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Measuring the performance of thermal power firms in China via fuzzy Enhanced Russell measure model with undesirable outputs

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ABSTRACT

Thermal power has accounted for the major part of the electricity generation over recent several decades in China. It plays an important role in supporting China's economic development while it also brings great pressure to the environment protection because of a large amount of pollution generated during its production. In order to solve or alleviate the environmental problem caused by thermal power firms, efficiency evaluation is the first important step. As thermal power firm is a complex system with multiple inputs and multiple outputs, usually including fuzzy data and undesirable outputs in the productions, in this paper, we build an integrated Enhanced Russell measure model based on data envelopment analysis for evaluating the performance of decision making units in the presence of the undesirable outputs in fuzzy circumstance. Then, this new model is applied to analyze the environmental performance and provide the benchmarks for the thermal power firms in China which can guide the decision makers to make suitable future production plans for improving their performance.

1. Introduction

China's economy has experienced fast-growing development over the last three decades since its reform and opening-up policy. In spite of rapid economic development, China is paying heavily because of over-exploitation and severe environmental pollution. Now, the increasing energy consumption and environmental pollution have raised great concern on the sustainability of China's economic growth. Due to accumulating negative impacts of environmental pollution on human health, Chinese government has proposed a strategic objective to build a resource-conservation and environment-friendly society so as to balance the three factors of economic development, energy consumption and environmental sustainability. For example, in 2014, China promulgated a new important environmental law, "Environmental Protection Law of People's Republic of China", which gives more punitive powers to environmental authorities and also defines geographical "red lines" where the area's ecology must require special protection (the NPC Standing Committee, 2014). Besides, Chinese government has recognized the importance of environmental efficiency measurement and improvement, and has taken a series of measures to deal with this issue, such as energy conservation assessment (ECA) and environmental impact assessment (EIA) (Hu, 2012). Among all kinds of energy types, electricity is the major resource of energy in China for many years. Further, among various ways of electricity generation, China relies heavily on thermal power, hydropower and thermoelectricity. In particular, thermal power accounted for about 78.57% of all the electricity in 2012. Such situation will be kept for a long time. As thermal power production usually produces large amount of pollution but with less treatment, it has becoming the major source resulting in the environmental problems of China. Thus, it is essential for us to measure the efficiency of thermal power firms individually so as to increase their productivity and reduce the emissions.

Data envelopment analysis (DEA) is a non-parametric programming technique for evaluating the relative efficiency of a set of homogenous decision making units (DMUs) with multiple inputs and multiple outputs. It has been popularly applied in schools, hospitals, farms, banks and many other areas (Cook and Seiford, 2009; Cooper et al., 2004). Traditional DEA models aim at producing the maximum quantity of outputs for the given amount of inputs or consuming the minimum quantity of inputs for the given amount of outputs. Besides, all traditional DEA models are radial models, such as CCR, BCC and their extensions, which are either input-oriented or output-oriented (Charnes et al., 1978; Banker et al., 1984). Comparing with

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these traditional DEA models, non-orientation modeling actually makes frontier efficiency studies more relevant to the production of thermal power firms because non-orientation ensures the analysis simultaneously captures slacks on both sides. Several non-orientation approaches have been built, such as additive model, Russell measure (RM) model, slacks-based measure and so on. It should be noted that among these approaches, Russell measure (ERM) model is a well-known non-orientation measure for evaluating DMUs' performance and has been applied to many areas, such as baseball batting performance, Taiwan's commercial banks (Lozano et al., 2011; Levkoff et al., 2012; Hsiao et al., 2011a,b), and, a later work showed that the slacks-based measure model (SBM) is actually equivalent to the enhanced Russell measure model in measuring the efficiency in its initial form (Cooper et al., 2007). Thus, in this paper, we choose Russell measure as a basic for performance evaluation.

As we know, undesirable outputs, such as smoke pollution and waste, are usually produced with desirable outputs in production processes of thermal power firms (Rivas and Magadan, 2010). These factors are expected to be as few as possible. Thus, the traditional DEA models are not applicable to measure the performance of the DMUs with undesirable outputs. Usually, the performance of DMUs with both desirable outputs and undesirable outputs is usually defined as environmental efficiency (Song et al., 2013; Wu et al., 2014). So far, many DEA models have been proposed to deal with undesirable outputs so as to obtain the environmental efficiency (Färe et al., 1989; Seiford and Zhu, 2002; Zhou et al., 2008).

