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Impact of emission regulation policies on Chinese power firms' reusable environmental investments and sustainable operations

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ABSTRACT

This study investigates the impact of emission regulation policies (i.e., emergency response policy versus long-term protection policy) on the investment levels of reusable environmental facilities (e.g., desulphurization pumps) used by coal-fired power plants in China to improve their sustainable operations. To set up a baseline for further analysis and compare the impact of emission regulation policies, an improved framework for performance evaluation of sustainable operations is developed in this study by integrating classical data envelopment analysis (DEA) and exponential learning curve. The proposed mathematical models are applied into an empirical study of 27 major million-kW coal-fired power plants in mainland China. Empirical analysis shows that the interactions among official emission regulation policies, reusable environmental investment (REI), and sustainable operations management of coal-fired power plants in China. Several policy suggestions are provided for power firm managers and policy makers in China. Specifically, we suggest that the Chinese government should implement long-term protection policies in less developed regions instead of emergency response policies.

1. Introduction

This study explored the impact of official emission regulation policies on the reusable environmental investments[1] (REIs) and sustainable operations management[2] (SOM) of Chinese coal-fired power firms. The significance of investigating this topic can be reflected in two aspects. First, determining the effect of official emission regulation policies on the REI and SOM of firms is a natural requirement arising from the practical operation of Chinese coal-fired power plants. China's coal-fired power plants contribute the biggest share of energy in China, but they also cause a serious pollution problem that attracts public attention. According to the *China Electric Power Yearbook* and *China Statistical Year book on Environment*, coal-fired power plants in China contribute about 80% of the country's annual electricity generation and over 30% of the annual total waste gas emission in the past decades. Coal-fired power industry in China left a negative impact on China's environment, which led to several environmental accidents, such as the recent engulfment of large hazardous smog in North China (Spegele and Abkowitz, 2015). Most coal-fired power plants in China implemented REIs to reduce the negative impacts of the coal industry on the environment. Examples of these REIs include *desulphurization pumps*, which can reduce pollu-

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[1] Environmental investments are a series of socially responsible investments that are made by firms to support environmentally friendly products or practical operations (Keane, 2009; Global Energy Network Institute, 2012). "Reusable" means that the environmental investment in one single production period can be used for multiple production periods. One typical example for REIs in coal-fired power industry, especially in coal-fired power industry in China, would be the investment of desulphurization pumps. To make our work focused on how REIs influenced power industry in China, we use this typical representation of REIs, i.e., desulphurization pumps, in the empirical part of this research.

[2] Sustainable operations is now considered as one of the key strategies for firms and organizations to balance the tension between individual economic goals and public sustainability concerns (White and Lee, 2009). To achieve sustainable operations, firms need to identify their consumer business risks and sustainability goals and realize economic, social, and environmental goals simultaneously (Kleindorfer et al., 2005). Typical aspirations for consumer sustainability concerns include controlling emissions, reducing the use of resources, increasing production efficiencies, etc. (Seuring and Müller, 2008; Gunasekaran and Irani, 2014). To focus our research on the analysis of coal-fired power industry in China, we restrict this work in the environmental dimension of "sustainability," focusing on the reduction of emissions and use of resources. Furthermore, to provide a benchmark for the reduction of pollutant emission and use of resources, we develop an improved measurement from the conceptual idea proposed by Schmidheiny and Stigson (2000), which suggests to measure the level of sustainability by the ratio of aggregated additional values and aggregated additional impacts.

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tant emissions. To promote pollution regulation, the Chinese government also promulgated several policies, such as *Heavy Air Pollution Emergency Plan* and *Emission Standard of Air Pollutants for Coal-Fired Power Plants*. Knowledge of official policies can influence firm operations (Delmas, 2001; Zhang et al., 2015; Li et al., 2016a); the use of REI in China's coal-fired power industry results in a high-cost but low-efficiency condition (as reported by *China Statistical Year book on Environment*); these conditions require optimal REI decisions that can improve the SOM performance in different policy scenarios of Chinese coal-fired power plants. Second, only a few studies attempted to analyze the interaction between the operations of Chinese firms and related policies, especially for energy firms. Given that China is one of the biggest developing economies in the world, the country's experience can be used as guideline for other developing countries. Moreover, our research, filling the gap in the literature, is significant in the theoretical aspect as well.

However, achieving a reasonable and valuable analysis of how different official emission regulation policies will affect REI and SOM of firms is a challenge for the following reasons. First, a number of social, economic, and environmental indicators, such as labor, profit, energy consumption, and pollution, should be taken into full consideration to characterize the SOM performance of Chinese coal-fired power plants (Krishnan, 2013). Simple aggregation of these factors, including weighted and non-weighted factors, is not sufficient to derive a composite indicator for decision making because such an approach can have obvious detrimental bias in practice (Chen and Delmas, 2011). Second, the real world conditions of sustainable operations of firms are complex and dynamic (Bettencourt et al., 2007); these conditions increase the difficulty of determining and combining the preferences of stakeholders (Baucells and Sarin, 2003). Some of these preferences can contradict each other because the characteristics and interests of stakeholders may shift dramatically in different scenarios (Griffin, 2000). This finding shows that providing appropriate exogenous characterizations of stakeholder preferences can be a formidable task. Lastly, positive and negative factors exist in the practical operational process of coal-fired power plants (Sueyoshi et al., 2010; Zhou et al., 2012; Bi et al., 2014). Most negative factors, such as greenhouse gas emissions and toxic waste releases, do not have a well-established market for obtaining reliable cost signals (Chen, 2014); this finding indicates the difficulty of prioritizing environmental factors in terms of profit and energy consumption.

