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China's total factor energy efficiency of provincial industrial sectors

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A B S T R A C T

The index of TFEE (total-factor energy efficiency) is used to assess the level of energy consumption to produce economic output (GDP (gross domestic product)) based on multi factors input, which is superior to conventional energy efficiency evaluation regarded as a partial-factor energy efficiency index. The objective of this study is to provide the changes of TFEE at sector and provincial level and to illustrate the drivers behind such various changes in China. The results show that the TFEE of most industrial sectors in the eastern provinces is higher than that in other provinces. The most important finding is that the gap of TFEE across sectors was narrowed in the eastern provinces and expanded comparatively in the central and western provinces. Such result implies that the gap reduction of TFEE across sectors would be one of the important drivers behind the increase of overall TFEE. Meanwhile, the Tobit regression results indicate that technology progress, energy price and economic development have positive influence on TFEE. And the impact of technology progress is found to be of the most significance.

1. Introduction

As China's economy has grown aggressively in the past three decades, the government is coping with current internal challenges of energy shortage and environmental degradation. Meanwhile, along with climate change becoming an increasingly pressing concern, China now is also facing mounting international pressures to cut back CO_2 emission [1]. On account of the size of China's economy, population, and its economic growth rate, China's energy consumption will keep a quick increase trend in the near future [2], and China is considered to play an important role in dealing with the challenges relating to the energy production and consumption among developing and transition nations [3]. One of the effective ways to reduce final energy consumption and pollutant emission is to improve energy efficiency [4]. Despite the fact that China's energy efficiency has continuously increased during the 1980s and most 1990s, the increasing trend of energy efficiency has reversed since the end of 1990s and early 2000s [5]. Moreover, China's energy efficiency is still much lower than that of developed countries although it has kept an increase trend in general (Fig. 1), and there is a great potential of improvement [6]. Hence, how to improve China's energy efficiency deserves more considerations.

A very wide range of factors determine the energy efficiency improvement. These include price-driven changes in demand, income-driven changes in demand, and AEEI (autonomous energy efficiency improvements) [7]. There are various definitions about energy efficiency [8]. The conventional energy efficiency index is actually the partial-factor energy productivity in which energy is the single input while substitution or complement among energy and other inputs (e.g., labor and capital stock) are neglected [9]. Hu and Wang (2006) propose a new indicator, the so-called TFEE (total factor energy efficiency) index defined as a ratio of the optimal-to-actual energy input under a multi-factor framework [10]. Since TFEE can avoid the plausible results caused by partial-factor energy productivity method in evaluating energy consumption (substitution exists between labor, capital and energy), it is preferred by some researchers [11].

2. Literature review

With the worldwide concern about China's energy consumption and environmental issues, energy efficiency has become one of the active researched topics [12]. Wang et al. (2013) measured China's regional energy efficiency based on DEA (Data Envelopment Analysis) method [13]. Their results show that the east area of China has the highest energy efficiency, while the efficiency of the west area is lowest. Wei et al. (2007) evaluated the energy efficiency of China's iron and steel sector with provincial panel data based on Malmquist Index Decomposition [14]. Their results demonstrate that technical

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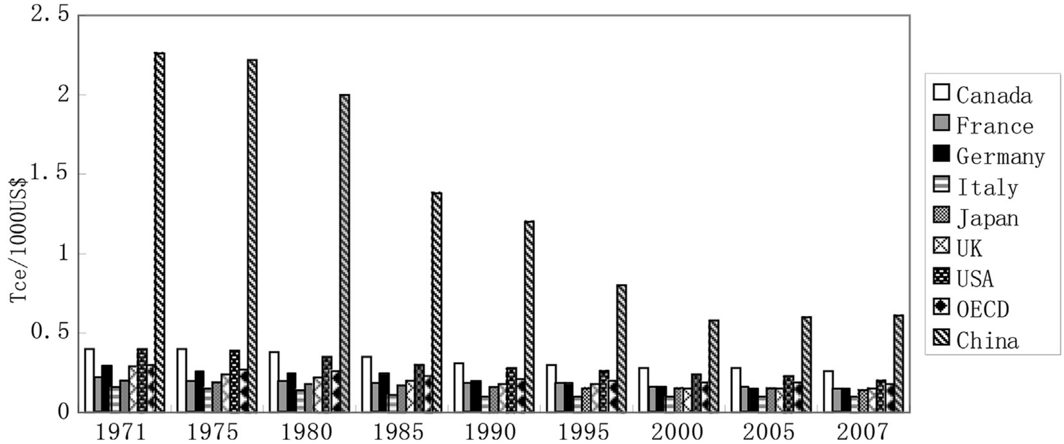

Fig. 1. Comparison of energy intensity between China and other countries, Data Source: EIA (energy information association) (2009) and CEEP (Center of Energy and Environmental Policy)'s calculation.

progress plays a more significant role in the increase of energy efficiency than technical efficiency improvement does. Feng et al. (2010) conducted a survey aiming at electricity consumers in Liaoning Province to analyze the barriers to energy efficiency [15]. These barriers include the lack of monitoring the performance standards of energy efficient products; distrust in energy efficiency labels and product standard.

