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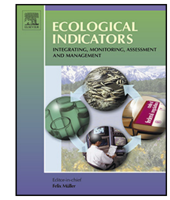

The elasticity of the potential of emission reduction to energy saving: Definition, measurement, and evidence from China

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ABSTRACT

Based on energy and CO_2 emission efficiencies, this paper proposes a definition of the elasticity of the potential of emission reduction to energy saving (E_{peres}), and measures the elasticity in China's 30 provincial regions. Although E_{peres} is a relative definition, it can be used (1) to measure the amount of reduced CO_2 emissions per unit fossil energy saving, (2) to reflect the effectiveness of fossil energy saving for CO_2 emission reduction in different regions, and (3) to provide decision-making criteria for selecting pathways for emission reductions in different regions. The results show that compared with energy saving, emission reduction is a more serious issue in China. This indicates that energy saving policies have been highly effective since their implementation during the 11th "Five-Year Plan". With respect to provincial disparities, the emission reductions caused by fossil energy saving are not significant in Beijing, Shanghai, and Guangdong. Fujian province has significant E_{peres}, indicating that emission reduction causing by fossil energy saving is effective. E_{peres} has been increasing over time in Hunan and Hubei. Hainan's E_{peres} has remained less than 1, indicating that its emission-reduction effect of fossil energy saving is worse than in other provinces. Moreover, the elasticity of Eastern China is greater than that of Central China and Western China. This finding sheds light on pathway selection for energy saving and emission reduction in China: it would be more appropriate to encourage fossil energy saving in Eastern China, and to promote clean energy use (e.g., water electricity and solar energy) in Central China and Western China.

1. Introduction

Energy saving and emission reduction have been vigorously measured by the Chinese government (Yang et al., 2017; Zhang et al., 2017). The energy intensity and CO_2 emission intensity of China are expected to be reduced by 16% and 17%, respectively, in 2015 (the end of the 12th "Five-Year Plan" (FYP)) compared with their 2010 levels (the end of the 11th FYP), respectively. In addition, CO_2 emission intensity must be reduced by 40–45% in 2020 (the end of the 13th FYP) compared with their 2005 levels (the end of the 10th FYP). There is a close relationship between the decreases in energy intensity and CO_2 emission intensity (Shao et al., 2016a, 2016b). Zeng and Chen (2016) and Zeng et al. (2016) suggested that an efficient allocation ratio for the carbon emission allowance can help realize energy conservation and emissions reduction goals in China. Similarly, Wang et al. (2011) suggested that reducing carbon emissions requires optimizing energy mix and cutting down energy intensity.

To reduce CO_2 emission intensity, Jiang et al. (2016) also emphasized the importance of building a comprehensive allocation mechanism associated with the carbon quota and increasing the initial proportion of free allocation. Generally, CO_2 emissions can be reduced through fossil energy saving and fuel-mix adjustments. While many studies have focused on energy and CO_2 emission efficiencies (e.g., Fan et al., 2015; Shao et al., 2016c), few papers discuss the correlation between fossil energy saving and CO_2 emission reduction. This paper focuses on the reduction of CO_2 emissions resulting from per unit fossil energy saving (we call it the elastic-

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ity of emission reduction to energy saving, E_{peres}). We empirically estimate the elasticity by using provincial-level data of China, and further analyze the selection of pathways for emission reductions in different regions of China.

In microeconomics, traditional elasticity takes the forms of supply price elasticity, demand price elasticity, demand income elasticity, and the cross-elasticity of demand. Some studies also apply the elasticity in the fields of energy and environmental economics. As a crucial production factor, energy is frequently used in different kinds of elasticities. Based on the application of energy-related elasticity in different cases, the related studies can be classified into several aspects.

First, elasticities have been applied in the general energy field, including a multi-stage energy replacement system (Lowe, 2003), European countries' Armington elasticity (Welsch, 2008), price elasticity concerning Japanese willingness to pay for energy efficiency labels (Galarraga et al., 2011), Mozambique's domestic energy demand (Arthur et al., 2012), income elasticity and price elasticity on industrial energy demand in the Organization for Economic Cooperation and Development (OECD) countries (Adeyemi and Hunt, 2014), and the cross-elasticity of Beijing's energy consumption behavior (He et al., 2014).

Second, elasticities have been applied in the electricity power field, including a short term and long term evaluation of the U.S. residential electricity demand (Silk and Joutz, 1997); the investigation of price elasticities in Pakistan (Jamil and Ahmad, 2011), China (He et al., 2011), South Africa (Inglesi-Lotz, 2011), Western Australia (Fan and Hyndman, 2011), Switzerland (Filippini, 2011), U.S. (Pielow et al., 2012), and Japan (Okajima and Okajima, 2013; and the estimation of the demand elasticity of the electricity market (Yan and Folly, 2014).

