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Research article

Study on eco-efficiency of industrial parks in China based on data envelopment analysis

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ABSTRACT

China's industrial parks have been playing a crucial role on driving regional economy development, but also been posing threats to local environment due to intensive resource consumption and waste emission. Chinese government facilitated eco-industrial development of industrial park, aiming to output more with less environmental burden. In our study, the eco-efficiency levels of 40 Chinese industrial parks in 2012 were assessed and ranked by Data Envelopment Analysis (DEA). This paper applied indicators relevant to resource, economy, and environment from industrial parks which can well reflect the characteristics of eco-efficiency conforming to the concept of sustainability. This paper introduced how to adjust less sustainable parks to be more sustainable according to the DEA results. The roles of industrial added value per capita, industrial structure, environmental policy and development scale as influence factors of eco-efficiency were discussed. The results show that large differences exist in the eco-efficiency of different industrial parks. It is shown that 20% of the parks are relatively efficient. 47% of the study parks being inefficient in terms of scale efficiency show decreasing returns to scale. Policy implementations for the management of industrial parks were also discussed based on the results.

1. Introduction

Among different human activities promoting economy growth in China, industrial parks are the major contributor. In the past 30 more years, China established more than 2000 industrial parks, which accounted for more than 60% of gross national industrial output value and more than 50% of GDP (Bao, 2013). In 2014, the GDP growth rate of industrial parks, 29.1%, prominently exceeded that of the national average, 7.4% (CADZ, 2014). However in the meantime they were extensive consumers of energy and resources and huge emitters of pollutants. It was increasingly important to keep productions sustainable over the long run. Eco-efficiency, a popular important indicator, is in conformity with the principle of sustainability (Hicks and Dietmar, 2007). Industrial parks should be optimized to gain high eco-efficiency in order to ensure environmental improvements along with economic growth.

Eco-efficiency is a tool for sustainability analysis, signifying how efficient the economic activity is in consideration of ecosystem's resources and services, and environmental impact. Eco-efficiency was primarily stated and used by the World Business Council for Sustainable Development (WBCSD) in 1991. WBCSD provides one of the highly widespread descriptions, namely that eco-efficiency is "achieved by the delivery of competitively priced goods and services that satisfy human needs and enhance quality of life, while progressively reducing ecological impacts and resource intensity throughout the life-cycle to a level at least in line with the Earth's estimated carrying capacity" (WBCSD, 1992). In one words, Eco-efficiency is basically a ratio of economic value to environmental impact, which is able to combine performance of economy and environment.

Recently the eco-efficiency concept has been reinforced by establishing a guideline for evaluating eco-efficiency (ISO 14045, 2012). Eco-efficiency could be evaluated through indexes based on the ratio of economy to environment (ISO 14045, 2012). In this case, eco-efficiency assessment requires environmental performance evaluated by life cycle analysis (LCA) to be connected with the economic value, based on a target and boundary determination. The latest studies show that eco-efficiency is earning more and more preference in various fields. The eco-efficiency concept has been applied at diverse levels of production (Park et al., 2007), service (I. Ribarova et al., 2014), company (Korhonen and Luptacik,

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2004) or one industry (Oggioni et al., 2011; Gössling et al., 2005). Kharel and Charmondusit (2008) quantitatively analyzed eco-efficiency of iron rod industry during the period of 2001–2005 by calculating the eco-efficiency of energy, material consumption, water use, waste generation, and CO_2 emission, respectively. Hua et al. (2007) evaluated the eco-efficiency of 32 paper mills along the Huai River. In addition, there are other alternative measures proposed to appraise the eco-efficiency (Glauser and Muller, 1997; Metti, 1999; Schaltegger and Burritt, 2000). The studies mentioned above adopt simple indexes like rates of "economic output per unit of waste" that are close to eco-efficiency from a really restricted viewpoint (Kuosmanen and Kortelainen, 2005). Most eco-efficiency indicators are concentrated on the enterprises or products levels. Decision makers are also interested in employing eco-efficiency principles since they are regarded to lead to national long-term preferences in international competitiveness, especially in the Asian region (Hur et al., 2004; Seppälä et al., 2005). For industrial park, LCA, material flow analysis (MFA), and economic returns are well-known assessment methods (Dong et al., 2013; Yu et al., 2006; Geng et al., 2012), Although they are useful, their indicators may not suitable for eco-efficiency assessment because they were not initially designed for eco-efficiency. Moreover most related studies are performed on cases, and comprehensive evaluations of multiple samples remain very rare. To date, there are some studies on industrial park efficiency (Kicherer et al., 2007; Huppes and Ishikawa, 2005). Most of these studies focus on the productivity efficiency rather than the eco-efficiency (Hu et al., 2010; Ma and Goo, 2005). Some researches have been performed to evaluate the eco-efficiency of industrial parks (Khodakarami et al., 2014; Liu et al., 2015). But their number of samples and the selected indicators is relatively small, which cannot comprehensively reflect the eco-efficiency. Also these researches cannot reveal the current situation due to the earlier study period. Because eco-efficiency has changed since eco-industrial development has been conducted popularly in recent years in China, we need to evaluate the latest eco-efficiency in industrial parks around the country.