Comparing with the traditional analysis of partial-factor energy efficiency, the study of TFEE has the advantage of considering the inputs of multi production factors. Hu and Wang (2006) employed the index of TFEE to evaluate 29 regional energy efficiencies in China during the period of 1995–2002, and pointed out the U-shape relation between area's TFEE and per capita income in their research [10]. Wang et al. (2011) investigated TFEE feature of Tianjin during the period of 1990–2008, and analyzed the influencing factors (such as industry structure, technology progress, the degree of opening up, etc.) based on Tobit model [16]. Rao et al. (2012) identified the limitation of previous studies which neglected the environmental effect of undesirable outputs, thus they evaluated TFEE in 30 regions from 2000 to 2009 by using slacks-based measure model of DEA with consideration of chemical oxygen demand and SO_2 as undesirable output [17]. Zeng and Huang (2009) explored the proportional relationship between energy consumption and GDP growth based on C–D (Cobb–Douglas) production function, and assessed TFEE by applying DEA approach [18]. Qu (2009) conducted an empirical analysis on TFEE of 30 provinces in China through applying DEA Malmquist productivity index, which decomposed the change of TFEE into technological progress and technological efficiency as well as decomposed the variation in technological efficiency into pure technological efficiency change and scale efficiency change [19]. Zhang et al. (2011) conducted a survey based on DEA window analysis, and found that China had the most rapid improvement in TFEE among 23 developing countries during the period of 1980–2005, which can mainly attribute to China's effective energy policy [20].

The most important contribution of this study to the current literature is that we analyze the change of TFEE both at provincial and sector level. Previous literature focus on TFEE change either at provincial level or at sector level and the studies at both provincial and sector level are absent. This paper makes the first attempt to fill the gap. The second contribution of this paper is that by analyzing the relationship between the changes of the difference of TFEE across sectors with the whole TFEE change in one region, we found that the gap reduction of TFEE across sectors would imply the increase of overall TFEE in the region.

3. Research method and data

3.1. Research method

3.1.1. DEA model

Since the introduction of measures of economic efficiency [21], two main kinds of energy efficiency assessment methods have been usually used. One is parametric method represented by SFA (Stochastic Frontier Analysis). In essence, SFA is a parametric estimation method with the use of MLE (Maximum Likelihood Estimation). However, pre-determined production function may not match the reality, and SFA faces challenges when dealing with the problem of multi-output. Compared with SFA, DEA is a non-parametric method, and it identifies a frontier on which the relative performance of all DMUs (decision making units) in the ample can be compared by using linear programming. DEA has the advantage of no need to assume particular functional forms relating to input and output which in many cases involves subjective judgment. Meanwhile, DEA can avoid the potential problems from assuming an inappropriate distribution of the error term. As a result, DEA is a sufficiently powerful analytical tool for measuring efficiency, and we use DEA method for analyzing TFEE change of provincial industrial sectors in China in this study. An important concept in DEA is DMU, which usually refers to a set of firms, while in this study it refers to a set of sectors in different provinces. Meanwhile, we use Tobit model to investigate the factors influencing TFEE, and explore the reasons for the differences of TFEE at sector level in different sample provinces.

In the DEA model, it is assumed that DMU_1, DMU_2,… , DMU_j ($j = 1,2,\ldots\ldots,n$) exist, and each DMU has m kinds of inputs and s kinds of outputs, where the input and output of the jth DMU are defined as:

$$x_{ij} = (X_{1j}, X_{2j}, \cdots, X_{mj})^T > 0, y_{rj} = (Y_{1j}, Y_{2j}, \cdots, Y_{sj})^T > 0,\ j = 1,2,\cdots,n \quad (1)$$

Accordingly, the weight coefficients of m kinds of inputs and s kinds of outputs are defined as:

$$v_i = (v_1, v_2, \ldots, v_m)^T, \quad u_r = (u_1, u_2, \ldots, u_s)^T \quad (2)$$

Hence, the efficiency index of each DMU is:

$$H_j = \sum_{r=1}^{s} u_r Y_{rj} / \sum_{i=1}^{m} v_i X_{ij},\ j = 1, 2, \ldots, n \quad (3)$$