Estimating Pollution Abatement Costs:
A Comparison of “Stated” and “Revealed” Approaches

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Abstract

Surveys have been the principal method used to estimate costs associated with environmental regulations in the United States. Although surveys have been widely used, there are concerns about their accuracy. In order to investigate the accuracy of survey estimates of pollution abatement costs, a joint production model is specified and data from electric power plants in the United States for 1994 and 1995 are used to estimate pollution abatement costs incurred by these plants. The estimates of pollution abatement costs generated by the joint production model are then compared with survey estimates of pollution abatement costs incurred by power plants.

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I. Introduction

Surveys have been the principal method used to estimate the costs associated with environmental regulations in the United States.[1] The "Pollution Abatement Cost(s) and Expenditures" (PACE) survey (U.S. Department of Commerce, 1996 and 2002) estimates pollution abatement costs borne by U.S. manufacturing industries for 1973 through 1994 (excluding 1987) and 1999, while the EIA-767 survey ("Steam-Electric Plant Operation and Design Report"), which is administered by the U.S. Department of Energy (2001a), collects information about the pollution abatement expenditures of electric power plants. These survey estimates of pollution abatement costs we refer to as "stated costs." In 1994, 64 percent of the pollution abatement expenditures in the Bureau of Economic Analysis' (BEA) discontinued annual report on pollution abatement expenditures were from surveys, while the remaining 36 percent were derived from other sources (Vogan, 1996, p. 54). Of the 64 percent, 28 percent were from the PACE and EIA-767 surveys, while the remaining 36 percent are associated with government activities such as sewage treatment, solid waste disposal, and regulation and monitoring.

Although the PACE and EIA-767 surveys have been conducted for more than twenty-five years, there are concerns about their accuracy. One of the concerns is the difficulty associated with estimating "change in production process" capital expenditures. The share of manufacturing air pollution abatement capital expenditures represented by "change in production process" techniques increased from 17.4 percent in 1973 to 48.3 percent in 1994 according to the U.S. Department of Commerce (1976, p. 47 and 1996, p. 25). As the share of the pollution

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[1] Throughout this study, "costs" and "expenditures" are used interchangeably. Since depreciation costs are not included, the model actually estimates the current account expenditures associated with pollution abatement activities.

abatement capital expenditures represented by "change in production process" techniques increases, it becomes more difficult to determine which operating costs are associated with pollution abatement activities, i.e., it has become increasingly difficult to estimate current account (i.e., operation and maintenance) expenditures associated with pollution abatement activities. In addition, some have expressed the concerned that respondents may have an incentive to overstate the costs associated with pollution abatement activities, while others have noted that certain opportunity costs of pollution abatement activities (e.g., paperwork costs) are excluded from survey estimates of pollution abatement costs.

An alternative method of estimating the costs associated with pollution abatement activities is based on observed or revealed data rather than surveys. One formulation, which was used by Martin, Braden, and Carlson (1990) and Bellas (1998), assumes pollution abatement activities are separable from the activities associated with producing the marketed output, and estimates pollution abatement functions. The second formulation relaxes the separability assumption and models the joint production of good and bad outputs, in the sense that the bad outputs are byproducts of the production of good outputs. There are some advantages to estimating pollution abatement costs by modeling the joint production of good and bad outputs. First, it does not require information about pollution abatement technologies and their associated costs. Hence, it is not necessary to assign inputs to either "productive" activities or pollution abatement activities.[2] Second, modeling the joint production of good and bad outputs avoids the difficulties associated with survey efforts to estimate pollution abatement costs due to changes in

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[2] While Swinton (1998) specified a joint production model with productive and abatement capital, the joint production model does not require modeling inputs used in productive and abatement activities separately.

the production process. Finally, synergies among the abatement processes of two or more pollutants are automatically captured by the joint output technology.