Third, elasticities have been applied in fuel and crude oil product fields, including coal demand elasticity of (Masih and Masih, 1996), demand elasticity of Turkey's imported crude oil (Altinay, 2007), price elasticity of gasoline (Brons et al., 2008), crude oil's imported price and its income elasticity in South Africa (Ziramba, 2010), the gasoline price and its income elasticity in Lebanon (Sita et al., 2012), the U.S.'s petrol price elasticity (Lin and Prince, 2013), and the impact of changes in fuel demand on CO_2 emissions in the Lisbon Metropolitan area (Melo and Ramli, 2014).

Most of these studies have focused on the measure of energy (including fuels and electricity) elasticity and its influencing factors. Only Melo and Ramli (2014) conducted a quantitative method to examine the correlation between energy and CO_2 emissions. They also adopted a scenario analysis to discuss how the goal of emission reduction is achieved through the change of fuel price. Their results show that the goal of emission reduction can be achieved only when economic growth slows down. However, this study only focused at the micro-level and cannot facilitate decision-making at the macro-level. Further, their results depend on a large amount of price information and future data information through a scenario analysis. In contrast to Melo and Ramli (2014), our study proposes and examines the elasticity of the potential of CO_2 emission reduction to energy saving. The elasticity measures the corresponding reduction in CO_2 emissions resulting from per unit energy saving. The larger the elasticity value, the more effective the CO_2 emission reduction from energy saving.

Some scholars have conducted meaningful attempts to model the elasticity of the environmental pollution with respect to economic growth (Zhao et al., 2016, 2017). Tapio (2005) constructed a framework to define and estimate the decoupling between environmental pollution and economic growth, focusing on the relationship among GDP, traffic volumes, and CO_2 emissions in the 15 European Union (EU) countries during 1970–2001. Baležentis and Hougaard (2014) investigated the decoupling of energy use and CO_2 emissions for the Lithuanian agricultural sector. Based on Tapio (2005) and using the log-mean Divisia index (LMDI) method, Zhang et al. (2015) provided an approach to identify the types of the decoupling between the changes in GDP and energy consumption in China. Zhou et al. (2006) constructed the slack-based measure index of environmental performance for 30 OECD countries from 1998 to 2002.

Although Zhou et al. (2006) and Baležentis and Hougaard (2014) focused on the relationship between economic development and environmental pollution using different indices, they did not complete an intertemporal comparison based on the input-output database and neither included an energy conservation potential calculation. To fill such a gap, this study focuses on energy saving and CO_2 emission reduction potentials, as well as the calculation of the elasticity. Based on the value of E_{peres}, we can reasonably select pathways for emission reduction in different regions using scientific and effective decision-making.

The value of E_{peres} can be measured using the Data Envelopment Analysis (DEA) method. This method logically reflects the production relationship between the input variables and the output variables at the macro-level. In addition, the method requires no price information and relaxes data availability limitation. Since Fare et al. (2007) proposed the idea of the Environmental Production Technology (EPT) which considers undesirable outputs, studies on measuring energy and environmental efficiencies have become increasingly popular. Zhou et al. (2008) provided a comprehensive literature review on this method, and Zhou and Wang (2016) further presented a literature review on CO_2 allocation issue based on the DEA method. Because of the strong systematic relationship among energy, economy, and the environment, more researchers are using different innovative DEA models to quantitatively investigate both energy and CO_2 emission efficiencies.

In the related literature, research samples have included: (1) the application of the non-radial DEA model at country and sectoral levels, such as for the energy and environmental efficiencies of 26 OECD countries (Zhou et al., 2007), agricultural and environmental efficiencies of European Union countries (Vlontzos et al., 2014), and the greenhouse gas (GHG) emission environmental performance index (EPI) in Lithuanian economic sectors using the Hicks-Moorsteen index (Baležentis et al., 2016); (2) studies on China's provincial efficiency, such as the calculation of resources and environmental efficiencies in China's 30 provinces using Shannon's entropy method (Bian and Yang, 2010), the estimation of China's regional industrial energy efficiency using fixing non-energy input DEA model (Shi et al., 2010), the measure of the potential of emission reduction and opportunity costs using the SBM model (Choi et al., 2012), and the calculation of energy and environmental efficiencies at China's provincial level using the window DEA method (Wang et al., 2012), multi-directional efficiency analysis (Wang et al., 2013a), and the range-adjusted measure approach (Wang et al., 2013b); (3) the studies on electricity generation and power plant performance, such as the measure of the energy and environmental efficiencies of electricity generation using the non-radial directional distance function for OECD countries (Zhou et al., 2012), Korea (Zhang et al., 2013), and China (Zhang et al., 2014), and the estimation of energy and environmental efficiencies using the slacks-based DEA model for China's thermal power generation (Bi et al., 2014).

Although these previous studies have made great progress with respect to methodology and empirical evidence, they leave some open questions. First, most existing studies estimated energy and CO_2 emission efficiencies based on two separate processes; however, the two kinds of efficiencies are inseparable in real-world conditions. The CO_2 emission efficiency is closely related to energy efficiency. In general, fossil energy saving can result in the reduction of CO_2 emissions. Second, although some recent studies simultaneously estimates energy and environmental efficiencies, the