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An application of a double bootstrap to investigate the effects of technological progress on total-factor energy consumption performance in China

Ke Li [a, c], Boqiang Lin [b, *]

[a] Key Laboratory of High Performance Computing and Stochastic Information Processing (HPCSIP) (Ministry of Education of China), College of Mathematics and Computer Science, Hunan Normal University, Changsha, Hunan, 410081, PR China
[b] Collaborative Innovation Center for Energy Economics and Energy Policy, China Institute for Studies in Energy Policy, School of Management, Xiamen University, Xiamen, Fujian, 361005, PR China
[c] Center for Electric Pricing Research, Changsha University of Science and Technology, Changsha, Hunan, 410076, PR China

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ABSTRACT

This paper proposes a total-factor energy consumption performance index (TEPI) for measuring China's energy efficiency across 30 provinces during the period 1997 to 2012. The TEPI is derived by solving an improved non-radial data envelopment analysis (DEA) model, which is based on an energy distance function. The production possibility set is constructed by combining the super-efficiency and sequential DEA models to avoid “discriminating power problem” and “technical regress”. In order to explore the impacts of technological progress on TEPI and perform statistical inferences on the results, a two-stage double bootstrap approach is adopted. The important findings are that China's energy technology innovation produces a negative effect on TEPI, while technology import and imitative innovation produce positive effects on TEPI. Thus, the main contribution of TEPI improvement is technology import. These conclusions imply that technology import especially foreign direct investment (FDI) is important for imitative innovation and can improve China's energy efficiency. In the long run, as the technical level of China approaches to the frontier, energy technology innovation and its wide adoption become a sustained way to improve energy efficiency. Therefore, it is urgent for China to introduce measures such as technology translation and spillover policies as well as energy pricing reforms to support energy technology innovation.

1. Introduction

Improving energy efficiency and employing low-carbon energy technologies have been given high priority in the energy development strategy for China. From 1997 to 2012, China's energy intensity (measured by tce/10^4 Yuan, constant 2000 prices) declined by 33.65% from 1.724 to 1.144[1]. This implies that China has observed a significant improvement in energy efficiency. Most literature argue that technological progress, or improvement in productivity is a fundamental determinant of China's energy efficiency advancement [1–4]. Energy efficiency in major sectors such as power generation, transport, building etc., is catching up with developed countries through full implementation and diffusion of advanced technologies [5,6]. Notwithstanding, few studies have showed how to improve energy efficiency through technological progress. From the perspective of technological progress sources, there are two basic channels to achieve technological progress; namely indigenous innovation and technology import. The interaction between indigenous innovation and technology import usually refers to imitative innovation. Intuitively, each channel may have different effects on energy efficiency. It is therefore meaningful to investigate which channel is appropriate for sustainable improvement of energy efficiency. This paper aims at offering some insights on this issue.

Energy efficiency measurement is an important topic for energy

* Corresponding author at: Collaborative Innovation Center for Energy Economics and Energy Policy, China Institute for Studies in Energy Policy, School of Management,Xiamen University, Fujian, 361005, China.
E-mail addresses: likekent1208@163.com (K. Li), bqlin@xmu.edu.cn, bqlin2004@vip.sina.com (B. Lin).

[1] If it is measured by kg of oil equivalent per $2011 PPP GDP, the energy intensity declined by 35.46% from 0.289 in 1997 to 0.187 in 2012.

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economics, since it allows for comparison of energy efficiency performance among different countries, regions, or firms; from which corresponding policies can be developed to improve performance. Although energy intensity is widely used in practice, it is a partial-factor energy efficiency indicator and quite inappropriate for analyzing the impact of changing energy efficiency over time. Also, it does not provide any information about the realizable improvement gap in energy efficiency [7]. Hu and Wang [8] argued that a multi-factor input model should be adopted to evaluate energy efficiency. They therefore introduced a total-factor energy efficiency (TFEE) index. Since then, a number of studies have attempted to measure China's TFEE using the data envelopment analysis (DEA) model or stochastic frontier analysis (SFA) [9–15]. It can be said that energy efficiency measurement on the basis of the total-factor framework has become a standard practice in the field of energy efficiency research [16,17]. It is also argued that the total-factor method is superior to the single-factor method because the former does not only measure the substitution effects between energy and non-energy inputs, but also presents the differences in energy efficiency across the evaluation units.

