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Better resource management: An improved resource and environmental efficiency evaluation approach that considers undesirable outputs

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ABSTRACT

Evaluating resource and environmental efficiency is helpful to stakeholders when making iterative improvements to resource management policies, with regards to either their business activities or to societal management. Traditional evaluation models—which consider undesirable outputs in measuring environmental efficiency—are output-oriented, and so they only pursue the minimum undesirable outputs and the maximum desirable outputs, based on current inputs. The growing depletion of nonrenewable resources makes it difficult to acquire the resources essential to socioeconomic development. In such circumstances, better consideration of resource use (i.e., inputs) is required when considering both desirable and undesirable outputs. This study aims to develop an improved approach by which to evaluate resource and environmental efficiency, based on data envelopment analysis; in this approach, the evaluation of resource inputs into the objective function is introduced. On account of its improvements, the new model can measure not only resource and environmental efficiency, but also efficiencies with regards to resource inputs, undesirable outputs, and desirable outputs. The feasibility of the model is verified through its use in undertaking further empirical analyses of data from mainland China's 31 provinces. The results of that analysis show the average resource and environmental efficiency value of China's inefficient provinces to be only 0.65—a value that suggests that mainland China's resource and environmental efficiency needs to be further improved.

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1. Introduction

Further promotion of sustainable resource management requires an improved evaluation approach, by which a better understanding of resource and environmental efficiency can be garnered; in this way, stakeholders can make iterative improvements to resource management policies, for the sake of both their business activities and societal management. Better and more science-based consideration of resource inputs and outputs, as well as of corresponding environmental efficiency and impacts, is critical. In production, undesirable outputs will always be produced alongside desirable outputs; for example, when a thermal power station uses coal to generate electricity, some undesirable outputs—such as sulfur dioxide—will be produced that damage the natural environment. Some developed countries have paid attention to this problem and taken measures to reduce their volume of undesirable outputs; they usually transfer high-pollution industries to developing countries, which unfortunately exacerbates environmental problems there. China's rapid socioeconomic development following its "opening up" and various reforms is based very much on energy-extensive consumption, which produces a large amount of emissions. As a result, environmental pollution in China today is becoming more and more serious. The total efficiency of energy processing and translation in China within the 1996–2004 period fluctuated by 69–71%, finally reaching 72.86% in 2010. The heating efficiency of electricity generation and power station increased slowly, reaching the maximum value of 42.43% in 2010, according to the annual *China Statistical Yearbook* (1997–2011). To reduce pollutant emissions, many countries have enhanced environmental supervision (such as the introduction of PM2.5, which refers to airborne particles with a diameter of 2.5 mm or less, as the main urban air quality index) and the enforcement of punishment. More and

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more efficiency evaluation systems are taking into account undesirable outputs; some scholars have put forward some ecological efficiency evaluation methods based on DEA, a method proposed by Charnes et al. (1978), to evaluate production efficiency (Liu et al., 2010).

Meanwhile, the worldwide costs of resources have increased in tandem with a rapid rise in resource demand among many countries. Currently, demand not only for mineral resources but also for renewable resources (e.g., human resources) is greatly increasing. However, a considerable number of studies on environmental or ecological efficiency do not consider resource inputs. If an economy is to be developed in a sustainable manner, resource limits cannot be exceeded. Therefore, it is necessary to take into consideration all resources (both renewable and nonrenewable) when any kind of data envelopment analysis (DEA) evaluation model is constructed so as to carry out more comprehensive efficiency analysis. This research aims to develop an improved resource and environmental efficiency evaluation approach that is based on DEA.

Academically, this study's contribution is in how it helps develop an improved resource and environmental efficiency evaluation approach that is based on DEA; this approach evaluates the introduction of resource inputs into the objective function. On account of this improvement, the new model can not only measure resource and environmental efficiency, but also measure efficiency with regards to resource input, undesirable outputs, and desirable outputs. The feasibility of this model is verified by undertaking further analyses of China's 31 provinces. The findings of this research are critical to achieving better decision-making among business stakeholders and policymakers with regards to resource management and circular economy promotion in China's "13-five planning period." Taken together, these are the practical contributions of this study.

The remainder of this paper is organized as follows. The second section comprises a literature review, and it examines the main achievements relevant to resource and environmental efficiency evaluation. The third section establishes the new resource and environmental efficiency evaluation model. The fourth section carries out resource and environmental efficiency evaluation of 31 provinces and cities in China by using the new model. Input redundancies and output deficiencies are calculated, and environmental efficiency values are compared to those made under the slacks-based measure (SBM) model of Tone (2001). The final section presents conclusions and prospects for future research.