Chiu et al. (2009) proposed that eco-efficiency is one of the important problems for the sustainable development of industrial park. In this study, three aspects containing resource, environment and economy of an industrial park were considered to evaluate the eco-efficiency, representing the sustainability of the park.

DEA has been widely employed to estimate the relative efficiency of a set of units since 1978 (Charnes et al., 1978). In this paper DEA was adopted as an approach to assess the relative eco-efficiency of typical industrial parks in China. Calculating and sorting eco-efficiency can help industrial parks in China to facilitate comparisons among different industrial parks and to regulate and adopt appropriate eco-efficiency improvement targets. The final aim of our study is to examine activities with evaluation to improve the sustainability of industry parks.

2. Method

2.1. DEA concept and operation

Data envelopment analysis is a very effective method to evaluate the relative efficiency of decision-making units (DMUs). DEA examines both production (output) and cost (input) data, looks for the points with the lowest input for maximal output utilizing the chosen parameters, and connects those points to form the efficiency frontier. The units not on the frontier are considered inefficient. A coefficient is granted to each unit, stating its relative efficiency. DEA is becoming an increasingly popular management tool since it has the following advantages in practice: (1) This method is suitable for the synthetic evaluation of the effectiveness of multiple input - multiple output; (2) DEA method does not need to carry out non-dimensional treatment on the data; (3) DEA does not need decision makers to provide the information on weights. The weights can be gained through a programming, that is, no pre-estimated parameters are needed; (4) The exact functional relationship (function formula) between inputs and outputs need not be considered in DEA.

2.1.1. Eco-efficiency evaluation with CCR and BCC models

To evaluate the efficiency of a number of producers, a typical statistical approach is characterized as a central tendency approach and it evaluates producers with respect to an average producer. In contrast, DEA is an extreme point method and compares each producer with only the "best" producers. By the way, in the DEA literature, a producer usually refers to a decision making unit (DMU). DEA is a linear programming based approach for assessing the relative performance of a series of units where the attendance of multiple inputs and outputs makes comparison difficult.

In general, the CCR model invented by Charnes et al. (1978) and the BCC model extended by Banker et al. (1984) based on the CCR model, which have the advantages of multifunctional, reasonable structure, easy operation and convenient for using, are used to measure efficiency. CCR model (Eq. (1)) and BCC model (Eq. (2)) are adopted in this study.

$\min \theta_c$

Subject to

$$\begin{aligned} &\theta_c x_0 - X\lambda - s^- = 0 \\ &Y\lambda - s^+ = y_0 \\ &\lambda \geq 0, s^- \geq 0, s^+ \geq 0. \end{aligned} \tag{1}$$

θ_c-the input-output efficiency of DMU_0 in CCR model;

X-the input matrix
Y-the output matrix;
λ-a 40-dimensional weight vector;
x_0-the input vector of DMU_0
y_0-the output vector of DMU_0;
s^- - input slack variable vector,
s^+ -output slack variable vector.

$\theta_c \leq 1$, and θ_c attains 1 only when both slack vectors are zero and none of the input variables of DMU_0 are larger than any linear combination of other DMUs (Cooper et al., 2000).

$\min \theta_B$

Subject to

$$\begin{aligned} &\theta_B x_0 - X\lambda - s^- = 0 \\ &Y\lambda - s^+ = y_0 \\ &e\lambda = 1 \\ &\lambda \geq 0, s^- \geq 0, s^+ \geq 0. \end{aligned} \tag{2}$$

e-a 40-dimensional unit vector

θ_B-the efficiency of DMU_0 in BCC model, also $\theta_B \leq 1$.

Other symbols have the same meanings as in Eq. (1) (Banker et al., 1984).

The CCR model is based on the assumption of constant returns to scale (CRS), while the BCC model is based on the postulation of variable returns to scale (VRS). The efficiency derived from CCR is called overall efficiency (OE), meaning the development level of eco-efficiency in current and future scale. The efficiency under BCC