Energy Economics 47 (2015) 87–97

Contents lists available at ScienceDirect

Energy Economics

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

Decomposition of environmental total factor productivity growth using hyperbolic distance functions: A panel data analysis for China

Zibin Zhang, Jianliang Ye *

Department of Economics and Center for Research of Private Economy (CRPE) at Zhejiang University, Hangzhou, China

ARTICLE INFO

Article history:
Received 20 May 2014
Received in revised form 16 October 2014
Accepted 28 October 2014
Available online 7 November 2014

JEL classification:
D24
Q43
Q53

Keywords:
China
Energy efficiency
Environmental efficiency
Environmental total factor productivity
Hyperbolic distance function

ABSTRACT

This paper extends recently developed parametric hyperbolic distance functions to the analysis of energy and environmental efficiency for a panel data of 29 provinces in China from 1995–2010, and then decomposes the growth of environmental total factor productivity into two component measures, namely, environmental efficiency change and environmental technical change based on the estimated hyperbolic distance functions. We find that there exists a great dispersion in environmental efficiencies across provinces and regions, and the growth of environmental productivity is almost due to the environmental technical change rather than the environmental efficiency change. However, the contribution of the environmental efficiency change has recently become increasingly positive and thus drives up the growth of environmental productivity from slowdown.

1. Introduction

Since the beginning of this century, China has drawn great attention for its higher economic growth, but this rapid growth has also resulted in considerable damage to the natural environment. From 2000 to 2005, the average annual growth rate of constant price of GDP in China is 9.54%, and this growth is fueled by large increases in energy consumption with average annual growth of 9.14% (Fig. 1). With a coal-dominated energy structure, this higher growth in energy consumption is associated with higher sulfur dioxide (SO_2) emissions (Fig. 2) and soot. These higher SO_2 emissions have significant impacts on human health and ecosystems in China. SO_2 pollution can cause severe respiratory disease and premature death in Chinese cities (Chen et al., 2012). Approximately 30% of the land areas in China suffer from acid rain (SEPA, 2007), resulting in damage to agricultural crops, forests, fisheries, buildings, and infrastructure. Acid rain has caused China an annual economic loss of US$ 13 billion (Hao et al., 2007). Recently, Wei et al. (2014) estimate that the agricultural losses in 2008 were close to US$ 1.5 billion, 0.66% of the total agricultural value added, due to industrial SO_2 pollution in China. With SO_2 being a major air pollutant in China, the environmental authorities of China have imposed strict environmental regulation policies on SO_2 emissions (see Schreifels et al. (2012) and Cao et al. (2009) for detailed SO_2 control policies in China).

To deal with these energy and environmental challenges, Chinese government initiated an Energy Conservation and Emission Reduction (ECER) program starting in the 11th Five-Year-Plan (FYP) (2006–2010) and continuing in the 12th FYP (2011–2015). ECER program set mandatory national targets of saving energy use per unit of GDP by 20% and reducing primary pollution emissions by 10% in the 11th FYP (NPC, 2006), and saving energy use per unit of GDP by 16% and reducing primary pollution emissions by 8–10%[1] in the 12th FYP (NPC, 2011). These targets were then disaggregated into energy saving and pollution reduction targets for each province. To implement this program, China has taken a series of actions such as establishing institutional organizations, monitoring and reporting on target achievement, promoting energy conservation in the key energy-consuming industrial enterprises, initiating programs to reduce energy intensity through structural adjustment, improving energy efficiency in buildings, developing energy efficiency fiscal incentive programs, and implementing dust removal and desulphurization projects in power industry. Taylor et al. (2010) and CPC-UNCSD (2012) provide some details about the ECER program. As a result, China's energy consumption per unit of GDP dropped 19.1%

---

* Corresponding author at: Department of Economics, Zhejiang University, 38 Zheda Rd., Hangzhou 310027, China. Tel./fax: +86 571 87952835.
E-mail addresses: Zbzhang@zju.edu.cn (Z. Zhang), Jianliangye@zju.edu.cn (J. Ye).

[1] Reducing SO_2 and chemical oxygen demand (COD) by 8%, and reducing ammonia–nitrogen and nitrogen oxide (NQ_x) by 10%.

http://dx.doi.org/10.1016/j.eneco.2014.10.023

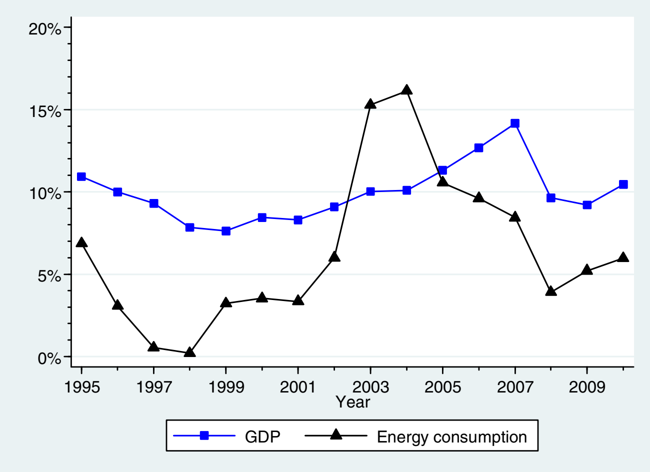

Fig. 1. Growth rates of GDP and energy consumption 1995–2010, China. Sources: Growth rates of GDP are calculated from indices of gross domestic product at constant prices in China's statistical yearbook 2012; growth rates of energy consumption are calculated from the total consumption of energy in China's statistical yearbook 2012.