2. Literature review

DEA is an analytical method based on linear programming; it is used to evaluate the relative efficiency of peer decision making units (DMUs). The term "DMUs" here refers to individuals such as firms, banks, or universities that convert inputs into outputs. The first DEA model based on the assumption of a constant returns to scale—the so-called Charnes–Cooper–Rhodes (CCR) model—was proposed by Charnes et al. (1978). In the CCR model, it is assumed that if a production set (x, y) is possible, then (tx, ty) is also possible for any positive t. To date, DEA has been widely used in many fields, such as enterprise management, production, and the banking industry, because it is a nonparametric analysis method and does not require advance knowledge of the weight of inputs and outputs (Kneip et al., 2011). The model of Banker et al. (1984)—the so-called Banker–Charnes–Cooper (BCC) model—allows for variable returns to scale. Yu et al. (1996) present the comprehensive DEA (GDEA) model with the introduction of three parametric variables (i.e., δ_1, δ_2, and δ_3). When these three variables are set at different values, different DEA models can be obtained. Tone (2001) directly introduced slack variables into the objective function and put forward the SBM model. Azadeh et al. (2012) propose an integrated fuzzy regression based on the DEA algorithm, having used it to estimate and optimize oil consumption, even in the presence of uncertain data.

Traditional CCR and BCC models consider only desirable outputs, without truly considering efficiency evaluations of any undesirable outputs. The discharge of undesirable outputs, as a byproduct of modern production, has rapidly increased—so much so, it far exceeds nature's self-cleaning ability (Coli et al., 2011). Scholars have started to discuss DEA models that take into account undesirable outputs; these studies have taken as their research direction the evaluation of environmental efficiency evaluation (Färe et al., 1989; Song et al., 2012). Färe et al. (1989) put forward a kind of nonlinear model as per the curve measure method. They consider that undesirable outputs are weakly treatable, and that desirable outputs can definitely be reduced if undesirable outputs were to be reduced; they assert that only when desirable outputs equal zero can undesirable outputs be zero. Hailu and Veeman (2001) suggest that the properties of minimum undesirable outputs are very similar to those of inputs, and can be handled as inputs. Chung et al. (1997) assert that an increase in desirable outputs and a reduction in undesirable outputs can be realized, and they propose the use of a model of directional output distance function. Finally, Tone and Tsutsui (2010) put forward a dynamic environmental efficiency evaluation model that can be used to evaluate the overall efficiency of DMUs for the full terms and term efficiencies.

With regards to data processing methods, Seiford and Zhu (2002) put forward data translation technology; they consider that desirable outputs can take a positive value, given their positive effect on efficiency evaluation results—and that undesirable outputs can take a negative value, given their negative effect. They then introduce a proper positive constant, to convert undesirable outputs into desirable outputs; they also construct a model for use in processing. However, that constant always takes strong subjective factors that may create deviations in the calculation results; such results can be unfavorable to the objective execution of efficiency evaluations. Färe and Grosskopf (2004), by comparing a data translation method to a directional output distance function method, put forward the idea that one direction can be set in advance, in which desirable and undesirable outputs can move towards the effective frontier surface in the same maximum proportion; they did so on the premise that there is no increase in inputs that can simultaneously increase desirable outputs and reduce undesirable outputs. Accordingly, they propose the linear directional output distance function method—a method that avoids the nonlinear problems inherent in the directional output distance function method put forward by Chung et al. (1997), but with great subjectivity on the setting of direction. Tone and Tsutsui (2010) put forward a new dynamic SBM, based on the SBM framework.

Several scholars have constructed environmental efficiency evaluation models, with an eye to real-world applications. Based on the Russell directional distance function—which considers both desirable and undesirable outputs—Barros et al. (2012) calculated Japanese banks' technical efficiency between 2000 and 2007. Davoodi and Rezai (2012) considered that each DMU will select the best input and output weight for itself, so as to obtain a higher efficiency value that is obviously overestimated; for this reason, they put forward a new efficiency evaluation method. Aliakbarpoor and Izadikhah (2012) believed that when using DEA, imprecise data (e.g., ordinal data) would derive from analyses of the evaluation of environmental efficiency with regards to undesirable outputs. For this reason, they present the modified CCR model. Sala-Garrido et al. (2012) used the DEA method to evaluate the technical performance of wastewater treatment plants in Spain's Valencia region, and Marques et al. (2012) used it to evaluate the performance of a Spanish recycling company. Wu et al. (2014) studied the efficiency

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