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Energy efficiency and marginal carbon dioxide emission abatement cost in urban China

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ABSTRACT

Energy efficiency improvement and carbon emission reduction are two important ways to mitigate energy consumptions and global warming. This paper aims to examine energy efficiency and carbon dioxide (CO_2) emissions abatement costs of city urban areas in China. To this end, an improved slacks-based measure approach is introduced, which considers the linkage between desirable and undesirable outputs. Then, measures of energy efficiency, CO_2 emission abatement cost and comprehensive state index of CO_2 emissions abatement cost and CO_2 emissions reduction potential are defined. The proposed model is then applied to the dataset of 285 cities in China during 2008–2012. The results show that most city urban areas in China have relatively low energy efficiencies. Surprisingly, there are gradually narrowing gaps regarding mean energy efficiencies between areas during 2008–2012. Nevertheless, there are great disparities in energy efficiencies between cities within a typical area, and even a provincial region. It is found that CO_2 emissions abatement cost in urban China exhibits an increasing trend during the study period. Also, significantly geographic disparities in abatement costs between areas, regions and cites are found. Specifically, energy efficiency has significantly positive correlation with the comprehensive state index in China. Some important findings and useful policy implications are achieved.

1. Introduction

Rapid economic growth along with fast urbanization process has resulted in huge amounts of energy consumptions and related CO_2 emissions. Nowadays, China has overtaken United States and become the largest energy consumer and CO_2 emitter in the world. In 2014, China's energy consumption accounts for roughly 23% of global energy consumption, which is larger than that of United States (i.e., 17.8%) (BP, 2015). It is reported that China's CO_2 emissions from fuel combustion is 9023.1 million tons in 2013, which is much larger than that of United State, i.e., 5119.7 million tons (IEA, 2015). In order to realize sustainable development, the central government has announced several new energy and CO_2 emission reduction targets by 2015 with 2010 as the base year, e.g., reducing energy consumption per unit of GDP by 16% and reducing CO_2 emissions per unit of GDP by 17% (Choi et al., 2012). In the current state, fossil energies (i.e., coal, crude oil and natural gas) dominated energy consumption structure in China cannot be significantly changed, and therefore, CO_2 emissions cannot be reduced dramatically. Thus, energy efficiency improvement has been widely recognized as one of the most cost-effective ways to increase energy security and reduce CO_2 emissions (Al-Mansour, 2011).

As an important administrative region, city has played a key role in economic growth, energy consumptions and also related CO_2 emissions. Due to great disparities in natural resources endowments, energy consumption structures, industrial structures, urbanization processes and even economic development modes, various cities may have their own typical energy saving and carbon reduction characteristics (Wang and Wei, 2014). In such a case, energy efficiency and CO_2 emissions reduction potentials may vary significantly across cities in China. This means that adopting the same energy saving and CO_2 emissions reduction policies, plans or modes in different cities in China is inappropriate. Thus, it is urgent and essential to measure energy efficiency and CO_2 emissions reductions of all cities in China.

Generally speaking, CO_2 emissions can be regarded as a by-product of economic production. In this context, CO_2 emissions reduction may lead to economic loss in production. In order to better reduce CO_2 emissions in production process, it also needs to balance CO_2 emissions abatement cost and economic loss. Thus, it is necessary to estimate marginal carbon emission abatement cost in China. This can also provide more policy making supports on carbon reductions as well as carbon pricing in emissions trading system in China.

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Specifically, China's National Development and Reform Commission set seven areas as the carbon emission trading system (ETS) pilots, including five municipalities (i.e., Beijing, Chongqing, Shenzhen, Shanghai and Tianjin) and two provinces (Guangdong and Hubei). ETS is believed to balance social abatement costs with benefits in order to achieve the efficiency in carbon reduction. However, as Jotza et al. (2013) suggested, there is uncertainty about price levels of carbon emissions in China. In particular, carbon trade prices have increased significantly since the ETS pilots were launched. Therefore, to reasonably determine carbon trade prices, more knowledge about carbon pricing is required. Unfortunately, the knowledge about carbon pricing in China is still limited (He, 2015). Intuitively, carbon emission abatement cost can provide some accurate information for determining carbon trade prices in practice.

According to the aforementioned evidences, to improve energy efficiency and reduce CO_2 emissions in urban China, two important issues are raised: (1) How to effectively evaluate energy efficiency by harmonizing the trade-off between economic growth, energy use and CO_2 emissions? (2) How to measure abatement cost of CO_2 emissions in urban China?