The primary objective of this study is to conduct a reasonable comprehensive analysis on how Chinese coal-fired power plants' REI and SOM performance will be influenced by different official emission regulation policies. The analysis reveals the interactions among policies, REI-related management decisions, and the SOM performance of firms. The implications of this study for firm managers and policy makers, respectively, are: *what kind of REI should be chosen* and *how to choose the most suitable REI*, and *what kind of policy should be made*. To achieve this objective, this study develops an improved SOM performance measurement framework of coal-fired power plants as the basis of analysis. We propose the use of performance measurement framework based on extended data envelopment analysis (DEA) model inspired by Chen and Delams (2011). DEA has significant advantage to other performance methods in dealing with multiple indices because it does require a priori assumptions about weights. Second, to simplify the mathematical model, this study categorizes the recent official policies of China into two types. The first type is the emergency response-type policy, which refers to policies that require pollution-causing organizations to reduce their emissions. An example of this policy is the *Heavy Air Pollution Emergency Plan*. The other type is long-term protection-type policy, which refers to policies that require pollution-causing organizations to restrict their emissions to a lower level at the end of a certain period in the future. An example of this policy is the *Emission Standard of Air Pollutants for Coal-Fired Power Plants*. Third, we integrate an exponential learning curve into the DEA models to better characterize the dynamic changes of SOM performance of firms in different policy scenarios. Learning curve is a well-known economic concept that refers to the capability of workers to improve their productivity through repeated actions. The learning curve phenomenon is not only observed in various industries, but also widely applied in operations management issues (Dutton and Thomas, 1984; Chand and Sethi, 1990; Mazzola and McCardle, 1996; Hatch and Mowery, 1998; Gray et al., 2009; Li et al., 2015; Yu et al., 2015). Finally, we use our proposed mathematical models to conduct an empirical analysis of 27 major million-kW coal-fired power plants in mainland China. Through this empirical study, the answers to the three questions mentioned at the beginning of this paragraph are obtained and presented in detail in the *Conclusions and Policy Suggestions* section.

The main contributions of this work are as follows. First, the strategic interactions between official emission regulation policies and the REI and sustainable operations of Chinese coal-fired power plants were analyzed for the first time in a quantitative manner via analytical models. This type of analysis will determine the operational roles of official emission regulation policies in realizing sustainable operations for each coal-fired power plant in China. This attempt can generate a series of managerial implications for the government and firm managers. Second, to make a reasonable measurement of sustainable operations in the individual level, this study proposes an improved evaluation framework based on classical DEA theory. The proposed framework is developed in a general condition and may have sufficient flexibilities in measuring the level of sustainability in other different scenarios. The development process of the proposed framework would be an effective paradigm for other related research. Lastly, we integrate learning curve into traditional DEA models, which would be an efficient supplement to the literature in classical dynamic DEA.

The rest of this study is organized as follows. Section 2 briefly reviews related literature. Section 3 presents the methodology. Section 4 presents the data and main results of the empirical study of 27 major coal-fired power plants in China. Section 5 presents related discussions from the perspectives of plant level and group level and demonstrates a comparison between the two policies. Section 6 concludes the study with policy suggestions.

2. Literature review

This work is related to the vast literature on SOM. In early SOM literature, scholars mainly focused on revealing the potential benefits of SOM to the public. Through a case study of a steel manufacturer, Chinander (2001) pointed out that good SOM performance has a positive impact on the image of a firm and the industry. Some scholars found that high SOM performance level will not only help companies avoid major accidents but also increase their productivity (King and Lenox, 2001; Klassen, 2001; Li et al., 2016b) and market share (Delmas, 2001; Li et al., 2017b). The recent empirical analysis of Ba et al. (2013) on the reaction of the stock market to green product development strengthened early research findings. In addition, some literature aimed to direct firms to achieve SOM in practice. For example, Ferrer and Whyback (2001) proposed a materials management system that can help managers make timely reactions to disruption risks, sales, and yield uncertainties. Guide and Van Wassenhove (2001) contributed a framework for analyzing the profitability of remanufacturing and showed how the management of product returns and remanufacturing influence operations management in the aspects of product design, product returns, and supply chain incentives. Majumder and Groenevelt (2001) investigated the competition between an original equipment manufacturer (OEM) and a remanufacturer using game theory; they showed that the remanufacturer has incentives to reduce the production cost of OEM. Flowers and Linderman (2003) proposed a new way for firms to dispose hazardous waste under air quality regulations. Atasu and Souza (2013) con-