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The shadow price of substitutable sulfur in the US electric power plant: A distance function approach

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Abstract

Given restrictions on sulfur dioxide emissions, a feasible long-run response could involve either an investment in improving boiler fuel-efficiency or a shift to a production process that is effective in removing sulfur dioxide. To allow for the possibility of substitution between sulfur and productive capital, we measure the shadow price of sulfur dioxide as the opportunity cost of lowering sulfur emissions in terms of forgone capital. The input distance function is estimated with data from 51 coal-fired US power units operating between 1977 and 1986. The indirect Morishima elasticities of substitution indicate that the substitutability of capital for sulfur is relatively high. The overall weighted average estimate of the shadow price of sulfur is -0.076 dollars per pound in constant 1976 dollars.

Keywords: Shadow sulfur price; Input distance function; *Indirect* Morishima elasticity of substitution; Porter hypothesis; Marginal abatement cost; *Internal/external* trading

1. Introduction

The regulation of sulfur dioxide (SO_2), known as a major precursor of acid rain, has been more stringent in the US since a national standard was set by the 1970 Clean Air Act. One goal of this act was to control emissions from coal-fired power plants, which contribute more than 70% of the SO_2 generated in the US Knowledge of marginal abatement costs—i.e., how much it would cost for power plants to reduce additional units of SO_2—allows environmental policy-makers to establish an optimal emissions limit to maximize social net benefits. In addition, estimation of marginal abatement costs provides useful information on the potential cost savings from reallocating abatement resources under a marketable allowance system.[1]

As of 1971, all new or modified coal-fired plants were required to emit no more than 1.2 pounds of SO_2 per million Btu. In 1977, new plants were also required to install pollution abatement equipment such as flue gas desulfurization (FGD) systems, known as scrubbers. Earlier legislation was tightened by the 1990 Clean Air Act Amendments, which also established a specific time schedule for reducing aggregate SO_2 emissions. The core of the Acid Rain Program (Title IV) is a market-based system for capping and trading SO_2 allowances.

There are two main approaches to estimating marginal costs of abating pollutants: the cost function approach and the distance function approach. Gollop and Roberts (1985) estimate a cost function for fossil-fueled power utilities in which a variable measuring the regulatory intensity of SO_2 is included as an argument. Since regulatory intensity is a function of actual emissions, the marginal cost of emissions reduction is derived by partially differentiating the cost function with respect to the actual emissions level. However, it should be recognized that firms would likely fail to minimize their production costs in the presence of various regulations, including those intended to control pollutant emissions (Atkinson and Halvorsen, 1984; Kumbhakar, 1992; Lee, 2002). As a result, use of

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[1] In equilibrium, the marginal abatement cost would be equal across plants and would equal the price of an allowance. In the case of private trade between two plants, the net gain per unit would be the difference between their marginal costs.

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a neoclassical cost function might lead to under-estimation of marginal abatement costs. Also, inconsistencies in the availability of relevant data by industry make it difficult to develop an adequate index that consistently gauges regulatory constraints across industries.[2]

Färe et al. (1993), Coggins and Swinton (1996), and Hailu and Veeman (2000) calculate the shadow prices or marginal abatement costs of undesirable pollutants by employing a distance function, which was originally introduced by Shephard (1953, 1970). A dual relationship between the distance function and the revenue function or cost function provides a theoretical formula for the shadow prices of pollutants, which can be interpreted as the opportunity cost of reducing an additional unit of undesirable output in terms of forgone desirable output or, equivalently, as the marginal cost of pollution abatement (Coggins and Swinton, 1996; Hailu and Veeman, 2000). The use of a non-stochastic linear programming technique allows us to estimate a distance function. Though linear programming does not produce statistics for the degrees of fitness,[3] it dose enable us to impose inequality restrictions associated with desirable and undesirable outputs or inputs (Hailu and Veeman, 2000). More advantages of the distance function approach over the cost function approach include the fact that information on input prices and regulatory constraints is not required, and that it is not necessary to maintain the hypothesis concerning cost minimization (Grosskopf et al., 1995).[4] In addition, the use of a non-parametric data envelopment analysis makes it possible to circumvent the presence of residual autocorrelation even when time series or panal data are used (see Färe et al., 1989; Yaisawarng and Klein, 1994).