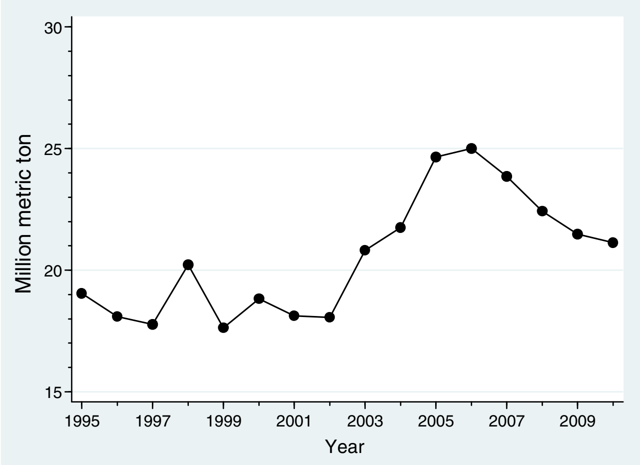

Fig. 2. Sulfur dioxide emissions in China 1995–2010.
Source: Aggregate provincial sulfur dioxide emissions in our sample.

during its 11th Five-Year Plan period (SCIO, 2012), which was also reflected in Fig. 1 as the slowdown of growth of energy consumption since 2005, as well as SO_2 emissions decreasing by 14.30%[2] in 2010 from 2005 level noticed in Fig. 2.

Given the importance of addressing energy and environmental problems for achieving sustainable development in China, policymakers in China are particularly interested in the answers to the following three related questions. First, what is the maximum potential in energy saving and pollutant reduction for each province at a given technology? Second, has the energy and environmental efficiency changed since implementation of the ECER program? Third, how improving energy and environmental efficiency will affect the environmental productivity growth? All these questions are related to how to measure energy and environmental efficiency and what determinate the growth of environmental productivity. Our research sheds some light on above three related questions by parametrically decomposing the Malmquist productivity index based on hyperbolic distance function models.

The major objective of this paper is to identify the sources of the growth of environmental total factor productivity (TFP) in China based on the measurement of the provincial energy and environmental efficiency. Employing the parametric hyperbolic distance function models, we analyze energy and environmental efficiency for a panel data of 29 provinces in China from 1995–2010. Using energy, labor, and capital stock as inputs to produce the desirable output (GDP) and the undesirable output (SO_2 emissions), we estimate how each province can improve its energy and environmental productive performance through increasing its desirable output and reducing its undesirable output, while simultaneously saving energy inputs, and examine how the ECER program will affect the energy and environmental efficiency for each province. Based on the estimated hyperbolic distance functions, we also use Diewert's (1976) Quadratic Identity Lemma and follow the general approach outlined in Orea (2002) to decompose environmental TFP change into environmental efficiency change, which is the movement toward the frontier, and environmental technical change, which is the shift of the frontier. These further analyses help us identify potential different contributions of environmental productivity growth for each province in China, and examine how the ECER program will affect the environmental productivity growth for each province.

In terms of literature on study environmental TFP change, our approach differs from the traditional approach in measuring energy and environmental efficiency and decomposing TFP change. Several studies employ the Shephard energy distance functions to study energy efficiency for OECD countries (Zhou et al., 2012b) and China's 30 administrative regions (Lin and Du, 2013) in a parametric approach without considering bad outputs in their production technologies. However, to account for bad outputs in the production technology, many studies use the directional distance function primarily through a data envelopment analysis (DEA) framework (e.g., Chambers et al., 1998; Chung et al., 1997; H. Wang et al., 2013; Picazo-Tadeo and Prior, 2009; Watanabe and Tanaka, 2007). Given the additive properties of the directional distance function, it is more easily to model efficiency using linear programming. Zhou et al. (2008) present a literature survey of 100 papers on the application of DEA to energy and environmental studies. The major limitation of DEA is that it is in a deterministic way, where all the detected distance from the frontier is treated as inefficiency without statistical noise, hence inference is not possible without bootstrapping (Simar and Wilson, 2004). Although Färe et al. (2005) have already built a good theoretical foundation on the quadratic directional distance function, there are still very few empirical applications estimating directional distance function through a stochastic frontier analysis (SFA) framework. In addition to being dominated by the nonparametric DEA for the directional distance function efficiency models, the resulting efficiency scores depend on the directional vector chosen by researchers (Färe et al., 2013). We extend the recently developed parametric hyperbolic distance function, first introduced by Färe et al. (1985) and then extended by Cuesta et al. (2009) in measuring environmental efficiency, to estimate energy and environmental efficiency in China through a SFA framework. As noted by Cuesta et al. (2009), the hyperbolic distance function can be easily imposed its property of almost homogeneity on a more flexible translog specification, whereas the directional distance function can be easily imposed its translation property on a quadratic specification. Moreover, as noted by Johnson and McGinnis (2009), the hyperbolic-oriented efficiency can be computed for cases when the directional-oriented efficiency is not feasible.

In addition to being different in measuring energy and environmental efficiency, our paper differs from the literature on decomposing environmental TFP change by providing a parametric method of decomposing of the Malmquist productivity index based on the hyperbolic distance function models. There are two lines of literature on studying environmental productivity growth. The first approach is based on decomposition the Malmquist productivity index that was introduced as a theoretical index by Caves et al. (1982) and further development by Färe et al. (1994). Kortelainen (2008) uses relative eco-efficiency scores to construct an environmental performance

---

[2] Own calculation from our sample data.