Efficiency Evaluation on Construction Industrial Circular Economy based on Improved DEA Model

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Abstract

Based on the characteristics of circular economy, the improved data envelopment analysis model is proposed with non-expected inputs (waste utilization) and non-expected outputs (waste emissions). Then, the circular economic efficiency of China's construction industry from 2006 to 2010 is analyzed. The results show that the overall circular economic efficiency of China's construction industry is on the rise, and scale efficiency is slowly to achieve optimal, but the apparent inadequacy of pure technical efficiency affect the development of China's circular economic in construction industry.

Keywords: data envelopment analysis; construction industry; efficiency of circular economy; non-expected input; non-expected output

1. INTRODUCTION

Under the big background of economic rapid growth, and the speeding up of industrialization and urbanization in China, construction industry has also been in a period of rapid development since the end of 20th century. But it has encountered the bottleneck of resources lacks and environmental protection. Therefore, construction industry needs to develop circular economy vigorously. In fact, the circular economy in Chinese construction industry has been developed from the ear-liest comprehensive resources utilization and terminal pollution control to clean production, green manufacturing and green reengineering of business process, during which circular economy in construction industry has been developed into practical application from the conception interpretation and great achievements in new technologies for recycling, new equipments and techniques have been obtained. Therefore, to analyze and evaluate the efficiency of construction industrial circular economy will provide important information for the management and planning of construction industry.

2. LITERATURE REVIEW

As for efficiency evaluation, there are many traditional methods using single indicator or complex and multiple indicators of production or finance. But it's rare of static or dynamic quantitative studies on a certain industry from the view of ecological economics. Circular economy, as a kind of ecological economy, is both a model of economic development and a technological paradigm. So there are circular economy operation efficiency, resources allocation efficiency and technical efficiency (TE).

Most foreign researches on circular economy operation efficiency focused on eco-efficiency. The World Business Council for Sustainable Development (WBCSD), for example, promoted eco-efficiency as a "combination of business and sustaina-

ble development" [1-2]. To companies, eco-efficiency means "conservation of resources and increase of competitiveness" [3]. In 1998, Organization for Economic Co-operation and Development (OECD) defined eco-efficiency as the efficiency that natural resources meet human needs from broad aspect combining welfare, competitiveness, impact on ecology of products throughout the life cycle, utilization of natural resources and environmental carrying capacity [4]. In the industry level, foreign researches also made a lot of achievements on ecological efficiency of circular economy. J. Korhonen et al. (2004) used DEA model to analyze the ecological efficiency of 24 power plants in one European country through two kinds of methods [5]. From the perspective of ecological economics and industry ecology, Kuosmanen et al. (2005) replaced the discharge pollutants index with environmental pressure index, and used DEA model to calculate and compare the relative ecological efficiency of three town highway transportation industry in Finland [6].

The research on circular economy efficiency in China is not enough, let alone of a certain industry. Inspired by overseas researches, Tian (2003), Chu et al.(2006) believed that "the nature of circular economy is to improve eco-efficiency, and eco-efficiency is an appropriate measure of circular economy"[7-8]; Zhou(2003) introduced the eco-efficiency conception applied widely in OECD countries, and conducted pilot study and design on the indicator system of circular economy evaluation using that of the eco-efficiency as a reference [9]. All of the above studies provided theoretical basis and method attempt for the research on operation efficiency of circular economy, but all are qualitative research, ignore TE of circular economy and that the circular economy is a new technology model.

Circular economy system is a complex system with multi-input and multi-output, so a quantitative and dynamic evaluation on efficiency of circular economy in Chinese construction industry is studied from the ecological and economic view using the data envelopment analysis (DEA) model based on the former studies in this paper.

