Measuring emission-reduction and energy-conservation efficiency of Chinese cities considering management and technology heterogeneity

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ABSTRACT

In response to global climate change and greenhouse gas emissions, China not only is under enormous pressure to reduce emissions from all over the world, but also confronts the problem of domestic energy shortage and ecological environment deterioration. Compared with other developed countries and regions, China has implemented an extensive development model over a long period, consuming large amounts of resources and sacrificing the environment. Therefore, how to reduce emissions and conserve energy is essential for the rapid development of China. To deal with this issue, this paper proposes the improved DEA models for measuring emission-reduction and energy-conservation (EREC) efficiency. Compared with other DEA models, the models in this paper consider not only the heterogeneity of energy management in varied regions, but also the technology gap between regions. In order to assess the level of technological development in different regions, this paper proposes a new technology gap ratio index (TGR). The proposed approach is applied for measuring the EREC efficiency of 211 Chinese cities. The results show that the overall EREC efficiency of Chinese cities is low, and the central area has the lowest EREC efficiency. There is significant technology gap between the regions; the technology level is the highest in the eastern region but the lowest in the northeastern region. We also reveal that managerial and technical factors are the two main sources for the loss of EREC efficiency in Chinese cities. The specific strategies of management and technology are suggested for all cities in different areas.

1. Introduction

In 2010, following decades of improvement, China's economic development attained considerable achievements to become the second-largest economy in the world (Lee, 2014; Bi et al., 2015). However, simultaneous with this great economic achievement, China is confronting issues of environmental pollution and resource shortage (Ji et al., 2017a; Song et al., 2015). Decision makers in the Chinese government generally set targets to reduce emission and conserve energy (Ji et al., 2017b). The strategies to achieve these targets are implemented at the city level. As the

major contributors to economic development, Chinese cities consume vast quantities of resources and energy as well as emit large volumes of pollutants. Emission of these pollutants contributes to serious ambient air pollution (Ji et al., 2017c). A typical example refers to one pollution-driven event that occurred in the winter of 2016, when hazy and overcast weather affected over 17 provinces in China and covered approximately 1,420,000 square kilometers. This event confirmed further that energy waste and pollution emissions from cities must be alleviated by implementing emission-reduction and energy-conservation (EREC) policies stringently.

Existing literature on EREC research is rooted in measuring and improving environment or energy utilization efficiency. Hu and Wang (2006) proposed a data envelopment analysis (DEA) model to assess energy utilization efficiency. Since then, many subsequent researchers have used varied DEA models to evaluate the energy utilization efficiency. For instance, Shi et al. (2010) utilized DEA models to estimate Chinese energy utilization

efficiency at the provincial level and analyzed the energy-saving potential of these provinces. Zhang et al. (2011) integrated a total-factor index into a DEA method to assess the energy utilization efficiency of developing countries using data from 1980 to 2005. From the perspective of environmental efficiency, Zhang et al. (2008) utilized a DEA model to evaluate the environmental efficiency levels of Chinese industries. Zhou et al. (2008) used a DEA approach to assess and compare environmental efficiency among eight world areas. In order to extend the total-factor technique for energy or environment efficiency, Zhou et al. (2010) proposed the evaluation indexes for the total-factor carbon emission efficiency. Wang et al. (2013a) analyzed carbon emission performance in Chinese provinces from the perspectives of timing and spacing. Wu et al. (2014) took the output competition into account, and proposed a DEA model with fixed sum outputs for evaluating the environment performance of China's industry. In order to analyze the efficiency of economic, environment and energy (3 E), Wang and Feng (2015) developed a slack-based DEA model. In addition, they discussed the influence factors of 3 E efficiency change from 2002 to 2011 in terms of technology, production scale and management ability. Sueyoshi and Yuan (2015) applied DEA for assessing the environment performance through considering PM2.5 and PM10 as undesirable outputs. They concluded that the Chinese government should implement more stringent energy consumption control policies in the major cities, such as Beijing, Tianjin, Shanghai and Chongqing. Prior research focused individually on energy-saving efficiency or emission-reduction efficiency. Wu et al. (2015a, b) proposed a fuzzy DEA model incorporating Russell technique under the imprecise circumstance. Then the proposed model was applied for benchmarking the Chinese thermal power firms' efficiencies. For decreasing the energy consumption and accelerating the sustainable development, Li et al. (2017) empirically examined the relationships among energy consumption, behavioral intention, and situational factors. They concluded that situational factors have the most significant and effective effect on energy saving behavior. As for evaluating both emission-reduction and energy-conservation efficiency, few scholars have addressed this issue from a general city-level standard aspect (see, e.g., Wang and Wei, 2014; Zha et al., 2016; Guo et al., 2017). However, since a huge number of Chinese cities are widely scattered throughout the country, and industrial development among them is heterogeneous, applying a general city-level standard to evaluate and analyze energy-saving and emission-reduction programs in these cities is inappropriate. Thus, to formulate and implement effective policies, measuring emission-reduction and energy-conservation efficiency from the perspective of management and technology heterogeneity among cities is very necessary.

