



An empirical analysis of the CO₂ shadow price in Chinese thermal power enterprises



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ABSTRACT

This paper estimates the shadow price of CO₂ and explores its determinants for thermal power enterprises in China. Using a parametric quadratic directional distance function, we evaluate the inefficiency and shadow price of CO₂ for 124 power enterprises in 2004, applying deterministic and econometric methods. A regression analysis is undertaken to examine the factors that drive shadow prices. Our results indicate that there are large inefficiencies in terms of electricity production and CO₂ emissions. The shadow price is a negative function of firm size, age, and coal share, and is positively correlated with the technology level. This correlation between shadow prices and its determinants is not sensitive to changing assumptions regarding directional vectors, although such changes do alter the distribution of shadow prices. The large variation witnessed in shadow prices across power enterprises argues in favor of market-based regulation such as an emissions trading system as opposed to the command-and-control regulation currently used in China to minimize overall abatement cost.

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1. Introduction

Over the past few decades, soaring economic growth in China has led to ever higher energy consumption and CO₂ emissions, creating in turn enormous challenges related to environmental pollution. Among all sources of emission, thermal power enterprises play a key role. In 2008, approximately 48% of Chinese emissions, and, by extension, 10.7% of global emissions, could be attributed to the power sector in China (IEA, 2010). In light of rapidly increasing electricity demand and a coal-based fuel structure, fossil-fuel power generation will comprise an even larger share of CO₂ emissions in the future.

The Chinese government attaches great importance to energy efficiency and the challenge of climate change, and has adopted a series of climate protection measures. One successful example is the mandatory energy-saving and emission-reduction program launched as part of the 11th National Five-Year Plan (2006–2010), which generated notable improvements in energy efficiency and environmental quality (Levine et al., 2010). New targets for this program, including the ambitious goal of reducing carbon intensity to 40–45% below 2005 levels by 2020, have been formulated and implemented in the

12th Five-Year Plan (2011–2015). All of these measures and policies are expected to positively support global emissions abatement efforts.

Given the significant contribution made by Chinese thermal power plants to greenhouse gas (GHG) emissions as well as China's effort to cut its carbon intensity, one key question is as follows: How can a CO₂ constraint be allocated among enterprises cost-effectively? According to environmental economics theory, the marginal abatement cost should be equalized across power enterprises in order to reduce pollution at the smallest cost (Baumol and Oates, 1988). However, power enterprises in the real world usually possess varying cost characteristics. From a cost-effective perspective, power enterprises with relatively lower marginal abatement costs should take on more of the emissions reduction burden (Perman, 2003). Accordingly, information concerning CO₂ marginal abatement costs can be used by policymakers to identify enterprises with the greatest/least abatement capacity and potential. In addition, tradable emission permit systems, like the U.S. EPA's SO₂ allowance trading system and the EU's ETS carbon market, have proved to be the most feasible and cost-effective among all pollution control instruments (Rose et al., 1998). Economic theory suggests that the equilibrium permit price in a perfect world should be equivalent to the derived marginal abatement cost. China has conducted pilot SO₂ emission trading projects in the power sector since the early 1990s and established several tradable emission permit markets, such as the Beijing Environment Exchange, Shanghai Environment and Energy Exchange, and Tianjin Climate Exchange. In an emission permit trading

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market of the future, the mean marginal abatement cost could be used to predict the initial permit price and the variance could be observed by decision makers to determine whether emission trading is worthwhile (Färe et al., 1993).

Although information on CO₂ marginal abatement cost is critical for both policymakers and power plant managers, it is usually unavailable since CO₂ is a non-tradable good. There have been numerous attempts to construct the shadow price of pollutants with data on abatement costs derived by technical characteristics or econometric estimation for a particular industry or area. However, as pointed out by Pittman (1983), either these approaches are likely to be subject to a wide margin of error, or exactly appropriate estimates are not available for a sample of individual plants. In a pioneering work, Färe et al. (1993) used duality theory to derive the general specification of shadow prices of both good and bad outputs. The advantage of this static approach is that it does not require any prior information on regulatory constraints. The derived shadow price reflects the trade-off between the good and bad outputs and can be treated as the opportunity cost or marginal abatement cost arising from regulations that prevent free disposal of pollutants. Following this idea, Coggins and Swinton (1996), Reig-Martínez et al. (2001), Kwon et al. (2005), Van Ha et al. (2008), and Park and Lim (2009) apply the parameterized translog output distance function to estimate the shadow price for some specific pollutants in the power sector and other pollutant-intensive sectors. Some recent studies have utilized the directional distance function in quadratic form to measure atmospheric pollutants' marginal abatement cost (Färe et al., 2005; Marklund and Samakovlis, 2007; Murty et al., 2007). The difference between the distance function and directional distance function is that the former can only find the proportional change in both good and bad outputs, while the latter can allow for a simultaneous expansion of good outputs and contraction of bad outputs.¹ This feature of the directional distance function fulfills policymakers' general preference to reduce pollution, and provides a natural way of modeling the production process (Färe et al., 2006). Nevertheless, most of these studies adopt a common setting for directional vectors. In Vardanyan and Noh (2006), the authors specify different functional forms and mapping vectors, benchmarking results by assessing the shadow price estimates against the pollution permit prices. Their results indicate that estimates for the shadow price of bad outputs vary crucially with the choice of the directional vectors.

