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Environmental efficiency evaluation of industry in China based on a new fixed sum undesirable output data envelopment analysis

Jie Wu [a], Qingxian An [a,b], Xin Yao [c,*], Bo Wang [d]

[a] School of Management, University of Science and Technology of China, He Fei 230026, China
[b] Industrial Systems Optimization Laboratory, Charles Delaunay Institute and UMR CNRS 6281, University of Technology of Troyes, Troyes, France
[c] China Center for Energy Economics Research, School of Economics, Xiamen University, Xiamen 361005, China
[d] School of Public Affairs, University of Science and Technology of China, He Fei 230026, China

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A B S T R A C T

The rapid economic development of China has intensified the country's environmental problems such as pollution and waste. As industry is the main contributor to environmental deterioration, the development mode of industry has attracted attention from the government and the public. In this paper, we have assumed that the industry is permitted a fixed total amount of pollution in order to avoid excessive pollution. If one province shows increased pollution, other provinces are required to reduce pollution by the same amount to maintain the total level of pollution. However, so far, few studies have considered such competition over outputs. This paper presents a new data envelopment analysis approach, which considers both the fixed and the variant sum desirable outputs in the performance improvement of a decision making unit, to evaluate the environmental efficiencies of China's industry from 2007 to 2011. The analysis results demonstrate that some economically developed provinces have better performance than less developed provinces; in particular, all efficient provinces are the developed ones. The Chinese government should focus on the increasing differences in environmental efficiencies among regions and take measures to address them.

1. Introduction

Since 1978, China has launched some major reforms after of the "Reform and Opening Up" policy. With this policy, China's economy has achieved significant development. From 1979 to 2010, the average annual growth rate of China's gross domestic product (GDP) was 9.91%, reaching a historical high of 15.2% in 1984 and a record low of 3.8% in 1990. China became the second leading economic entity in the world following the United States in 2010 (Zhang and Yang, 2013). The gross domestic product of China in 2012 reached 51,932.2 billion RMB (about 8490.9 billion US dollars). Some scholars have predicted that China may exceed the United States to be the world's largest economy by the end of this decade (Troilo and Sun, 2010).

However, rapid industrialization and inefficient environmental supervision have resulted in many environmental issues such as the depletion of energy resources, environmental degradation, and pollution (Nordström and Vaughan, 1999; Cherniwchan, 2012; Wong, 2013b). The Chinese government has expressed great concern over these environmental problems. Many environmental regulations were strengthened and clean energy technologies have been promoted, to enable sustainable growth of the economy and environment (Wong, 2013a). However, because of the absence of professional evaluation and detailed environmental targets, polluting industries still have access to inexpensive land, water, electricity, oil and bank loans. Among the different kinds of environmental problems, industrial waste gases have attracted enormous attention as they have largely changed the chemical composition of the atmosphere.[1] In order to limit or reduce the total waste gas pollution, it is very necessary for decision makers to know the performance of industry in each province regarding the industrial waste gases problem. Environmental efficiency can

* Corresponding author.
E-mail address: lyhneyao@sina.com (X. Yao).

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comprehensively reflect the operational situation of industry because it considers both economic and environmental factors in the efficiency evaluation system (Song et al., 2012). Therefore, it is essential to evaluate efficiency for setting the environmental targets for provinces in China.

There are two main methods for measuring environmental efficiency. One is the stochastic frontier analysis method, which is a parametric approach; the other is the data envelopment analysis method, which is a nonparametric approach (Coelli et al., 2005). The stochastic frontier analysis method is suitable for a one-output scenario, which would not be disturbed by the stochastic error; however the production functions need to be estimated and results largely depend on the predicted forms of the functions. Therefore, incorrect results may be obtained due to using an incorrect form of a function. Data envelopment analysis (DEA) is a non-parametric programming technique for measuring the relative efficiency of a set of homogenous decision making units (DMUs) (Cook and Seiford, 2009; Sarkis and Weinrach, 2001). It does not require the assumption of functional form in the production function and it can well measure the efficiency of a system with multiple inputs and outputs. As the economic factors and the environmental factors in industry involve multiple outputs, the DEA approach is chosen as our tool for the efficiency evaluations in this paper.

