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Research article

Operational and environmental performance in China's thermal power industry: Taking an effectiveness measure as complement to an efficiency measure

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A B S T R A C T

The trend toward a more fiercely competitive and strictly environmentally regulated electricity market in several countries, including China has led to efforts by both industry and government to develop advanced performance evaluation models that adapt to new evaluation requirements. Traditional operational and environmental efficiency measures do not fully consider the influence of market competition and environmental regulations and, thus, are not sufficient for the thermal power industry to evaluate its operational performance with respect to specific marketing goals (operational effectiveness) and its environmental performance with respect to specific emissions reduction targets (environmental effectiveness). As a complement to an operational efficiency measure, an operational effectiveness measure not only reflects the capacity of an electricity production system to increase its electricity generation through the improvement of operational efficiency, but it also reflects the system's capability to adjust its electricity generation activities to match electricity demand. In addition, as a complement to an environmental efficiency measure, an environmental effectiveness measure not only reflects the capacity of an electricity production system to decrease its pollutant emissions through the improvement of environmental efficiency, but it also reflects the system's capability to adjust its emissions abatement activities to fulfill environmental regulations. Furthermore, an environmental effectiveness measure helps the government regulator to verify the rationality of its emissions reduction targets assigned to the thermal power industry. Several newly developed effectiveness measurements based on data envelopment analysis (DEA) were utilized in this study to evaluate the operational and environmental performance of the thermal power industry in China during 2006–2013. Both efficiency and effectiveness were evaluated from the three perspectives of operational, environmental, and joint adjustments to each electricity production system. The operational and environmental performance changes over time were also captured through an effectiveness measure based on the global Malmquist productivity index. Our empirical results indicated that the performance of China's thermal power industry experienced significant progress during the study period and that policies regarding the development and regulation of the thermal power industry yielded the expected effects. However, the emissions reduction targets assigned to China's thermal power industry are loose and conservative.

1. Introduction

The thermal power industry remains a major source of China's greenhouse gas emissions and air pollution. In 2013, total carbon dioxide emissions in China were 9.77 billion tons, and the thermal power industry was responsible for 38% of this total. In order to control emissions, China's government formulated energy conservation and emissions reduction targets in the last two decades, such as the Shutting Down of Small Thermal Power Units Action (Wang et al., 2016a). In addition, in the 11th Five Year Plan (FYP) and the 12th FYP periods (2006–2010 and 2011–2015), China's

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government listed specific energy conservation and emissions reduction targets for the thermal power industry. However, because of resource endowment, the growing demand for electricity, and the time required to structurally adjust the electricity industry, it is not realistic to change the situation that thermal power is the dominant component in China's electricity mix in the short term. China's thermal power industry needs, on the one hand, to reduce pollutant emissions for environmental protection and, on the other hand, to improve production efficiency to meet the market demand. Therefore, improving both operational performance and environmental performance is considered the core for the sustainable development of China's thermal power industry.

Frontier analysis is a widely used method to evaluate productive efficiency in the electric power industry. Nonparametric linear programming-based data envelopment analysis (DEA) helps analysts to estimate the production function without a functional form assumption and to identify a productive efficiency frontier by defining efficiency as a ratio of a weighted sum of multiple outputs to a weighted sum of multiple inputs. In the case where both industries have the same levels of input resources, a thermal power industry is considered efficient if it generates at least as much electricity as another observed thermal power industry.

