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An empirical analysis of China's energy efficiency from both static and dynamic perspectives

Zhaohua Wang [a, b, *], Chao Feng [a, b], Bin Zhang [a, b]

[a] School of Management and Economics, Beijing Institute of Technology, Beijing 100081, China
[b] Center for Energy & Environmental Policy Research, Beijing Institute of Technology, Beijing 100081, China

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ABSTRACT

Utilizing the global DEA (data envelopment analysis), this paper analyzes China's energy efficiency from both static and dynamic perspectives based on China's provincial panel data for the period of 2001–2010. We present the evolution of energy efficiency in China from 2001 to 2010, and identify the key factors influencing the energy efficiency from the aspects of technical progress, productive scale and management level. The results show that there was an overall declining trend for China's energy efficiency from 2001 to 2005, and technical regress and the decrease in scale efficiency were the main reasons for this decline. Then an overall rising trend appeared during 2005–2010, and technical progress was the most important motivation for this increase. Moreover, among the three main regions in China, the eastern China was leading in the energy efficiency during the sample period, while the energy efficiency in western China fell far behind since the beginning. And the energy efficiency in central China was in the middle. This indicates that west region may be China's promising growth engine of energy efficiency in the future, and further technical progress is thought to be the key motivation for this improvement.

1. Introduction

In the past decades, China's booming economy has driven rapid increase in energy consumption. According to the statistics, in 2010, China's GDP (gross domestic product) accounted for 8.6% of global economic output, while its energy consumption accounted for 19.3% of global level. China's energy consumption per unit of GDP was more than twice of the world average level in 2010. Obviously, China's energy efficiency is relatively low, and its current economic growth model with extensive and inefficient energy consumption is unsustainable.

Recently, the Chinese government has already noticed this problem and began to take measures to improve energy utilization efficiency. It can be seen that Chinese government's efforts have already achieved some initial positive results since the set of energy-saving targets in the five year plan from 2006 to 2010. By the year 2010, the energy consumption per unit of GDP had decreased 19.1% comparing with 2005. However, China's energy efficiency is still at a relatively low level. In this context, in August 2012, China's State Council announced that China aimed to reduce the energy consumption per unit of GDP by 16% by the year 2015 based on the 2010 level to make a further step on energy-saving and the improvement of energy efficiency. In this way, learning from China's successes as well as failures in energy-saving and the improvement of energy efficiency in the past years would certainly provide important references for China's further energy policy making. Therefore, calculating and analyzing China's historical performance on energy efficiency is this study's target.

In the existing literature, there are two methods used for measuring the efficiency of energy utilization: one is the single-factor method; the other is the total-factor method. The single-factor method only takes energy input into account while neglecting other key inputs such as capital and labor. For example, energy intensity, which is defined as the ratio between total energy consumption and economic output, is one of the most widely applied indices based on the single-factor evaluation framework. Despite being operated easily, the single-factor method has many obvious defects. Firstly, the single-factor method cannot measure the underlying technical energy efficiency and it would lead to a misunderstanding [1]. Secondly, energy alone cannot produce any output, and it must be combined with some other non-energy factors such as labor and capital to produce economic outputs [2].

* Corresponding author. School of Management and Economics, Beijing Institute of Technology, Beijing 100081, China. Tel.: + 86 10 68918213; fax: +86 10 68912483.
E-mail address: wangzh1018@hotmail.com (Z. Wang).

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The traditional single-factor method simply ignores the importance of other non-energy inputs, therefore they cannot reflect substitution effects between energy and other non-energy factors.

In response, the total-factor framework, in which the energy input and other non-energy inputs are both incorporated, has gradually become popular in the field of energy efficiency research. In the total-factor framework, substitution effects between energy and other non-energy inputs are fully reflected and the importance of other non-energy inputs are also well considered in the practical production process. Thus, the total-factor method is superior to single-factor method. So far, the total-factor framework has been utilized widely to explore the energy efficiency of different countries and regions. Generally, there are two main methods used for the total-factor framework: one is the parametric method of SFA (stochastic frontier analysis) proposed by Aigner et al. [3]; the other is the nonparametric method of DEA (data envelopment analysis) proposed by Charnes et al. [4]. In the parametric method (e.g., SFA), artificial parameters are needed. While in the nonparametric method (e.g., DEA) no artificial parameters are required. Hence, the DEA is superior to the SFA for eliminating the influence of subjective factors on estimation results.

In recent years, the data envelopment analysis (DEA) has been widely used for calculating energy efficiency [5]. According to Wang et al. [12], DEA methods utilized in the existing literature related to energy efficiency can be roughly divided into two groups according to their research perspectives.