All literature employing a distance function measures the shadow prices of pollutants as the opportunity cost of abatement in terms of forgone outputs. But estimates of the shadow price of SO_2 fail to account for the substitution possibility between sulfur and productive capital.[5] Either investments in improving boiler fuel-efficiency or shifts to production processes that are effective in removing SO_2 can be used to meet legal emissions limits in the long run. The more substitutable sulfur and capital are, the less costly sulfur regulation is, *ceteris paribus*. As a result, it would be more appropriate to estimate SO_2 abatement costs as the opportunity costs of lowering sulfur in terms of forgone capital. Porter (1991) suggests that an increase in the stringency of environmental regulations may stimulate innovation, resulting in a positive impact on economic performance. This view is called the 'Porter hypothesis'.[6] A high substitutability of sulfur and capital is likely to support the Porter hypothesis in the long run.

In this paper, following Kolstad and Turnovsky (1998), we quality-differentiate coal into quantities of heat, sulfur, and ash. The use of an input distance function not only permits estimation of the shadow prices of sulfur and ash in terms of forgone capital, but also the indirect elasticities of substitution between inputs, particularly the substitution possibilities of capital for sulfur. We use data from 51 coal-fired units in 38 plants.[7] We also compare differences in the shadow prices of sulfur between units of the same plant and between plants

This paper is organized in the following manner. Section 2 defines an input distance function with 'good' inputs and 'bad' inputs and provides the formula for *indirect* elasticities of substitution. A methodology for estimating the shadow price of sulfur is described in Section 3. Empirical results are analyzed in Section 4. Section 5 concludes.

2. The input distance function

Consider a technology that produces an output y with a vector of inputs $x \in \Re_+^N$. The vector of inputs not only includes 'good' ones, $x_1 \in \Re_+^H$, but also 'bad' ones, $x_2 \in \Re_+^{N-H}$, so that $x=[x_1,x_2]$. Denoting $B(y)=\{x: x \text{ can produce } y\}$ as the input set, we define the input distance function introduced by Shephard (1953), which measures the maximum amount by which all inputs can be proportionally reduced while maintaining the level of output (Färe and Grosskopf, 1990; Hailu and Veeman, 2000):

$$I(y,x,t) = \sup\{\delta > 0 : x/\delta \in B(y)\} \tag{1}$$

where t is a time index allowing for technological change. Note that $x \in B(y)$ if and only if $I(y, x, t) \geq 1$. The distance function is monotonically non-decreasing in x_1, non-increasing in x_2, and non-increasing in y. It is also homogenous of degree one in x, i.e., increasing x by

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[2] Due to lack of information, Gollop and Roberts define an unconstrained emissions rate as the average of emissions rates greater than 1.5 pounds per Mbtu. This uniform definition pays no regard to differences in allowed emissions limits and fuel-quality environments facing different firms.

[3] To overcome this limitation, Grosskopf et al. (1995) use a bootstrapping methodology. Recently, a few authors including Atkinson et al. (2003) estimate the stochastic distance function.

[4] However, Kolstad and Turnovsky (1998) indicate that unobservable distance functions and endogeneity of explanatory variables might cause econometric problems.

[5] A referee argues that earlier papers do not explicitly specify that relationship but do not preclude such trade-offs. However, it depends upon the sample period they use. The use of cross-sectional data or a few years' worth of panal data could hardly capture substitution between sulfur and capital occurring in the long run.

[6] Previous articles that formally analyzed the Porter hypothesis include Oates et al. (1993), Porter and van der Linde (1995), Simpson and Bradford (1996), Jaffe and Palmer (1997), Xepapadeas and de Zeeuw (1999), and Mohr (2002). All papers except Porter and van der Linde and Mohr found little strong evidence for the feasibility of the hypothesis.

[7] In fact, it is individual units (generators) that are subject to the legal emission limits. However, most previous studies used company or plant level data due to lack of unit level data. This may lead to biased estimates.