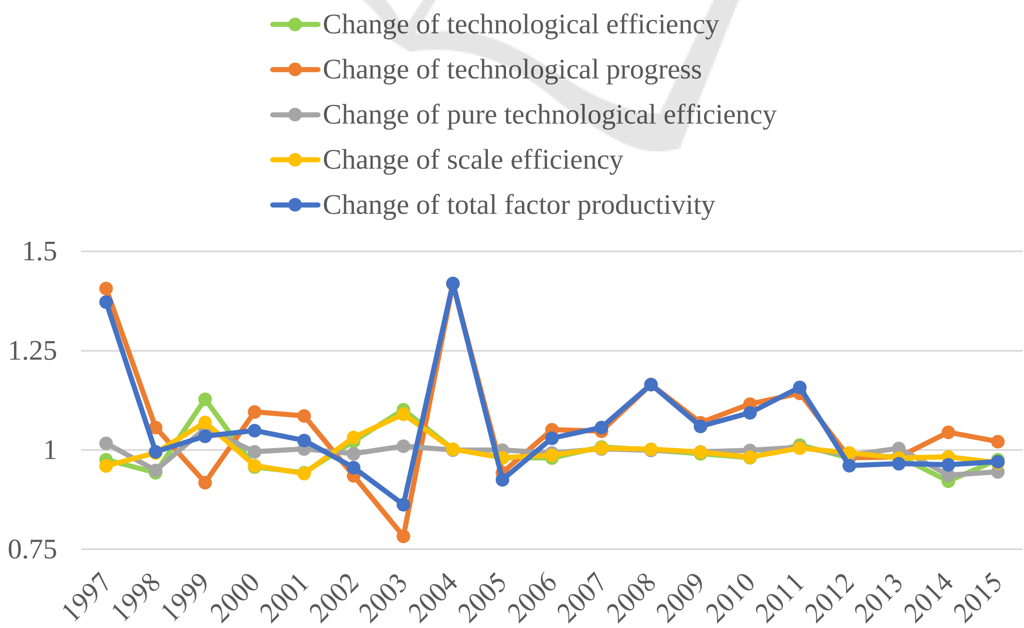

Figure 1. The change of ecological efficiency for the Pearl River Delta Urban Cluster.

3.4. Suggestions for improving ecological efficiency in the Pearl River Delta Urban Cluster

Based on the above-mentioned results, the suggestions for improving ecological efficiency in the Pearl River Delta Urban Cluster was put forward from three aspect. First, some input needs to be reduced when considering the redundancy, which mainly includes non-residential electricity, cultivated land, and built-up area. In order to reduce the non-residential electricity consumption, the industry should transfers into that of low energy consumption, and the energy-saving awareness of employees should be improved. The productive cultivation technique needs to be studied and developed to decrease the redundancy of the cultivated land. In terms of the input of built-up area, a more rational planning are necessary combining with the urban development ability and orientation. Second, undesired output needs to be reduced, which mainly includes the waste gas and wastewater. The industry is required transferred from high emission to low emission. Third, the urban network in the Pearl River Delta Urban Cluster needs to be optimized, which requires a more holistic industrial planning in the whole urban cluster where different cities develop advantageous complementary industry.

4. Conclusions

In order to check the effect of industrial transformation, the concept of ecological efficiency was introduced in this paper regarding its integration of economy, resource, and environment. The evaluation indicator system of ecological efficiency was established. The evaluation model based on data envelopment analysis and the Malmquist index was also developed, which is hopeful to reduce the evaluation subjectivity without confirming the weights of different indicators. The Pearl River Delta Urban Cluster-the representative of industrial transformation in China-was selected as the case to demonstrate the application of the established evaluation indicators and mathematical model. It is indicated that the ecological efficiency of the Pearl River Delta Urban Cluster generally increased during the process of industrial transformation but with declined returns to scale, which implies the lack of satisfactory coordination among different cities. Such suggestions to improve ecological efficiency is finally proposed as reduce certain input and undesired output, and strength the holistic industrial planning in the Pearl River Delta Urban Cluster.

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