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Data envelopment analysis for unified efficiency evaluation: an assessment of regional industries in China

Linlin Zhao, Yong Zha*, Nannan Liang, Liang Liang

School of Management, University of Science and Technology of China, 96 Jinzhai Road, Hefei, Anhui, 230026, PR China

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A B S T R A C T

Data envelopment analysis has recently gained popularity and attention in operational and environmental assessment. A common feature of previous studies is decreasing an input vector to decrease the vector of undesirable outputs which is referred to as natural disposability. However, little research has considered how to increase the amount of capital input for clean production technology to decrease the amount of undesirable outputs in a data envelopment analysis framework, which is referred to as managerial disposability. Thus, this paper proposes an improved approach that considers measuring unified (operational and environmental) efficiency for managerial disposability, and compares this approach with the one for natural disposability. The proposed approach provides a positive strategy to reduce undesirable outputs and improve unified efficiency through increasing capital investment in clean production technology. A case study of regional industries in China in 2006–2010 utilizing this approach is also presented. The empirical study shows that the unified efficiencies of regional industries in China have relatively high scores for managerial disposability, and increasing capital investment is vital to achieve sustainable development in clean production technology.

1. Introduction

In China, the economy has rapidly developed along with the implementation of economic reform and opening up policy (Zhang and Yang, 2013). The China Statistical Yearbook (2013) reports that the gross domestic product (GDP) has increased from 364.52 billion RMB Yuan in 1978 to 51,628.21 billion RMB Yuan in 2012. However, China's great economic growth is mainly driven by energy-intensive heavy industries, which has resulted in increased fossil energy consumption and serious environmental problems (Wang et al., 2013). For example, the total industrial waste-gas emissions has increased three times during the past decade, and the industrial waste-water emissions was 221.60 (100,000,000 tons), which accounts for 35.0% of China's total waste-water emissions in 2012 (National Bureau of Statistics of China (NBSC), 2013). Moreover, the industrial pollutants have serious impacts on health, water security, and food security (Lo, 2014).

To mitigate the environmental problems, build an environmental-friendly society, and realize sustainable economical development, China must reduce fossil-energy consumption and industrial pollution. The Chinese government has exerted considerable efforts to reduce industrial pollution. For example, it has recently encouraged the development of various clean production technologies, shut down small coal-fired power plants, and strengthened environmental regulations (Wong, 2013). In order to effectively limit or reduce industrial pollutants, decision makers must professionally evaluate the performance of the industry in each region by obtaining a comprehensive understanding of the operational processes of regional industries.

An industrial production is a joint-production process, i.e., pollutants are generated when an industrial product is produced by consuming labor, capital, and other resources (Zhou et al., 2008). In the literature, researchers have focused on the balance between economic activities and pollution reduction (Sueyoshi and Goto, 2012a). Traditional economists and policymakers believe that there is a trade-off between environmental regulation and economic prosperity, and regulations concerning environmental pollution may have detrimental effects on economic development (e.g., Palmer et al., 1995). However, modern corporate strategists in US business schools devote to investigate the possibility for an

* Corresponding author. Tel.: +86 551 63606215; fax: +86 551 63600025.
E-mail address: zhabeer@ustc.edu.cn (Y. Zha).

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organization to attain both environmental improvement and economic prosperity by advancements in technology (e.g., Porter and Van der Linde, 1995).

The above mentioned two conflicting academic concerns have different policy implications and development strategies. Therefore, it would be helpful to develop a new approach for operational and environmental assessment that conceptually incorporates these two conflicting academic concerns regarding economic development and environmental protection.

Initiated by Charnes et al. (1978), data envelopment analysis (DEA) has been widely employed to model environmental efficiency of various organizations in the world. For instance, Cooper et al. (1996) provided a summary of more than 100 previous studies on how Operation Research/Management Science methods were used in preventing air-pollution issues. Zhou et al. (2008) summarized previous DEA applications in environmental performance studies in the past three decades. Recently, applying DEA to model environmental efficiency at the macro level has become a popular trend, and such DEA research efforts include Guo et al. (2011), Wang et al. (2013) and Wu et al. (2012).

A methodological contribution of previous DEA studies to environmental evaluation is that they found the importance of separating outputs into desirable and undesirable categories (Sueyoshi and Goto, 2012b). Such research efforts include Bevilacqua and Braglia (2002), Korhonen and Luptacik (2004), Picazo-Tadeo et al. (2005), and Triantis and Otis (2004).

