Applied Energy 87 (2010) 3262–3270

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Total-factor energy productivity growth, technical progress, and efficiency change: An empirical study of China

Tzu-Pu Chang, Jin-Li Hu *

Institute of Business and Management, National Chiao Tung University, Taiwan

ARTICLE INFO

Article history:
Received 30 October 2009
Received in revised form 9 March 2010
Accepted 26 April 2010
Available online 1 June 2010

Keywords:
Total-factor energy productivity
Efficiency change
Technical change
Total-factor energy efficiency
Directional distance function
China

ABSTRACT

This article introduces total-factor energy productivity change index (TFEPI) based on the concept of total-factor energy efficiency and the Luenberger productivity index to evaluate the energy productivity change of regions in China with a total-factor framework. Moreover, the TFEPI can be decomposed into change in energy efficiency and shift in the energy use technology. According to the computation results, China's energy productivity was decreasing by 1.4% per year during 2000–2004. The average total-factor energy efficiency improves about 0.6% per year, while total-factor energy technical change declines progressively 2% annually. The factors affecting TFEPI are also examined: (1) The east area has a higher TFEPI than the central and west area; (2) increasing the development status and electricity share of energy consumption will improve the region's TFEPI performance, while increasing the proportion of GDP generated by the secondary industry deteriorates TFEPI of a region.

1. Introduction

In the course of economic development, energy use provides the embodied and disembodied technical progress and productivity growth [1,2]. In fact, several studies have found positive relationships between energy consumption and economic growth [3,4]. However, energy use is also a major source of greenhouse gas causing environmental problems [5–8]. Under the concern of economic growth and environmental pressure, the study of energy use, such as energy efficiency, energy intensity, and energy productivity, has become a significant research issue over the past several decades.

The energy issue is more important in China, as the economy has grown aggressively in the past two decades, and China is now the second largest energy-consuming economy in the world behind the United States. In 2004, China consumed primary energy over 59 quadrillion Btu, which accounted for 13.3% of the world [9]. Moreover, Crompton and Wu [10] forecast that the total energy consumption in China shall increase at an annual growth rate of 3.8% from 2003 to 2010. Along with this progressive demand for energy, the assessment of energy use should be taken into consideration under China's energy policy. Due to the above concern, the Chinese government has been actively shifting its economic development mode and reforming the economic structure since China's Agenda 21 was adopted in 1993. The 10th 5-Year Plan carried out in 2001 also emphasizes improving energy efficiency and conservation. For example, energy consumption per 10,000 RMB yuan GDP in 1990 prices should be reduced to 2.2 tons of standard coal; energy conservation should be accumulated to 340 million tons of standard coal; and the annual energy conservation ratio shall reach 4.5% by 2005. Whether or not these energy policies actually improve regional energy efficiency in China remains to be examined by empirical research.

There are two well-known indicators used to study how energy inputs are efficiently used: One is energy intensity which measures the amount of energy consumption for every economic output produced in the economy, and the other is energy efficiency (or energy productivity) defined as economic output divided by energy input [1,11–13]. Notice that each represents identical measures from different perspectives, but we only focus on the application of the later (energy productivity) in this paper. 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. Some researchers suggest that only using partial-factor energy productivity to evaluate energy consumption may obtain a plausible result [12,14]. For example, the energy efficiency index may increase solely when energy is substituted by labor, instead of any underlying improvement in technical energy efficiency [11].

Hu and Wang [14] propose a new indicator, so-called the total-factor energy efficiency (TFEE) index defined as a ratio of the optimal-to-actual energy input, in order to compute the relative

* Corresponding author. Address: Institute of Business and Management, National Chiao Tung University, 118, Chung-Hsiao W. Rd., Sec. 1, Taipei City 100, Taiwan. Fax: +886 2 23494922.
E-mail address: jinlihu@yahoo.com (J.-L. Hu).
URL: http://jinlihu.tripod.com (J.-L. Hu).

0306-2619/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.apenergy.2010.04.026

energy efficiency of each region in China under a multi-factor framework. Meanwhile, they conclude that the commonly used energy efficiency index overestimates the benefit from energy consumption because of significant substitution effects among inputs. Wei et al. [15] later extend the work of Hu and Wang [14] to explain what factors cause the variation in the cross-regional TFEE. Moreover, Hu and Kao [16] and Honma and Hu [17] also apply the concept of TFEE to investigate related issues in APEC economies and Japan's regions, respectively. However, the methodology used by previous studies only focuses on computing relative energy efficiency among objects in each year such that it lacks insights with longitudinal data. Therefore, an innovative method will be proposed in this paper to deal with dynamic energy productivity changes.

The main purpose of this article is to evaluate the energy productivity change of regions in China with a total-factor framework during 2000–2004. In order to study the energy productivity changes, this paper introduces a total-factor energy productivity index (TFEPI) which integrates the concept of the TFEE index with the Luenberger productivity index to measure the change of total-factor energy productivity. Note that the terms, energy efficiency and energy productivity, are used interchangeably in traditional literature, while they are clearly distinguished in this paper. The term energy productivity in this study is similar to the well-known definition as a ratio of the output (GDP) to energy inputs. Nevertheless, energy efficiency is defined as using less energy input to produce the same amount output under a production frontier representing the current technology to use energy.