Several previous studies use DEA to evaluate the operational efficiency of an electric power industry. For example, Sueyoshi and Goto (2001) employ a slack-adjusted DEA to evaluate the operational efficiency of the electric power generating companies in Japan from 1984 to 1993. They claim that their DEA results imply that integrating generation and transmission may not enhance efficiency. Chen (2002) measures the efficiency of 22 distribution districts of the Taiwan Power Company and finds that the first task of inefficient distribution districts is to determine the critical targets that can be used as benchmarks for guiding further improvement. Ma and Zhao (2015) evaluate the operational efficiency of hundreds of power plants in China from 1997 to 2010 based on DEA and SFA methods. They find that a large proportion of the overall efficiency improvement occurred in the last decade but that this improvement is not likely to continue. Some studies extend the DEA models to include undesirable outputs, and in addition, evaluate environmental efficiencies. For example, Welch and Barnum (2009) give a performance analysis of power generation companies in the U.S. from 2002 to 2005. Their results show that both fuel costs and carbon pollution can be reduced simultaneously, given the current technology, by increasing the technical efficiency of inefficient plants to a level closer to that of their more efficient peers. Sueyoshi et al. (2010) use the DEA method to evaluate the performance of coal-fired power plants under the U.S. Clean Air Act (CAA). They find that the CAA became increasingly effective in terms of operational and unified efficiency measures. Yang and Pollitt (2009) evaluate two data sets of China's coal-fired power plants, one containing 221 plants and one containing 582 plants, in 2002 using a traditional DEA model and several uncontrollable variable-adjusting DEA models. Their results confirm the hypothesis that at least some power plants with relatively low efficiency scores in the traditional model achieve these results partly due to their relatively unfavorable operating environments. Bi et al. (2014) estimate the total factor energy efficiency of China's thermal power generation system in each provincial region from 2007 to 2009 with DEA models. They find that environmental efficiency plays a significant role in the energy performance of China's thermal generation sector. There also have been many studies using DEA to evaluate the energy and environmental efficiency and the production performance of the electric power industry (e.g., Chitkara, 1999; Pahwa et al., 2003; Azadeh et al., 2008; Feroz et al., 2009; Picazo-Tadeo et al., 2011; Chen et al., 2012; Shrivastava et al., 2012; Wang et al., 2012; Macpherson et al., 2013; Mou, 2014; Ignatius et al., 2016; Wang et al., 2016b, 2016c; Wang and Wei, 2016).

In recent years, fierce market competition as well as strict environmental regulation both in China and abroad have led to the development of a performance evaluation method that applies to both market and environmental performance. However, the above studies only consider typical efficiency evaluations and do not fully consider the influence of market competition (when desirable outputs need to be sold and not just produced) and environmental regulation (when undesirable outputs are regulated). Thus, efficiency estimation alone is not enough to evaluate the operational and environmental performance of an industry relative to specific targets such as sales and emissions control. In this study, performance estimation that takes these specific targets into account is defined as effectiveness. Therefore, the measurement of operational performance can be divided into two parts: operational efficiency (which is evaluated to improve the ability of production) and operational effectiveness (which is evaluated to improve the ability of market competition). When the operational performance of the thermal power industry is measured, electricity production is commonly considered to be the desirable output. However, electricity should be consumed when it is produced because it cannot usually be stored; otherwise, the inputs for thermal power production are wasted. The amount of electricity consumed is defined as the demand limit. In our study, the concept of the demand limit is neither the lower limit nor the upper limit of electricity demand but is used to capture the gap between electricity generation and electricity consumption in a region, which reveals the effort of a region to match its electricity generation to the local electricity demand. Excess production, which means that more electricity is generated than the local electricity demand, will imply that some electricity cannot be sold or consumed, and the associated inputs are wasted. On the other hand, insufficient production, which means that less electricity is generated than the local demand, will imply that local electricity generation cannot meet local demand and will interrupt normal economic activity. Thus, from the perspective of the thermal power industry, a measure of operational performance should include not only the capacity to generate more electricity given the same inputs (operational efficiency) but also the capacity to meet electricity demand (operational effectiveness).

Similarly, the measurement of environmental performance should also include two components: environmental efficiency, which is evaluated to improve abatement ability, and environmental effectiveness, which is evaluated to improve the rationality of environmental regulations. It is generally known that when thermal power is generated, pollutant emissions are generated at the same time. In order to protect the environment, the government could assign an emissions limit to the thermal power industry, and, in this case, both the capacity of the thermal power industry to decrease the amount of emissions and the rationality of the emissions limit assigned by the regulator should be evaluated. If the emissions reduction technology of a thermal power industry is advanced (high efficiency) but its emissions are still above the emissions limit assigned by the regulator (low effectiveness), the emissions limit assigned to the thermal power industry is considered to be tight. On the contrary, if the emissions reduction technology of a thermal power industry is backward (low efficiency) but its emissions are still less than emissions limit assigned by the regulator (high effectiveness), we assume a loose limit is assigned to the thermal power industry. Therefore, from the perspective of the government regulator, a measure of environmental performance should include not only the capacity of the thermal power industry to decrease the amount of emissions (environmental efficiency) but also the rationality of the emissions limit assigned to