3. EVALUATION METHOD BASED ON DEA

Charnes, Cooper and Rhodes (1978) firstly invented a method using DEA model(C2R) to measure the efficiency of individual decision making units (DMUs) with multi-input and multi-output [10]. It is a linear programming method, a non-parametric statistics to evaluate whether the DMUs with multi-input and multi-output are technologically effective, based on the conception of relative efficiency. DEA method considers inputs and outputs separately, so it is strongly objective and practical due to its less calculation [11]. DEA method has been widely used in the fields of the advancement of technology and productivity, costs and benefits, resources allocation and technology innovation, etc., in recent years. A large number of theoretical literatures and actual data have shown that DEA method is one of the major comprehensive measurements of efficiency [12-14].

3.1. The Basic DEA Model

Suppose there are n DMUs, and each production activity of DMU has m types of inputs, $X_i > 0$ (i=1, 2, …, m) , and has s kinds of outputs, $Y_r > 0$ (r=1, 2, …, s). Then any production activity can be expressed as vector pairs (X_j, Y_j), where $X_j = (x_{1i}, x_{2j}, …, x_{mi})^T$, $Y_i = (y_{1i}, y_{2i}, …, y_{sj})^T$. The C^2R model for measuring efficiency based on inputs is as follows:

$$\max \ h_{j0} = \frac{\sum_{r=1}^{s} u_r y_{rj0}}{\sum_{i=1}^{m} v_i x_{ij0}}$$

$$\text{s.t.} \ h_j = \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \le 1 \qquad (1)$$

$$u_r \ge 0, v_i \ge 0, j = 1,2,...,n$$

Where v_i and u_r are the weights of inputs and outputs. Through Charnes-Cooper transformation and duality transformation, added slack variables s^+ and remaining variables s^-, the equation(1) is changed into:

$$\min \ \theta - \varepsilon E^T(s^+ + s^-)$$

$$\text{s.t} \ \sum_{j=1}^{n} \lambda_j X_j + s^- = \theta X_{j0}$$

$$\sum_{j=1}^{n} \lambda_j Y_j - s^+ = Y_{j0} \qquad (2)$$

$$\lambda_j \ge 0, s^- \ge 0, s^+ \ge 0, j = 1,2,...,n$$

The C^2R model can be used to evaluate whether the DMUs is of the optimal circular economy technology efficiency. However, the precondition is that each DMU is under the optimal scale returns, so the C^2R model cannot be used to simply evaluate whether the TE of the DMUs re optimal. In fact, there is also the case to simply evaluate the technical efficiency under variable SE of DMUs, and then BC^2 model should be used. BC^2 model only adds a condition in equation(2):

$$\sum_{i=1}^{n} \lambda_j = 1 \qquad (3)$$

The difference between the C^2R and BC^2 model lies in that efficiency in the C^2R model is comprehensive efficiency of technical and scale efficiency, which can be called constant returns-to scale tech-

nology efficiency (CRSTE), as for BC^2 model, the efficiency is variable returns-to-scale technology efficiency (VRSTE), which can be called pure technology efficiency.

3.2. DEA Model for circular economy

In general, the production process of an economic system DMU is to produce products with resources consumption. And the aim of evaluation on DMUs efficiency is to get more outputs with fewer inputs. The more outputs, the more efficient the DMUs are. During some processes of production, non-expected output besides products will be generated. For example, pollutants such as waste residue will be generated in construction industry. These two types of output objects should be treated differently minimize the non-expected output while increasing the expected output and achieve a win-win in environmental protection and economic development, which is exactly the meaning of circular economy efficiency evaluation.

Support the inputs can be divided into expected input $(i = 1,2,...,l)$ and non-expected input $(i = l+1, l+2,...,m)$, and output also can be divided into expected output $(r = 1,2,...,k)$ and non-expected output $(r = k+1, k+2,...,s)$ .then the efficiency evaluation indicator of DMU$_j$ was defined as:

$$\max \ h_{j0} = \frac{\sum_{r=1}^{k} u_r y_{rj0} + \sum_{i=l+1}^{m} v_i x_{ij0}}{\sum_{i=1}^{l} v_i x_{ij0} + \sum_{r=k+1}^{s} u_r y_{rj0}}$$

