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Estimating the environmental efficiency and marginal CO_2 abatement cost of coal-fired power plants in China

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HIGHLIGHTS

- A novel plant-level dataset derived from the *National Economic Survey* in China is used.
- There are large opportunities for CO_2 emissions reduction in China's coal-fired power plants.
- Subsidies can reduce environmental inefficiency but increase shadow price.

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ABSTRACT

We estimate the environmental efficiency, reduction potential and marginal abatement cost of carbon dioxide (CO_2) emissions from coal-fired power plants in China using a novel plant-level dataset derived from the first and second waves of the *National Economic Survey*, which were implemented in 2004 and 2008, respectively. The results indicate that there are large opportunities for CO_2 emissions reduction in China's coal-fired power plants. Given that all power plants operate fully efficiently, China's CO_2 emissions in 2004 and 2008 could have been reduced by 52% and 70%, respectively, accompanied by an expansion in electricity output. In other words, the opportunities for 'double dividend' exist. In 2004, the average marginal abatement cost of CO_2 emissions for China's power plants was approximately 955 Yuan/ton, whereas in 2008, the cost increased to 1142 Yuan/ton. The empirical analyses show that subsidies from the government can reduce environmental inefficiency, but the subsidies significantly increase the shadow price of the power plants. Older and larger power plants have a lower environmental efficiency and marginal CO_2 abatement cost. The ratio of coal consumption negatively affects the environmental efficiencies of power plants.

1. Introduction

China is currently one of the largest greenhouse gas emitters in the world because of its rapid economic growth and soaring energy consumption. According to the IEA (2014), China's total carbon dioxide (CO_2) emissions in 2012 was approximately 8.2 billion tons, which accounted for approximately 26% of the world's total CO_2 emissions that year. The majority of China's CO_2 emissions primarily comes from the power industry. In China, the CO_2 emissions from electricity and heat production account for approximately half of the total emissions from combustion in 2012 (IEA, 2014). Although the Chinese Government has encouraged the development of renewable energy (such as hydropower, wind power and solar power) over the past decade, at present, fossil fuel-fired power (especially coal-fired power) remains the dominant form of electricity generation (Xie et al., 2012). Therefore, it is particularly important to investigate the environmental efficiency, reduction potential and marginal abatement cost of CO_2 emissions from the power sector, for the sake of China's overall greenhouse gas reduction.

Previous studies have emphasized the important role of the power sector in environmental protection. The environmental efficiency and marginal abatement cost of various pollutants (such as SO_2, CO_2 and NO_X) for power plants have been widely discussed. Related studies include those of Färe et al. (2005), Lee (2005), Murty et al. (2007), Zhou et al. (2012), and Sueyoshi and Goto (2013), among others. However, only a few researchers have focused on the environmental efficiency and pollution abatement cost of power plants in China, partly because of the lack of high-quality plant-level data. Yang and Pollitt (2009) investigated the

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SO_2 emission performance of China's power industry based on a dataset of 221 surveyed coal-fired power plants. Wei et al. (2013) estimated the shadow price of CO_2 emissions and its determinants, using the data of 124 coal-fired power plants located in Zhejiang Province, China. Their data are derived from the first wave of the *National Economic Survey*, which was implemented by Zhejiang Province in 2004. Zhang and Choi (2013) analyzed the dynamic changes of the carbon performance of fossil-fuel power plants in China, but their analysis focused on a limited sample of 259 large (capacity greater than 1 GW) state-owned plants.

In this paper, we estimate the environmental efficiency, CO_2 reduction potential and marginal abatement cost of CO_2 emissions for China's coal-fired power plants. We utilize a cross-sectional plant-level dataset derived from the first and second waves of the *National Economic Survey* of China, which were implemented in 2004 and 2008, respectively. The novelty of our paper is that we have constructed a new dataset by combining the data of the *National Economic Survey* with those of the *Compilation of Statistical Data of the Power Industry*. Compared to the previous studies, our dataset consists of a much larger sample and more information on China's coal-fired power plants. Consequently, our empirical results may be more representative and reliable. We also analyze the effects of subsidies on the environmental efficiency and shadow price of the power plants, which are usually ignored in the literature. Our work thus contributes to the literature by offering new evidences and more insights.

