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A performance evaluation of the energy, environmental, and economic efficiency and productivity in China: An application of global data envelopment analysis

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HIGHLIGHTS

- This study calculates China's E3 efficiency and productivity using global DEA.
- The result shows that China performs well on the economic efficiency.
- While the energy and environmental performances are not optimistic.
- Energy and environmental efficiency have improved gradually in recent years.
- Technical progress is the most powerful contributor to China's productivity growth.

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ABSTRACT

The current mode of economic development in China is typified by high growth, high energy consumption, and high pollution characteristics and this has caused great stress on both energy consumption and the environment. This paper focuses on a historical analysis of China's energy, environmental, and economic ('E3') efficiency and the sources of E3 productivity growth therein. A developed slacks-based measure is utilized to evaluate the performance of E3 efficiency and decompose the performance fluctuations into three components: energy, economy, and environmental efficiency fluctuations. By applying a method based on global data envelopment analysis, we also analyze the key factors responsible for the change in E3 productivity during 2002–11 from the point of view of technical progress, production scale, and management level. The results show that China performs well on the economic front, while the energy and environmental performances are not optimistic. Fortunately, energy and environmental efficiency have gradually improved in recent years. Further analysis shows that the trend in E3 productivity in China has begun to follow an ascending path. Technical progress is the most powerful contributor to China's E3 productivity growth, while falling scale and management efficiency are the two main obstacles preventing improvement in E3 productivity.

1. Introduction

Since 1978, China's reforms and its open policy have allowed the country to achieve remarkable progress in terms of economic and social development. However, for a long time, China's scale-oriented economic development has led to inefficient use of natural resources and energy in the production process, as well as high consumption and serious pollution. Due to its rapid development in such a short time, China is set to face a serious energy and ecological crisis [1]. According to the China Statistical Yearbook (2011), China's gross domestic product (GDP) in 2010 accounted for 8.6% of the global economic output, while its energy consumption accounted for 20.3% of the global level. China's energy consumption per unit of GDP was more than twice the average level in the world in 2010. In addition, the challenges associated with expansion of environmental pollution are also very severe in China and have become worse in recent years. In 2010, the chemical oxygen demand (COD) and sulfur dioxide (SO_2) emission in China were as high as 12.38 and 21.85 million tons, respectively. The air pollution in many big cities became even more serious in

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2012 and 2013.[1] It is reported that 90% of the groundwater in China has been polluted to varying degree, and as much as 60% of all the underground water is classified as undrinkable.[2] According to the 'Chinese Environmental and Economic Accounting Report 2010', in 2010, the economic cost of ecological degradation in China was as much as 1.54 trillion RMB, accounting for around 3.5% of GDP [2].

China's mode of economic development typically shows high growth, high energy consumption, and high pollution characteristics. In recent decades, excessive energy consumption and environmental pollution have changed from soft into hard constraints on China's economic growth. As such energy and environmental conditions are expected to worsen, China urgently needs to find a new sustainable development strategy, one which has the ability to overcome the current dilemma and to ensure that its future prosperity can be enhanced. The problem of improving energy-saving and emission reduction, and increasing energy and environmental efficiency, so as to promote the quality of its economic growth has gradually become one of the major challenges to China's future economic development. In this context, construction of an 'energy–environment–economy' or 'E3' system that is well-functioning is currently becoming a mutually-recognized ambition of everyone in China. It will also certainly provide good support for sustainable development of China's economy. Fortunately, the Chinese government has already taken note of the severity of the situation and has begun to take measures to improve energy utilization and environmental efficiency. The measures adopted include implementing energy-saving and emission reduction targets set at the beginning of the 10th 'five year plan' (2000–5), adjusting the country's industrial structure, and eliminating excess capacity.

However, as discussed above, China's energy and environmental problems are still far from being fundamentally solved and have tended to get worse in recent years. What is more, according to statistics, China's economic growth decreased from 14.2% in 2007 to 7.7% in 2012. On the whole, China's performance with respect to the E3 system is not optimistic. The open question is, what has happened to China's E3 system in the past few years? Which parts of the E3 system are well-functioning and which parts need improving? Furthermore, what can and should we do in the future to make the E3 system work well? In this context, it is not difficult to understand that in addition to being an important area of research, the issues addressed in this paper are of considerable interest to China's policymakers. In this way, learning from China's successes as well as failures in constructing an E3 system over the past few years, we can certainly provide a significant reference for China's policy making in the future. Therefore, analysis and calculation of the historical performance of China's E3 system is also a target of this study.