$$\text{st} \ h_j = \frac{\sum_{r=1}^{k} u_r y_{rj0} + \sum_{i=l+1}^{m} v_i x_{ij0}}{\sum_{i=1}^{l} v_i x_{ij0} + \sum_{r=k+1}^{s} u_r y_{rj0}} \le 1 \qquad (4)$$

$$u_r \geq 0, v_i \geq 0, j = 1,2,...,n$$

After transformation:

$$\min \ [\,\theta - \varepsilon E^T(s^d + s^u + s^g + s^b)\,]$$

$$\text{st} \quad \sum_{j=1}^{n} \lambda_j X_j + s^d = \theta x_{i0}$$

$$\sum_{j=1}^{n} \lambda_j X_j - s^u = x_{i0} \qquad (5)$$

$$\sum_{j=1}^{n} \lambda_j Y_j^g - s^g = y_{j0}^g$$

$$\sum_{j=1}^{n} \lambda_j Y_j^b + s^b = \theta y_{j0}^b$$

$$\lambda, s^b, s^g, s^d, s^u \geq 0, \varepsilon > 0, j = 1,2,...,n$$

4. EFFICIENCY EVALUATION ON CHINESE CONSTRUCTION INDUSTRIAL CIRCULAR ECONOMY

4.1. Evaluation indicators

Efficiency of circular economy in construction industry means to obtain maximal products or profits and minimize pollution under the premise of vigorous development of circular economy. Evaluation indicators of circular economy efficiency in construction industry are indicators provided for managers to establish development target of circular economy and bring forward an improved plan, and for operator to refer.

According to the principle that the data have scientific properties, consistency and comparability, and also considering the data availability, our input and output indicators based on DEA model are listed in Table 1.

Tab. 1 Input and output indicators

Item	Indicator
expected input	Number of enterprise Number of employees The total power of equipment Total capital
non-expected input	Waste utilization
expected output	Industrial Added Value Housing construction area Total construction industry contract Total of profits and taxes
non-expected output	Waste residue emission Wastewater emission Waste-gas emission

In this paper, we select totally 31 provinces. To guarantee the reliability of the index data, we extract the index data from China Construction Industry Statistics Yearbook.

4.2. Circular economy efficiency analysis on China's construction industry

The circular economy efficiency of Chinese construction industry, mainly including CRSTE, VRSTE and SE, are analyzed using the improved DEA model. The results are listed in Table 2.

Tab. 2 The circular economic efficiency of construction industry

Year	Annual Average value		
	CRSTE	VRSTE	SE
2006	0.835	0.897	0.931
2007	0.828	0.881	0.940
2008	0.873	0.919	0.950
2009	0.889	0.925	0.961
2010	0.913	0.929	0.983
Average Increase	0.078	0.032	0.052

The VRSTE in 2006 is 0.897 and 0.929 in 2010, average increased by 0.032, and for SE, it is 0.931 in 2006 and 0.983 in 2010, average increased by 0.052. It can be seen that the values of TE is larger than VRSSE form 2006 to 2010, and are increasing with low speed. It indicates that most growth of the circular economic

inefficiency in Chinese construction industry lies in the SE.

It also can be seen that the scale benefit of Chinese construction industry is increasing but has not yet reached the optimal value, which indicates that the scale of construction enterprises in China need to be expanded. It is an indisputable fact that the concentration degree of Chinese construction industry is low.

5. CONCLUSION

Efficiency evaluation on industrial circular economy is one of the important parts of measuring the sustainable development of industry. Based on the existing eco-efficiency evaluation, the concept of efficiency evaluation on construction industrial circular economy is prompted. Pollutants emission is inducted into the DEA model as a non-expected input to analyze and evaluate the efficiency of construction industrial circular economy. The results show that the efficiency of construction industrial circular economy in China is not high as a whole, but is increasing. The main measure to improve the efficiency of construction industrial circular economy is to improve the pure technical efficiency.

6. References

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