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Review of the network environmental efficiencies of listed petroleum enterprises in China

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ABSTRACT

In this study, we create a set of network DEA models that can be used to divide efficiency scores into two subunits, thus providing more accurate results. This approach can help open the "black box" of efficiency measurement and help determine the advantages and disadvantages of various subunits in each decision-making unit. This study uses the newly presented models to examine changes in production and environmental efficiency among 20 listed petroleum enterprises in China. These examinations are conducted on a stage by stage basis using the enterprises' detailed production chains from the 2006–2011 period. Additionally, this study analyzes the input surpluses and output deficits from 2011. The results of using this approach (which looks to improve the input–output efficiency of enterprises) can be considered helpful in improving petroleum enterprises' technology and management efficiency.

Contents

1. Introduction

With the gradual elimination of trade and investment barriers, the world has become one large market with rapid factor flows between countries. To further reduce production and trading costs, producers have gradually disseminated numerous working procedures and segments inherent in the manufacturing process to various countries [1]; as such, vertical and specialized production modes have formed [2]. It can be said that the division of labor based on vertical specialization is an important expression of economic globalization; however, in terms of global production, China has always been at the lower end of the industrial chain, focusing as it has on labor and resource-intensive industries. This not only means that there is little chance for China to improve the quality of its labor force, but also that China's environment has been greatly damaged by resource-intensive industries [3]. Given

Abbreviations: CBA, cost–benefit analysis; CCR model, Charnes–Cooper–Rhodes model; DDF, distance direction function; DEA, data envelopment analysis; DMU, decision-making unit; SBM, slacks-based measure

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the country's weak environmental regulations, some countries have transferred their pollution-intensive enterprises to China, as they consider it to be a "pollution haven."

Severe environmental problems not only affect the physical and psychological health of the populace, but also threaten China's sustainable development. Recently, countries worldwide have striven to develop "green" economies in order to break the link between economic growth and high levels of pollution. Although China has taken measures to combat its environmental problems, it still suffers from severe environmental deterioration, including discharged greenhouse gases and water pollution. In order to determine the best solution for enterprises' environmental pollution problems, this study conducts an in-depth examination of the root causes of pollution created by firms in the petroleum industry, the most pollution-intensive of six such industries in China (i.e., petroleum, mining, paper-making, textiles, chemistry, and electricity).

Over the past few decades, China's petroleum industry has grown substantially due to rapid growth in the national economy and car ownership [4]. Increases in the capability of China's petroleum industry have driven managers to seek improvements in efficiency. Unlike simply continuing to develop capacity, improving efficiency is considered an ideal solution to the problematic link between increased demand and environmental degradation. However, production processes within the petroleum industry are very complicated, and improving efficiency would involve evaluating multiple processes that cannot be easily measured by traditional approaches. To address this dilemma, we use a network data envelopment analysis (DEA) model to examine China's petroleum industry and provide some valuable suggestions regarding efficiency.

The remainder of this paper is organized as follows: The second section is a review of the literature on environmental cost efficiency problems, and the third section briefly describes the network DEA model and the indicator data used. The fourth section touches on empirical tests and demonstrates the relevant inputs and outputs of listed petroleum enterprises. Discussions and policy recommendations are presented in the fifth section. Finally, the conclusions are provided in the last section.

2. Literature review

Environmental cost efficiency has attracted considerable attention from Chinese and non-Chinese scholars alike. Non-Chinese scholars began by studying energy conservation, emission reductions, and environmental cost efficiency at the enterprise level. Their work covered such topics as investment in pollution-intensive industries, technological improvements, and management innovation. In order to avoid the externalities created by unclear property rights, it is generally believed that enterprises should internalize their external costs as much as possible. Based on this tenet, Nordhaus and Tobin developed the net economic welfare indicator, which deducts social costs that stem from economic activities (such as pollution in urban areas) from GDP [5]. Repetto et al. put forward the net domestic production indicator and focused on the relationship between economic growth and the consumption of natural resources [6]. Walley and Whitehead examined investment in pollution-intensive projects and argued that environmental protection affects an enterprise's competitiveness [7]. Bartolomeo et al. analyzed the temporary conditions and development prospects of European environmental management accounting from four viewpoints; namely, external financial reporting, social accountability reporting, energy and materials accounting, and environmental management accounting [8]. In order to analyze environmental costs, Mylonakis and Tahinakis put forward an extended cost–benefit analysis (CBA) model that took time into consideration [9]. Lohmann also asserted that the "internalization of external costs" is a valid method for establishing emissions standards and environmental taxes [10]. By using location analysis and the Belgian intermodal terminals model, Macharis et al. constructed an analytical framework of intermodal transport in order to research the relationship between increases in fuel price and the internalization of external costs [11]. Máca et al., by studying the externalities of environmental pollution from electricity generation in Middle and Eastern Europe, found that market-oriented policy tools were not particularly effective [12].

Since DEA was proposed by Charnes et al. [13], it has become one of the most popular performance evaluation tools. It can be used to measure the relative efficiency scores of decision-making units (DMUs), especially in the absence of any information about the relationships between inputs and outputs or their weights. Ever since the pioneering work of Färe et al., this approach has been widely used to calculate environmental efficiency [14]. Since then, a considerable number of studies have been undertaken with regards to environmental performance measurement, which requires dealing with undesirable outputs. Dyckhoff and Allen [15] proposed a systematic approach by which to derive ecological DEA models to measure environmental efficiency. Kuosmanen and Kortelainen [16] used DEA to aggregate various types of environmental pressures and construct a comprehensive eco-efficiency index. Zhou et al. [17] used and extended DEA models to evaluate the relative performance of electricity generation utilities. Zhou and Ang [18] adopted a non-radial DEA model to calculate the environmental performance of OECD nations. Oggioni et al. [19] developed several DEA models for analyzing the eco-efficiency of 21 prototypes in the cement industry (in which pollution can be considered as either an input or an undesirable output). The study by Chung et al. [20] was the first to use the distance direction function (DDF), which is based on DEA, to measure environmental performance. Several later studies related to the DDF include those of Lee et al. [21], Picazo-Tadeo et al. [22], Macpherson et al. [23], Zhou et al. [24], and Chen [25]. Song et al. [26] provided a detailed review of environmental efficiency evaluations that relied on DEA in terms of the ways in which undesirable outputs could be treated. Other recent measurements of environmental performance that relied on DEA include those of Kim and Kim [27], Riccardi et al. [28], Wu et al. [29], and Zhang and Choi [30].

In recent years, Chinese scholars have studied environmental cost efficiency problems in pollution-intensive industries based on specific national conditions. However, such theoretical research lags far behind accounting practices. Feng researched environmental cost problems in a paper-making company and separated environmental costs from the total operating cost (so as to control cost more explicitly) [31]. Li investigated the effects of changes in enterprise structure as well as economic development on environmental cost accounting [32]. Nevertheless, research on China's environmental cost efficiency problems still lags far behind that of developed countries. Furthermore, given the lack of proper measurement techniques, such research has remained at a theoretical stage. The current study looks at enterprise management while using the concepts of Feng [31] and Li [32]; we use a network DEA model to express the optimization of environmental costs and determine ways of making improvements.

3. Network DEA model and data

3.1. Introduction of the DEA model

DEA is a relatively effective method of evaluating DMUs by using multiple input and output indicators. It requires that there