With growing concerns on energy and environmental problems, there are an increasing number of studies that have addressed energy efficiency issues. In the literature, data envelopment analysis (DEA) is considered as a successful method to evaluate energy efficiency with multiple inputs and outputs (Zhang et al., 2011; Choi et al., 2012). As Zha et al. (2016) suggested, the extant studies on evaluating energy efficiency based on DEA approach are mainly classified into two streams. The first stream applies DEA models to measure energy efficiencies of different units (e.g., countries, regions, cities or industries) while not considering CO_2 emissions (Hu and Wang, 2006; Honma and Hu, 2014; Li and Lin, 2015). As CO_2 emissions are inevitably generated by consuming fossil fuels, energy efficiency evaluation ignoring CO_2 emissions is not reasonable. This approach cannot provide appropriate measures for efficiency comparisons (Zhou and Ang, 2008). The second stream attempts to evaluate energy efficiencies of countries, regions or industries by taking CO_2 emissions into account. This stream measures energy efficiency by minimizing energy consumption and (or) CO_2 emissions while keeping other inputs and outputs constant (Zhou and Ang, 2008; Wang et al., 2012; Wu et al., 2012; Lozano et al., 2013). Note that, efficiency measures in most of the above mentioned studies are radial measures, which optimize all inputs or outputs with an equal proportion. As such, these measures cannot identify the typical inefficiency information for specific inputs or outputs, and this may lead to a biased estimation (Fukuyama and Weber, 2009). To overcome the weakness of radial measure, some studies have applied non-radial methods such as slacks-based measure (SBM) approach to evaluate energy efficiency, e.g., Zhou et al. (2006) and Rao et al. (2012). As we know, in practical production process, GDP and CO_2 emissions are produced jointly, and thus the indicator of CO_2 emissions is weakly disposable in efficiency evaluation. Although, Zhou et al. (2006) have considered weak disposability of CO_2 emissions, slack variable related to CO_2 emissions is not imposed in their model. Furthermore, the linkage between GDP and CO_2 emissions is not considered in their models, which may not be suitable in efficiency evaluation. Thus, an improved SBM model is required to reasonably measure energy efficiency in the presence of CO_2 emissions.

Since carbon emission abatement cost cannot be obtained directly in practice, shadow price is usually applied to estimate the abatement cost. In the literature, DEA approach has been widely used to estimate shadow prices of pollutants (Zhou et al., 2014). Some studies mainly focus on examining shadow prices of waste gases (e.g., dioxide and nitrogen oxides) (Ke et al., 2008; Kaneko et al., 2010) and industrial wastes (Ke et al., 2010; Wang et al., 2015). Specifically, within the China's context, an increasing number of studies have investigated CO_2 emission abatement cost in recent years.

Lee and Zhang (2012), He (2015) and Wang and He (2017) have applied distance function approaches to estimate CO_2 emission abatement costs of manufacturing industries, regions and transportation industries in China, respectively. Under the DEA framework, Wang and Wei (2014) explore marginal carbon emission abatement costs of industrial sectors for 30 Chinese major cities during 2006–2010. Zhou et al. (2015) employ multiple distance function DEA approaches to estimate shadow prices of CO_2 emissions for Shanghai industrial sectors in 2009–2011. Notably, most of the previous studies use radial efficiency measures that cannot capture all technical inefficiency in inputs, desirable outputs and CO_2 emissions. Three exceptions are Choi et al. (2012), Wei et al. (2012) and Wang et al. (2016). The first two studies apply traditional SBM approach to estimate regional marginal abatement costs of CO_2 emissions in China during 2001–2010, and CO_2 reduction potentials and marginal abatement costs for 29 provinces over 1995–2007, respectively; while Wang et al. (2016) evaluate carbon emissions efficiency and reduction costs of 30 provinces in mainland China from 1996 to 2012 by using non-radial directional distance function DEA method. However, weak disposability of CO_2 emissions and the linkage between GDP and CO_2 emissions are ignored in their models.

To the best of our knowledge, limited studies have estimated abatement costs of CO_2 emissions at city level in China. One exception is Wang and Wei (2014) that focuses on examining CO_2 emission abatement costs of industrial sectors at city level in China. In their work, only 30 major cities are considered and their used efficiency measure is a radial one. This study attempts to examine energy efficiency and energy-related CO_2 emission abatement costs of urban areas at city level in China. To this end, an improved SBM model by incorporating the linkage between GDP and CO_2 emissions is proposed. Based on the introduced SBM model, measures of energy efficiency, CO_2 emission abatement cost and comprehensive state index of CO_2 emission abatement costs and reduction potentials are defined. The proposed approach is then applied to evaluate energy efficiencies and CO_2 emission abatement costs for urban areas of 285 cities in China during 2008–2012.

The main contributions of this study to the existing literature are summarized as the following two aspects. First, to our best knowledge, this study is the first to examine energy efficiencies and CO_2 emission abatement costs for urban areas of all possible cities in China. Second, the analysis is conducted by using an improved SBM approach, which considers the linkage between GDP and CO_2 emissions. Some useful policy implications are achieved. The rest of this paper is organized as follows. Section 2 firstly introduces an improved slacks-based measure approach, and then measures of energy efficiency and CO_2 emission abatement cost are defined. Cities, variables and data sources are described in Section 3. Sections 4 and 5 present the results of energy efficiencies and CO_2 emission abatement costs with respect to urban areas for 285 cities in China during 2008–2012, respectively. Specifically, a measure of comprehensive state index of CO_2 emission abatement costs and CO_2 emission reduction potentials are defined in this section. Conclusions and policy suggestions are provided in Section 6.

2. Methodology

In this section, we firstly present an improved slacks-based measure model, and then, measures of energy efficiency and abatement cost of CO_2 emissions are derived.

2.1. *Efficiency evaluation approach*

Consider that there are n independent cities in China, denoted by CU_j ($j = 1, 2, \ldots, n$). In production, each city uses multiple inputs, i.e., labor, capital and energy, represented as XL_j, XK_j and XE_j ($j = 1, 2, \ldots, n$), respectively, to produce GDP (YG_j) along with generating CO_2 emissions (YC_j).

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