Improving the technical level through technological progress is regarded as an effective and reliable policy measure in achieving the objectives of energy policy, especially with a cost that society is willing to pay [18–22]. According to the *Porter Hypothesis*, energy and environmental policy instruments can lead to competitiveness (energy efficiency improvement in this paper) by stimulating innovation [23–25]. Cagno et al. [26] investigated the link between innovation practices and energy efficiency. Their evidence indicated that diversifying innovation practices could lead to a better energy efficiency performance. Herrerias et al. [27] found that both foreign and domestic innovation efforts are conducive for improving China's energy efficiency.

Some literature investigate how to stimulate energy-efficient technological progress. van Soest [28] investigated the impact of environmental taxes and quotas on the timing and adoption of energy-saving technologies. Because of environmental and innovation externalities, Noailly and Batrakova [29] analyzed the links between energy-efficient innovations using patent counts and public policies in the Dutch building sector; arguing that market-based measurements (such as tax, energy price subsidies) rather than command-and-control measurements (such as technology and performance standards) are conducive for energy-efficient innovation. Urpelainen [30] investigated the determinants of energy efficiency innovation on the basis of neoclassical economic theory, highlighting the importance of relative prices; that is, a reasonable energy price system plays an important role for energy efficiency innovation [31].

It is imperative to know that, a low cost of energy consumption could undermine the foundation for innovation. Alcorta et al. [32] analyzed the financial benefits of investing in energy savings projects and ventures of 119 projects across nine manufacturing subsectors in developing countries. Song and Oh [33] found that, research and development (R&D) personnel ratio have a positive effect on both product and process innovation, while R&D intensity has a positive effect on process innovation in Korean's energy intensive industry.

As stated above, technology is vital to energy efficiency improvement. So this study pays special attention to different technological channels influencing energy efficiency in China. Several existing studies have identified several technological channels for improving the energy efficiency, including R&D activities. Yang et al. [34] found that indigenous R&D activity and interregional R&D spillovers can decrease industrial CO_2 intensity. Herrerias et al. [27] argued that both foreign and domestic innovation efforts play a significant role in improving energy efficiency in China, however, the interaction between foreign and indigenous innovations was modest.

The contribution of this study is in two facets: first, a new indicator of energy efficiency, known as the total-factor energy consumption performance index (TEPI) is introduced by using an improved DEA method. It is based on an energy distance function and its production possibility set is constructed by combining the super-efficiency and sequential DEA models to avoid "discriminating power problem" and "technical regress" [35]. Second, in order to investigate the various effects of different channels of technological progress on energy efficiency, a two-stage double bootstrap method is used [36]. In the first-stage of the analysis, the TEPI is corrected for biasness using the homogeneous bootstrap procedure. In the second-stage, the bias-corrected TEPI scores are regressed on different channels of technological progress by employing the truncated regression with bootstrap. The motivations for this research stem from the following considerations: (i) performance of China's energy efficiency is of high interest to the government and to academia. Notwithstanding, the TFEE introduced by Hu and Wang [8] may not be accurate for measuring energy efficiency since it is based on general distance function and may be regarded as total-factor productivity [7,37]. (ii) a two-stage double bootstrap method is not only conducive for obtaining a robust performance measurement of energy efficiency (since it accounts for biasness [38]), but also sheds light on the various effects of technological progress channels on energy efficiency accurately.

The remainder of this paper is organized as follows. Section 2 presents the methodology, which includes the concept of non-radial energy distance function and the latest development of the DEA model. Section 3 shows the data employed in the empirical

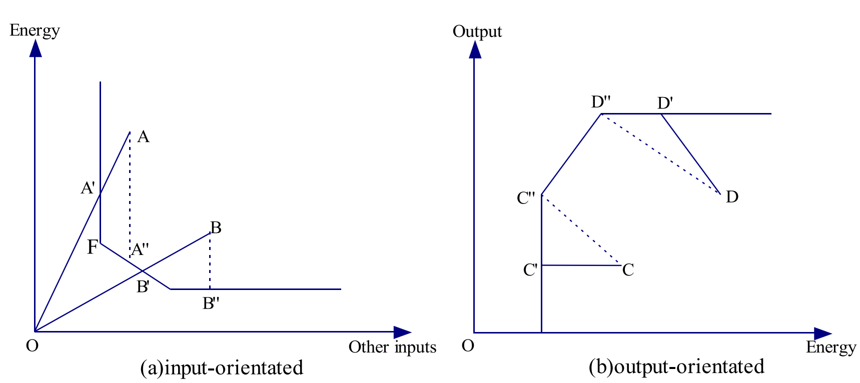

Fig. 1. Energy efficiency based on the framework of a distance function.