The Luenberger productivity index introduced by Chambers et al. [18], as a difference of directional distance function, measures whether total-factor productivity changes from the base period to the next period. As shown by Luenberger [19] and Chambers et al. [20], the directional distance function provides a flexible method to calculate both input contractions and output expansions. According to the flexibility of directional distance function, some researchers have considered that the Luenberger productivity index is more appropriate than the well-known Malmquist productivity index [21,22]. Moreover, Chambers et al. [18] illustrates that the Luenberger productivity index can be decomposed into efficiency and technical changes. Hence, our study applies a non-parametric programming method, commonly known as the data envelopment analysis (DEA) approach, to compute the total-factor energy productivity change. Additionally, TFEPI can be decomposed into two components: One is the change in relative energy efficiency, indicating that an object is getting closer to or farther from its annual frontier (catch-up effect or fall-behind effect). The other is shift in the technology level of energy use, showing the shift in the production frontier under the total-factor framework. The improvement of energy technology may be because of many aspects, such as changing energy mix, innovating and diffusing energy-saving technologies, and upgrading production process and equipments [6,23].

Comparing to traditional parametric methods (such as the Cobb–Douglas function and translog production function), the advantage of using the DEA method is that this method avoids model misspecification [21,24]. Moreover, the DEA-Luenberger index can easily compute total-factor productivity change, efficiency change, and technical change. Since the DEA-Luenberger index cannot analyze the change in single factor productivity under total factor concern, the TFEPI is introduced to deal with this issue in this article.

The remainder of this paper is organized as follows. Section 2 introduces the proposed total-factor energy productivity index using the DEA approach. Section 3 interprets data sources and variables' descriptions. Section 4 presents and discusses empirical results in the case of China. Finally, Section 5 concludes this paper.

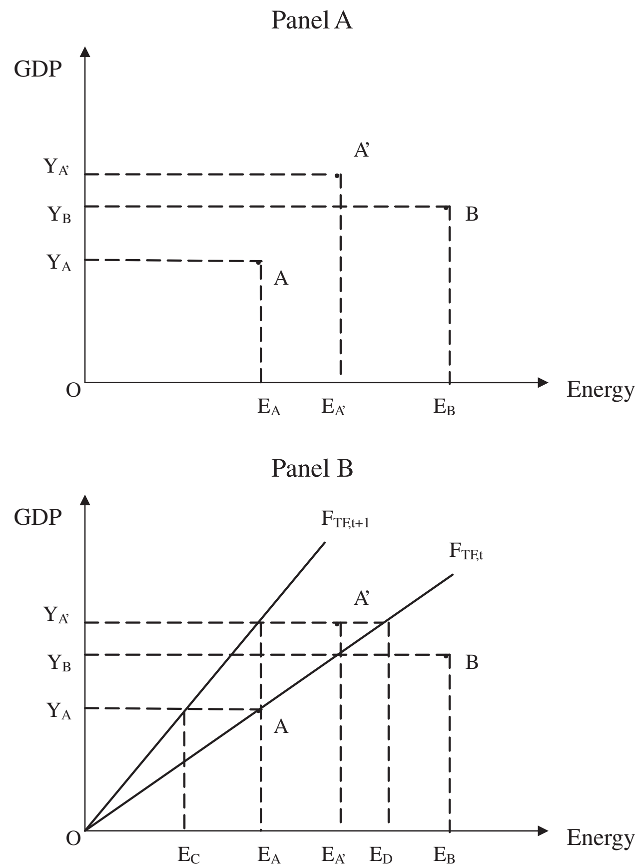

Fig. 1. The graphic conception of traditional productivity, TFEE, and TFEPI.

2. Total-factor energy productivity index

The ratio of GDP to energy consumption is one of the most popular indicators to measure energy efficiency due mainly to its simplicity and intuitive [25]. However, the TFEPI introduced in this study provides two advantages: first, traditional energy efficiency indicator only takes account of energy as single input. This indicator may easily overestimate the real change in energy productivity when energy is substituted for other inputs. Second, traditional indicator disregards the technology level of energy use. In other words, the traditional indicator assumes the technology is always consistent year after year. In fact, the productivity would improve because of technical progress [26]. Hence, this paper uses Fig. 1 to illustrate above-mentioned concerns.

Panel A of Fig. 1 sketches the conception of traditional energy efficiency (or productivity) indicator. If two objects operate at point A and B, their traditional energy productivity would equal to Y_A/E_A and Y_B/E_B, respectively. In this example, the energy productivity of point A is higher than point B. When we consider that one object has increased its energy productivity from 1 year to the next (from point A to point A′), the improvement of energy productivity is equal to $(Y_{A'}E_A - Y_AE_{A'})$[1].

Hu and Wang [14] propose TFEE indicator under total-factor framework to compare the relative energy efficiency among regions in China. We use Panel B of Fig. 1 to demonstrate their ideas and consider a special case assuming the production frontier for

[1] In this paper, the Luenberger productivity index is used to examine the energy productivity change in China. Therefore, any change here is based on differences rather than more traditional ratios. For more advantages about differences, see Boussemart et al. [21].