The remainder of the paper is organized as follows. In Section 2, the relevant background and literature are presented. Section 3 describes the data envelopment analysis (DEA) method used in this work. In Section 4, the panel data used in the empirical study is briefly introduced. The empirical results are presented and discussed in Section 5. Our conclusions are in given in Section 6.

2. Literature review

Data envelopment analysis is a relatively new, non-parametric approach to efficiency evaluation of decision-making units (DMUs) [3]. Based on DEA, total-factor frameworks have been widely used for measuring economy-wide efficiency performance. Generally, three key input factors (e.g. energy, capital, and labor), as well as economic output factors (GDP), are all included in conventional total-factor frameworks [4–11].

Hailua and Veeman [12] have argued that conventional total-factor frameworks only use desirable outputs (such as economic outputs) and simply ignore undesirable outputs (such as environmental pollutants). As a result, the evaluation of social welfare and economic performance is distorted in these studies. In recent years, progressively greater numbers of researchers have realized that the early estimates of efficiency and productivity are, to some extent, biased as they only take economic efficiency into account and ignore undesirable outputs like environmental pollution [13]. In addition, as some scholars have already discussed, there is a close relationship between energy consumption, economic growth, and emission [14–19]. Therefore, as the global energy demand has expanded, the issues of energy security, environmental pollution, and global climate change have correspondingly received more attention. In this context, eco-efficiency in terms of sustainability of energy, the environment, and economy has increasingly attracted greater interest [20–24].

In response, some scholars have tried to incorporate environmental factors into the total-factor framework. Indeed, there are studies [25–31] that treat the emission of environmental pollutants as inputs (assuming that environmental pollutant emission corresponds to the environmental resources utilized in production). Treating these emissions as inputs is easy to implement, and the assumption itself seems reasonable. However, there are certain defects caused by treating the undesirable outputs as inputs. First of all, such a treatment cannot reflect the real production process [32,33]. Second, taking undesirable output as an input will result in conflicts in the material balance equation [34]. Third, according to practical production processes, economic benefit is one of the desirable outputs, which is expected to be maximized. On the other hand, the emission of environmental pollutant is one of the undesirable outputs, which is expected to be minimized. Taking an undesirable output as an input, therefore, does not meet this condition.

There are also studies that transform undesirable outputs to 'desirable outputs'. Obviously, this transformation still cannot meet the third condition, i.e. that one can increase the desirable outputs and decrease the undesirable outputs simultaneously. For this purpose, Chung et al. [35] (following Luenberger [36]), provided a basis for representing the joint production of desirable and undesirable outputs by extending the output distance function proposed by Shephard [37] to a directional output distance function (or radial DEA). By applying a directional output distance function, one can measure the eco-efficiency of increasing the desirable outputs and reducing the undesirable outputs simultaneously by the same proportion. However, these radial efficiency measures simply ignore the slacks of variables and lead to biased estimates [38]. To overcome this defect, Fare et al. [39] developed a more generalized non-radial and non-oriented directional distance function based on a slacks-based measure (SBM). So far, the generalized directional distance function has been widely utilized to explore eco-efficiency and eco-productivity [40–42]. In these studies, a non-radial directional distance function approach is used to maximize the desirable outputs and minimize the undesirable outputs and inputs simultaneously while taking the slacks of variables into consideration. Evaluation based on the non-radial directional distance function performs much better, and can provide more reasonable and more accurate estimation results, compared to other methods.

Nevertheless, there are still some problems in the existing studies on China's eco-efficiency and eco-productivity in respect of sustainability of energy, the environment, and economy. First of all, in

[1] A toxic fog covered a large area of eastern China for a long time at the beginning of 2013 (see http://www.chinadaily.com.cn/china/2013-01/13/content_16109839.htm). It is just the latest example of the serious environmental pollution in the country.

[2] See http://news.hefei.cc/2013/0327/021565436.shtml.