Undesirable outputs, which are usually produced with desirable outputs in the production process, such as smoke pollution and waste (Perez-Calderon et al., 2011; Zhang et al., 2008), are expected to be as few as possible. Some scholars apply the concept of environmental efficiency or ecological efficiency, defined as the kind of efficiency that considers both desirable outputs (such as the economic factor) and undesirable outputs (such as environmental factors), to address the undesirable outputs problem (Hua et al., 2007; Song et al., 2013). Several important DEA works on environmental efficiency or ecological efficiency have been carried out (Zaim and Taskin, 2000; Hua et al., 2007; Sarkis and Cordeiro, 2012; Nouri et al., 2013). Currently, research on undesirable outputs through DEA has become a popular topic and has been largely studied as well. Studies in this area can be classified into two categories: direct approaches, in which the strong disposability of outputs is replaced by a weakly disposable assumption (Färe et al., 1989; Seiford and Zhu, 2005; Tone, 2004; Zhou et al., 2008), and indirect approaches, which are of two types, treating the undesirable outputs as the inputs for processing (Liu and Sharp, 1999; Hailu and Veeman, 2001; Dyckhoff and Allen, 2001) and monotonic decreasing transformation approaches (Scheel, 2001; Seiford and Zhu, 2002).

All of these approaches calculate a DMU's efficiency by allowing each DMU to freely improve its outputs in the production possibility set (PPS). The approaches involve the assumption of complete output independence among the DMUs, i.e., the outputs of any given DMU do not affect the outputs of others. However, we often encounter a situation where the total outputs of all DMUs are fixed, such as the limits on pollution in some countries or regions, or the total number of gold, silver and bronze medals in the Olympic Games. There exists a competition among the DMUs because losses (or gains) of one DMU must be gained (or lost) by others. Some researchers have dealt with the problem of fixed-sum outputs. Lins et al. (2003) indicated the constant sum of outputs, i.e., the number of different kinds of medals in the Olympic Games, and built a zero-sum gains DEA model (ZSG-DEA). Two strategies were presented in their model: One assumed equal reductions of output for all DMUs, and the other assumed that the output reduction for each DMU was proportional to every output by the DMU. Then, Gomes and Lins (2008) revised the ZSG-DEA model for performance assessment in the presence of undesirable outputs and applied it to the evaluation of carbon dioxide emissions. Later, Yang et al. (2011) proposed a fixed sum output DEA (FSODEA) model and proposed a new strategy for performance improvement, in which a minimum output improvement was needed to be technically efficient. However, the above approaches only make improvements on fixed-sum outputs, which cannot exactly reflect the real efficiency because DMUs may improve their outputs simultaneously.

It has been indicated that the minimum output improvement strategy is more efficient than the two previous approaches for output improvement, because it can provide information on the optimal opponents (Yang et al., 2011). Based on the above analysis, this paper considers adjustment of all kinds of outputs (the desirable and undesirable outputs) by the minimum output improvement strategy in measuring the efficiencies of DMUs. Next, we propose a new undesirable fixed sum outputs DEA approach for evaluating the efficiencies of the DMUs. These models include both desirable and undesirable outputs. An important feature of this approach is that it also considers the competition among the DMUs over undesirable outputs. This is the first work to consider the improvement of competitive outputs and un-competitive outputs when evaluating environmental efficiency. Moreover, our DEA models can inherit the benchmark function of the traditional DEA model.

Environmental efficiency in China can be better understood in our models. Results show that efficiency performances are different in different areas of China. In general, the economically developed areas have higher environmental efficiency than undeveloped areas. We also investigate the change of environmental efficiency in China from the year 2007–2011. Moreover, the benchmark of industry in each province, which can be used to set the environmental target, can be gained from our study.

There are many acronyms in this paper. In order to make this paper more readable, we list them as follows: DEA (data envelopment analysis), DMU (decision making unit), GDP (gross domestic product), PPS (production possibility set), ZSG-DEA (zero-sum gains DEA model), FSODEA (fixed sum output DEA), VRS (variable returns to scale), FAI (total investment in fixed assets of industry), EC (electricity consumption by industry), RPI (gross regional product of industry), ND (nitrogen dioxide pollutant emissions).

The rest of this paper is organized as follows. The FSODEA model is briefly reviewed and our proposed models are described in the next section. The index construction is shown in Section 3. Next, the environmental efficiencies of 31 Chinese regional industries are analyzed based on our approach in Section 4. Then, we discuss the approach and the results of China's industry in Section 5. Conclusions are reported in the last section.

2. Fixed sum output DEA model

In this section, we show the previous work, i.e., fixed sum output DEA models, and point out their deficiencies for measuring efficiency. Then, we present our new model.

2.1. Fixed sum output DEA model for desirable outputs

Yang et al. (2011) proposed a fixed sum output data envelopment analysis model (FSODEA), which considers the competition over fixed-sum outputs under variable returns to scale (VRS). The model is output-oriented and the outputs in their models are desirable. Their approach represents a situation where some of the outputs are fixed and the gain (or loss) by one player must be compensated by the loss (or gain) by others.

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