Motivated by the studies outlined above, Bian and Yang (2010) extended a Shannon-DEA procedure to establish a comprehensive efficiency measure for appraising resource and environment efficiencies of the provinces in China. Shi et al. (2010) developed three extended DEA models by treating undesirable outputs as inputs to measure industrial energy overall efficiency, pure technical efficiency and scale efficiency of 28 administrative regions in China. Choi et al. (2012) used non-parametric efficiency to estimate the energy efficiency, potential emission reductions, and marginal abatement costs of energy-related CO_2 emissions in China. Wu et al. (2012) constructed both static and dynamic energy efficiency performance indexes to measure industrial energy efficiency with CO_2 emissions in China. Song et al. (2013) used a statistical and forecasting program to analyze the relationship between environmental efficiency and its influential factors in the different districts of China. Wu et al. (2014) proposed a fix sum undesirable outputs DEA approach to evaluate the environmental efficiencies of industry in China.

A common feature of previous research efforts is that they only evaluate energy and environmental efficiency within a production framework. To the best of our knowledge, little study has considered the impact of capital input for technology advancement on operational and environmental assessment in China.

In this study, we propose a positive strategy that increases capital investment in technology advancement to decrease the amount of undesirable outputs. This strategic concern on the reduction of undesirable outputs provides us with a new conceptual basis for operational and environmental assessment. Since undesirable outputs are usually produced with desirable outputs in the production process, we measure both operational efficiency on desirable outputs and environmental efficiency on undesirable outputs in a unified manner (Sueyoshi and Goto, 2011). The two types of efficiency are unified and referred to as "unified efficiency" in this study. We propose non-radial DEA models for unified efficiency evaluation based on different strategies such as increasing capital investment and decreasing inputs. In addition, the impact of transforming strategy on unified efficiency is modeled to illustrate the effect of capital investment in clean production technology. Detailed analysis of unified efficiency in Chinese industry sectors is illustrated to better verify the proposed approach.

The remainder of this paper is organized as follows. In Section 2, concepts related to natural and managerial disposability are discussed. Then, the non-radial DEA models for natural and managerial disposability are presented. The impact of transforming strategy is also modeled. In Section 3, the proposed DEA approach is applied to study the unified efficiencies of regional industries in China in 2006–2010. Conclusions are given in Section 4.

2. Methods

This section first presents the natural and managerial disposability concepts, and then proposes related DEA models. Based on the proposed approach, the index is provided to model the impact of transforming strategy.

2.1. Natural and managerial disposability concepts

A decision-making unit (DMU) may have different strategies to satisfy environmental regulation (Sueyoshi and Goto, 2012a). In this study, we consider the two concepts related to adaptive strategy of a DMU on the reduction of undesirable outputs, which has been discussed in Sueyoshi and Goto (2012b).

Natural disposability: According to Sueyoshi and Goto (2012b), natural disposability implies that a DMU decreases an input vector to decrease the directional vector of undesirable outputs. Given the reduced vector of inputs, a DMU attempts to increase the desirable outputs as much as possible. In this case, the input formulation in DEA is $\sum_{j=1}^{n}\lambda_j x_{ij} \le x_{io} \quad (i = 1, \ldots, m)$.

The natural disposability is a negative adaptation strategy for environmental regulation, in which a DMU reduces its operational size until the undesirable outputs satisfy the requirements of environmental regulation (Sueyoshi and Goto, 2012a). This negative adaptation strategy originated from Palmer et al. (1995), believes that there is a trade-off between economic development and environmental regulation.

Managerial disposability: The second concept indicates that a DMU increases an input vector to decrease the vector of undesirable outputs. Using the increased input vector, a DMU increases desirable outputs as much as possible. In this study, a DMU increases the capital input for technology innovation to decrease the amount of undesirable outputs, which seems to be more consistent with reality (Sueyoshi and Goto, 2014). The capital input formulation in DEA is $\sum_{j=1}^{n}\lambda_j x_{ij} \ge x_{io} \quad (i = 1, \ldots, m)$.

The managerial disposability is a positive adaptation strategy (Sueyoshi and Goto, 2012a). This strategy is associated with Porter hypothesis (Porter and Van der Linde, 1995), which believes that a DMU can attain both environmental improvement and economic development by advancements in technology.

2.2. Unified efficiency for natural disposability

To describe DEA operational and environmental evaluation, this study assumes there are n DMUs, denoted by $DMU_j (j = 1,\ldots,n)$, each of which represents a province of China. Each DMU uses h capital inputs $k_{ij} (i = 1,\ldots,h)$ and p regular inputs $x_{lj} (l = 1,\ldots,p)$ to produces desirable outputs $g_{rj} (r = 1,\ldots,s)$ and t undesirable outputs $b_{fj} (f = 1,\ldots,t)$. It is assumed that $K_j = (k_{1j},\ldots,k_{hj})^T$, $X_j = (x_{1j},\ldots,x_{pj})^T$, $G_j = (g_{1j},\ldots,g_{sj})^T$, $B_j = (b_{1j},\ldots,b_{tj})^T$, and $K_j > 0$, $X_j > 0$, $G_j > 0$, $B_j > 0$ for computational tractability. The production technology set can be defined as:

$$T = (K, X, G, B) : (K, X) \quad \text{can produce} \ (G, B) \tag{1}$$

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