Few studies have focused on Chinese power enterprises due to the scarcity of appropriate firm-level data. To the best of our knowledge, only Yang and Pollitt (2010) use a non-parametric DEA model to measure the inefficiency level of China's coal-fired power enterprises. This paper is the first micro-level study to analyze the shadow price of pollutants and its determinants in the Chinese power sector.

The directional distance function in quadratic form is utilized in the following analysis to value the pollution cost of CO₂ emissions as a by-product for 124 thermal power enterprises in Zhejiang province in 2004. Both deterministic and econometric techniques are used to estimate the directional distance function. Unlike most previous studies, we examine the impact of different directional vector settings on shadow prices and econometrically explore the forces behind variation in CO₂ shadow prices. Our results show that great abatement potential and win-win opportunities exist for thermal power enterprises. The estimated shadow prices, which depend on the directional vectors and computational techniques, vary greatly across enterprises and suggest that the market-based approach is preferable to command-and-control regulation from a cost-effectiveness perspective. In addition, CO₂ shadow prices are found to be positively correlated to the technology level and negatively correlated with the plant's scale, age and coal share. The relationship between

shadow prices and its determinants is stable and not sensitive to change in directional vectors.

The paper is structured as follows. Section 2 presents the theoretical model. Section 3 details the empirical model. Section 4 describes the data and variables. Section 5 estimates the inefficiency and shadow prices, discusses the regression results, and performs a sensitivity test. Finally, Section 6 summarizes conclusions.

2. Theoretical model

2.1. The directional output distance function

Let us consider a production process that uses a vector of inputs $x \in \mathfrak{R}_+^N$ to produce two kinds of output: good output and bad output, which are denoted by the vectors $y \in \mathfrak{R}_+^M$ and $b \in \mathfrak{R}_+^J$, respectively. The relationship between input and output is represented by an output set:

$$P(x) = \left\{ (y, b) : x \in \mathfrak{R}_+^N \text{ can produce } (y, b) \in \mathfrak{R}_+^M \times \mathfrak{R}_+^J \right\}. \quad (1)$$

Apart from the standard convex and compact assumptions, the output set (Eq. (1)) satisfies free disposability of good outputs, that is: $(y, b) \in P(x)$ and $y' \leq y \Rightarrow (y', b) \in P(x)$. It indicates that it is possible to reduce the good output without reducing the bad output. Also, the input is freely disposable if $x' \geq x \in \mathfrak{R}_+^N \Rightarrow P(x') \supseteq P(x)$. Furthermore, we assume that the bad outputs and good outputs satisfy joint weak disposability: if $(y, b) \in P(x)$ and $0 \leq \theta \leq 1$, then $(\theta y, \theta b) \in P(x)$. Weak disposability implies that it is feasible to reduce both good and bad outputs proportionally by θ . The idea is to make sure that it is "costly" to reduce bad output. Finally, good and bad outputs are assumed to satisfy the null-jointness or by-product axiom, that is: if $(y, b) \in P(x)$ and $b = 0$, then $y = 0$, which implies that good output cannot be produced without producing the bad output. In other words, bad output is jointly produced with good output.

To accommodate these assumptions concerning the environmental production technology, the directional output distance function is adopted and defined as follows (Chung et al., 1997):

$$\bar{D}_0(x, y, b; g_y, -g_b) = \max \left\{ \beta : (y + \beta g_y, b - \beta g_b) \in P(x) \right\}. \quad (2)$$

Fig. 1 provides some graphic intuition of the directional output distance function. The output set $P(x)$ is used to illustrate the environmental technology. The vertical and horizontal axes denote the good and bad outputs, respectively. The output set $P(x)$ in Fig. 1 satisfied the null-jointness property because the origin 0 is the only point in common between the good output (y -axis) and the output set $P(x)$. Given the production technology $P(x)$ and the direction vector $g = (g_y, -g_b) > 0$, the directional output distance function aims to achieve the maximum feasible expansion of good output y and

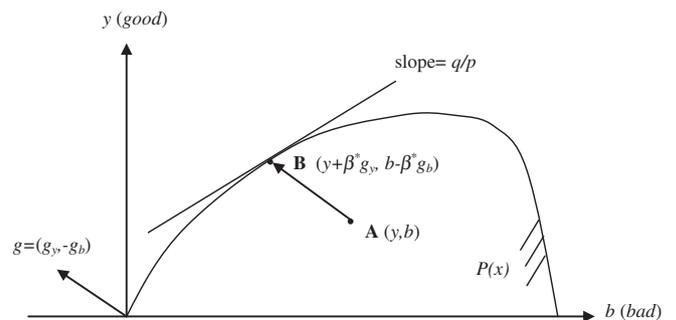


Fig. 1. Directional output distance function.

¹ The directional distance function is a variation of Luenberger's shortage function and is a generalization of Shephard's output distance function. More technical details can be found in Chung et al. (1997).

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