Considering management and technology heterogeneity, Wang et al. (2015a) further assessed both emission-reduction and energy-conservation efficiency from empirical analysis of Chinese cities, and concluded that high- and low-earning cities have higher EREC efficiency while the middle-earning cities have the lowest the EREC efficiency. However, these studies, including Wang et al. (2015a), assessed the EREC efficiency through the traditional or proposed models considering only a set of weights. This may overestimate EREC efficiency. Our paper differs from the above literature in not only incorporating management and technology heterogeneity, but also unifying the energy-saving and emission-reduction into a framework through a different weighting scheme to accurately evaluate EREC efficiency, which further extends the work of Kuosmanen (2005) and Wang et al. (2015a).

For methodologies of measuring efficiency, directional distance function (DDF) has been extensively employed to evaluate energy utilization or environment efficiency (Oh, 2010; Zhou et al., 2012; Sueyoshi and Goto, 2012). Compared with traditional DEA models, DDF can simultaneously increase desired outputs and reduce undesirable ones in the process of efficiency calculation. Owing to this characteristic, Färe et al. (2007) and Chiu et al. (2012) applied a DDF method to assess and compare the environment efficiency of coal-burning power plants from the United States and the countries of the Organization for Economic Co-operation and Development. Picazo et al. (2012) and Beltrán et al. (2014) proposed a new DDF that integrates the meta-frontier method to study the ecological efficiency of farmers in Spain. Conventional DDF models frequently adopt a radial measure (Färe et al., 2007; Ji et al., 2016), which reduces undesirable outputs and increases desirable ones in accordance with the same proportion. Nevertheless, this approach could not be normally applied in reality because undesirable and desirable outputs are difficult to change at the same rate. To solve this problem, Wang et al. (2013b) employed an improved DDF method from a non-radial angle to measure Chinese energy utilization efficiency. Zhang et al. (2014) assessed the CO_2 emission and energy utilization efficiency of Chinese power stations and analyzed the effect of scale on efficiency. Zhou et al. (2016) proposed a DEA-Malmquist method for analyzing efficiency changes in Chinese cities' energy utilization and pollutant reduction over time. The empirical results indicate that China's city efficiency growth rate is approximate 16% per year.

For the characteristics of DEA models considering undesirable outputs, most of the previous studies employed Shephard's approach (Shephard, 1970, 1974) to examine the tradeoffs between the desirable and the undesirable outputs. However, Kuosmanen (2005) argued that the Shephard approach would ignore the feasible DEA axioms of input-output vectors. These DEA models using the Shephard technology will lead to the overestimated efficiencies for the evaluated DMUs, even in the case of large samples. Besides, the benchmarks for inefficient DMUs trend to be technically inefficient (Kuosmanen and Matin, 2011). Kuosmanen and Podinovski (2009) also used a simple numerical case to validate that Shephard's technology are non-convex, and difficult to satisfy the key axioms of DEA. The subsequent study by Podinovski and Kuosmanen (2011) further pointed out that Shephard technology does not have a theoretical explanation if the convexity assumption is relaxed or only convexity of output sets is assumed.

The other characteristics of the previous studies can be summarized as follows. First, most of studies used the technology gap ratio (TGR) index to represent the technology heterogeneity between two different types of frontiers. Some scholars have used the non-radial DDF and the meta-frontier techniques to calculate the TGR. However, Wang et al. (2016) pointed out that the TGR may be greater than unity if non-radial DDF is incorporated into the meta-frontier technique. If there are a large number of samples to be evaluated, the TGR results may deviate from real values. Second, the above research focuses on EREC in the process of production. A comprehensive grasp of the overall picture of EREC is still relatively few (Zhou et al., 2016). Third, some studies provided a subjective preference for EREC index. Wang et al. (2015a) pointed out that heavily weighting EREC will fail to support the targeted policy development adequately.

Motivated by the aforementioned research gaps, this paper will evaluate the cities' EREC performance by considering management and technology heterogeneity. Particularly, this paper aims to answer the following questions: (1) How to model the