With regard to the results from the multifold specifications of regression, we find that the environmental efficiency of China's coal-fired power plants has decreased between the years 2004 and 2008. There is ample room for CO_2 emissions reduction in China's coal-fired power plants. Specifically, if all of the power plants had operated efficiently (at the frontiers), the CO_2 emissions in 2004 and 2008 could have been reduced by 52% and 70%, respectively. The average marginal abatement cost of CO_2 emissions for the power plants has increased with time, approximately 955 Yuan/ton in 2004 and 1142 Yuan/ton in 2008, respectively. We also find that subsidies from the government increase the shadow price but significantly reduce the environmental inefficiency. Older and larger power plants are less environmentally efficient, but it is cheaper for them to reduce their CO_2 emissions. A higher ratio of coal consumption in a plant results in a lower environmental efficiency. Compared to the central region, the power plants located in the western region have both lower environmental efficiencies and a lower shadow price, whereas those in the eastern region only exhibit a higher environmental efficiency.

The remainder of the paper is organized as follows: Section 2 briefly reviews the existing studies and describes the estimation methodology; Section 3 reports the empirical results; Section 4 is conclusions and policy implications.

2. Methods

2.1. Literature review

The recent development of the environmental production theory and directional distance function makes it possible for researchers to estimate the environmental efficiency and shadow price (marginal abatement cost) of non-marketed pollutants without price and cost information (Färe et al., 1993). Under this estimation framework, the pollutants are usually considered as undesired byproducts. The existing literature on the estimation of the environmental efficiency and shadow price of pollutants can be roughly classified into three groups based on the estimation techniques, i.e., the non-parametric Data Envelopment Analysis (DEA) approach, the parametric Linear Programing (LP) approach, and the parametric Stochastic Frontier Analysis (SFA) approach (Zhou et al., 2014).

The non-parametric DEA approach constructs the production frontier by combining all of the observed inputs and outputs to form a piecewise production boundary. The prominent merit of the DEA approach is that it is not necessary to impose a specific functional form for the underlying technology in advance (Zhang and Choi, 2014). The DEA approach applies to both the Shephard distance function and the directional distance function (Chung et al., 1997; Shephard et al., 1970).[1] The related research includes Choi et al. (2012), Kaneko et al. (2010), Lee et al. (2002), Maradan and Vassiliev (2005), and Wei et al. (2012), among others.[2] However, the DEA approach does not guarantee the differentiability of the estimated distance functions everywhere. For any inflection point located on the frontier, its slope is not unique. The choice of the slopes for these inflection points by the researcher will affect the values of the shadow prices considerably (Lee et al., 2002). Furthermore, the DEA approach has suffered from many other problems, e.g., the impact of outliers (Vardanyan and Noh, 2006).

The parametric LP approach estimates the production frontier by minimizing the sum of the differences between the estimated distance functions of the observed production bundles and that of their projections on the production frontier. Both the Shephard and the directional distance functions can be estimated by this approach. The Shephard distance function is usually parameterized to have a translog functional form, whereas the directional distance function is usually parameterized with a quadratic functional form because of its special properties. The related studies include Coggins and Swinton (1996), Lee and Zhang (2012), Marklund and Samakovlis (2007), Matsushita and Yamane (2012), Rezek and Campbell (2007) and Swinton (2004), among others. The main advantage of the LP approach is that the estimated frontier is differentiable everywhere. It can also perform estimations that take all of the constraints of the environmental production technology into account. The weakness of the LP approach is that it ignores statistical noise. However, this can be remedied by resorting to bootstrap simulations (Simar and Wilson, 2000; Zhang and Choi, 2014; Zhou et al., 2010).

The parametric SFA approach constructs the production frontier by econometric estimation, thus it has the merit of taking statistical noise into account. Furthermore, the frontier estimated by the SFA approach is also differentiable everywhere. This approach only applies to the directional distance function but not to the Shephard distance function. The reason is that the SFA approach is essentially based on the translation property, whereas the Shephard distance function does not satisfy this property. Relevant previous studies include Färe et al. (2005), Murty et al. (2007), and Wei et al. (2013), among others. The primary weakness of the SFA approach is that it cannot include the constraints of the environmental production technology in the estimation process. The usual procedure applied in the previous studies is to first run the SFA estimation ignoring the constraints, and then check if the estimated results meet the constraints ex-post. Only those observations meeting the constraints will be kept for further analysis. However, this process may induce estimation bias (Du et al., in press).

From the above review of the estimation approaches, we find that the parametric LP approach has specific merits relative to the

[1] The Shephard output distance function assumes that the desirable outputs and undesirable outputs only adjust proportionally, whereas the directional output distance function permits an increase of the desirable outputs but a reduction of the undesirable outputs. Actually, the former is a special case of the latter (Chambers et al., 1998).

[2] For more detailed review of the DEA approach in energy and environment analysis, please refer to Song et al. (2012) and Zhou et al. (2008).