Based on the above analysis, an approach by using the Russell measure considering the undesirable outputs is needed to measure the environmental efficiency of thermal power firm. However, according to our best knowledge, there are many theoretical works in Russell measure and undesirable output areas respectively but few works integrated them. Moreover, during our investigation on the thermal power firms, we found the undesirable output "solid waste" of the thermal power firm is so complexity as it contains the garbage, refuse, sludge and other discarded materials including solid, liquid, semi-solid, or contained gaseous material that the data of undesirable output is difficult to be measured precisely. We can only obtain a fuzzy description of the "solid waste". This requires us to further extend the above approach to be applicable to the fuzzy circumstance. But this kind of DEA work is not available in the previous works. In this paper, we will propose a new enhanced Russell measure model which can well address the fuzzy data and undesirable outputs problems simultaneously, and apply the new approach to analyze the thermal power firms in Anhui province of China. Our model can provide improvements for DMUs in more directions and in more realistic situation, and can be flexibly applicable to other similar cases.

The rest of this paper is organized as follows. Section 2 will briefly review the previous studies related with Russell measure, Fuzzy DEA and undesirable outputs in DEA. The Russell measure model and Enhanced Russell measure model and our new models are shown in Section 3. Then an empirical example is analyzed by our approach in Section 4. Finally, conclusions are presented in the last section.

2. Literature review

In the following subsections, four streams of literature relevant to this research are briefly summarized. They include Russell measure, Fuzzy DEA methods, undesirable outputs and environmental efficiency. Based on the literature review, the research gap is pointed out.

2.1. Russell measure

Russell measure was first introduced by Färe and Lovell (1978). It was named as "Russell" because the scholar R.R.Russell subsequently contributed to its further development. Due to its non-radial property, it has a wide of applications. Lozano et al. (2011) proposed a Russell non-radial eco-efficiency measure to compute eco-efficiency scale elasticity bounds. Hsiao et al. (2011a,b) introduced the entropy concept to Russell measure DEA model for eliminating the equal-weight effect in order to increase evaluation accuracy. Although this original Russell measure accounts for all the inefficiencies of an evaluated DMU in both input side and output side, there are some evident disadvantages of this measure. One is that RM models are usually non-linear programming problems, which makes the computation complicated. Another one is that this measure cannot be well interpreted because it is a weighted average of arithmetic and harmonic means (Pastor et al., 1999).

In order to avoid the mentioned difficulties, Pastor et al. (1999) proposed a closely extended measure based on Russell measure which called Enhanced Russell measure (ERM). ERM can be interpreted as the ratio of the average efficiency of inputs and the average efficiency of outputs, which is a better interpretation about efficiency than Russell measure. Moreover, it can be decomposed into input component of average efficiency and an output one to analyze the performance of the evaluated DMUs. Besides, ERM has been extended by many other researchers because its advantage in calculation and interpretation. For example, Cooper et al. (2007) proposed an aggregate ERM that can be formed with all the desirable properties of an aggregate measure. Ashrafi et al. (2012) built an Enhanced Russell measure model considering non-discretionary factors. Esmaeili (2012) developed a new approach based upon the ERM for dealing with interval data in DEA.

2.2. Fuzzy DEA models

As we know, traditional DEA models assume that all the data for inputs and outputs are crisp, so they cannot deal with imprecise data. To solve this uncertain situation, fuzzy data theory is introduced in DEA area. The concept of fuzzy set was firstly proposed by Zadeh (1965) to deal with imprecise estimates in uncertain circumstance. Recent years, numerous DEA models have been developed in the fuzzy environments. For example, Kao and Liu (2000a, 2000b) developed a procedure to measure the efficiencies of DMUs with fuzzy observations by applying α-cut approach. Leon et al. (2003) built several DEA models in fuzzy form by using some ranking methods based on the comparison of α-cut. Lertworasirikul (2001) developed DEA models considering imprecise data represented by fuzzy sets. They indicated that fuzzy DEA models taking the form of fuzzy linear programming are usually solved with the aid of some methods that can rank the fuzzy sets. Wen and Li (2009) employed a fuzzy DEA model based on credibility measure and proposed a method for ranking all the DMUs. However, these previous fuzzy DEA models were extended from CCR or BCC models, which are radial models and do not account for all the slacks of the inputs and outputs simultaneously. In order to solve these deficiencies, Wang and Li (2010) proposed a fuzzy DEA model to deal with efficiency evaluation problem with imprecise data based on ERM model. Later, Wang and Li (2014) extended it to super efficiency form for fully ranking DMUs. Hsiao et al. (2011a,b) proposed a fuzzy super-efficiency slack-based measure DEA model (Fuzzy Super SBM) and a fuzzy slack-based measure DEA model (Fuzzy SBM DEA) to analyze the operational performance of parameters with fuzzy-numbered.

2.3. Undesirable outputs and environmental efficiency

As we know, undesirable outputs are usually produced with desirable outputs in the production process, such as smoke pollution and waste (Perez-Calderon et al., 2011). These factors are expected to be as few as possible. Now, research on undesirable outputs has