The first group consists of static methods which utilize the static DEA models. Models such as the CCR and BCC utilized in the static methods are used for evaluating DMUs (decision-making units') energy efficiency [5]. Differences between DMUs' efficiency of energy utilization can be seen through the analysis and comparison of the estimation results based on the static methods. In addition, if the evaluation is based on panel data, we can also see the changing trends of each DMU's energy efficiency on the timeline. Despite providing us with these effective implications, the static methods have certain defects. For the reason that evaluations based on the static methods only provide us with relative levels of energy efficiency in each DMU, they fail to reveal the specific reasons for the rise or fall of each DMU's energy efficiency between each two periods. Therefore, empirical conclusions and recommendations based on the static methods cannot provide very specific and effective guidance for practical production.

The second group consists of dynamic methods which utilize dynamic DEA models. Generally, models such as DEA-Malmquist index and DEA-Malmquist-Luenberger index utilized in the dynamic methods are used for evaluating DMU's energy efficiency change or productivity change over time. The index based on the dynamic methods can be further decomposed into three components: TCH (technical change), PCH (pure efficiency change) and SCH (scale efficiency change) [7]. These three indices represent the efficiency changes of technology, management and scale in the actual production, respectively. Through the analysis of the evaluation results based on the dynamic methods, we can find out the specific reasons for the rise or fall of DMUs' energy efficiency among each periods from the aspects of technical progress, productive scale and management level. However, evaluation results based on the dynamic methods cannot reflect the relative levels of each DMU's energy efficiency as well as the differences of energy efficiency among DMUs. Therefore, the dynamic methods also have certain defects.

Most of existing studies are conducted from only static (e.g., [2,8–15]) or dynamic (e.g., [16–25]) perspectives. Hence, these studies have certain limitations. Besides, most of the existing research conducted from the dynamic perspective utilizes contemporaneous or single-phase benchmark technologies to construct single-phase reference production sets, which are subsequently used for calculating the index and its decompositions. As a result, estimation results from these studies lack stability and may deviate from the practical production activity [26,27]. What's more, utilizing the single-phase reference production sets to evaluate the energy efficiency and index will lead to the result that estimations from the dynamic model and the static model are not consistent with each other.[1] This is also the reason why very few of existing studies do their research by combining the dynamic model and the static model.

In order to fill these research gaps, the concept of global DEA is introduced into our analysis. Then, with the application of global DEA, we focus on analyzing regional total-factor energy efficiency in China from both dynamic and static perspectives.[2] In this way, we not only present the evolution of China's energy efficiency from 2001 to 2010, but also identify the influencing factors of energy efficiency from the aspects of technical progress, productive scale and management level. Estimations based on the “static-dynamic” method could help us find out the potential of China's energy efficiency improvement as well as the corresponding approaches. The energy efficiency evaluation model proposed by Wang et al. [12] is adopted as the static model. Then a global Malmquist model, which is finally proposed as the dynamic model in our study for measuring energy efficiency change between each two periods, is developed by combining the global DEA method and the conventional DEA-Malmquist index model.

What we are looking forward to is that through the calculation and analysis of China's historical performance of energy efficiency and by revealing the significant differences in energy efficiency between regions and provinces, this research could deepen the international readers' understanding of the evolution of China's energy utilization at the national, regional, and provincial levels. In addition, by taking the further step to analyze the key factors responsible for the change of energy efficiency from the point of view of technical progress, productive scale, and management level, we try to put forward corresponding suggestions for the Chinese government for the energy efficiency's further improvement from the aspects of production technology, management and scale. We believe that the results and conclusions of this paper will certainly provide significant references for the Chinese government's energy policy making in the future.

The rest of this paper is organized as follows: Section 2 describes the methods and data sources of this study. Section 3 presents the results of research and necessary discussion. Finally, in Section 4, conclusion and some corresponding recommendations are proposed based on our findings.

2. Methods and materials

DEA is proposed by Charnes in 1978 [4] and is a mathematical procedure using linear programming technique to assess the efficiencies of DMUs. In this paper, it is used for measuring energy utilization efficiency in China. According to the main purpose of this article, the calculation is to be undertaken based on the global DEA method. Hence, before introducing our empirical DEA models, a brief introduction to the global DEA method is first given in Section

[1] In the previous study of the authors [6], the calculation and analysis are operated from both the static and dynamic perspectives based on the single-phase reference production sets. The authors found that estimations from the dynamic model and the static model are not consistent with each other. As it may be difficult for the international readers to read this reference [6] (in Chinese), we decide to demonstrate this disadvantage briefly in the following Section 2.3.

[2] To our knowledge, very few of the existing studies use the global Malmquist index for China's regional energy efficiency estimation.