A number of studies have specified joint production models to measure the marginal abatement costs of reducing emissions from electric power plants. Turner (1995) applied the methodology developed by Färe et al. (1993) to data from 1985 to 1987 to estimate the marginal abatement cost of sulfur dioxide (SO_2) emissions. Using data from 1990 to 1992, Coggins and Swinton (1996) also used the Färe et al. (1993) methodology to estimate marginal costs of reducing SO_2 emissions by 14 Wisconsin power plants. Swinton (1998) extended the Coggins and Swinton study with a sample of plants from Wisconsin, Illinois, and Minnesota for 1990 to 1992. Kolstad and Turnovsky (1998) and Carlson et al. (2000) specified joint-production cost functions to estimate the marginal costs of reducing SO_2 emissions, while Gollop and Roberts (1985) estimated marginal costs of reducing SO_2 emissions by specifying a cost function with emissions introduced as part of the regulatory intensity variable. However, only Färe, Grosskopf, and Pasurka (1986) specified a joint production model to assess the total opportunity cost of pollution abatement activities.

When estimating pollution abatement costs with a joint production model, we distinguish between two technologies. The first is the free disposability or unregulated technology which assumes that bad outputs can be “thrown away” at no cost to the producer, whereas the second -- the weak disposability or regulated technology -- models assume reductions in the production of the bad output at the margin via a decrease in the good output. Within this framework, pollution abatement costs are determined by computing the difference between the maximum production of the good output under the unregulated and regulated technologies. Since the unregulated and regulated production possibilities frontiers are constructed from data that reflect the actual behavior of producers, we refer to the cost estimates as the “revealed costs” (i.e., lost revenue) of pollution abatement activities.

The recommendations of a recent workshop concerned with the future of the PACE survey of manufacturers include: “assess the validity and accuracy of the survey instrument” and “match the PACE data with emissions data from EPA” (Burtraw et al. 2001, p. 10). The electric utility industry represents a unique case in which plant-level data for inputs, the good output, and bad outputs are publically available. In this study, we match information on pollution abatement expenditures from the EIA-767 survey of electric power plants for 1994 and 1995 with emission data from the U.S. EPA. For each power plant included in this study, its “stated” pollution abatement costs reported on the EIA-767 survey are compared with its “revealed” costs of pollution abatement activities estimated by modeling the joint production of the good and bad outputs within the data envelopment analysis (DEA) framework. Hence, we will demonstrate that emission data can be used to assess the accuracy of survey estimates of pollution abatement expenditures.

By investigating the relationship between the EIA-767 survey estimates of O&M expenditures associated with abating particulate and sulfur emissions and modeling estimates of pollution abatement costs, this study represents the first attempt to compare estimates of pollution abatement costs from a survey with pollution abatement costs estimated by a modeling approach and it allows us to determine the extent and sources of any divergence between the survey and modeling. Throughout the remainder of this study, we refer to survey estimates of pollution abatement expenditures as SPAC and modeling estimates of pollution abatement costs as MPAC. The remainder of this study is organized in the following manner. In Section II, we introduce the theoretical model of the joint production of good and bad outputs that underpins our empirical work, and the associated linear programming (LP) and non-linear programming (NLP) problems used to implement the theoretical model. In Section III, the data and results are presented. Finally, Section IV summarizes this study, discusses future avenues of research, and examines the implications of the empirical results of this study.[3]

II. Modeling Pollution Abatement Costs

The opportunity cost of pollution abatement activities is the foregone production of the good output resulting from the reallocation of inputs from producing the good output to pollution abatement activities. In this section, a formal model of pollution abatement costs is developed from a model of the joint production of good and bad outputs where the cost of pollution abatement activities is the value of lost potential output due to regulation. This is the cost which we will compare to the estimates of pollution abatement costs from the EIA-767 survey in order to provide an indication of the accuracy of such surveys.

To derive pollution abatement costs and show that it can be interpreted as the value of lost potential output we formulate two production models, one "regulated" and one "unregulated." In the regulated model, we explicitly recognize that good and bad outputs are jointly produced and that the bad outputs cannot be disposed of freely. On the other hand, in the unregulated model we allow bad (and good) outputs to be freely disposable.

In measuring the potential output loss, we differ from Färe, Grosskopf, and Pasurka

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[3] All appendices, data, and GAMS programs are available from Carl Pasurka on request.

(1986) by scaling only on the good output, instead of scaling on both good and bad outputs. To model the abatement cost we introduce the joint production model. Denoting inputs by $x = (x_1, \ldots, x_N) \in \mathbb{R}^N_+$ and outputs by $y = (y_1, \ldots, y_M) \in \mathbb{R}^M_+$, the output sets are given by

(1) $P(x) = \{y\text{: x can produce y}\}, \ x \in \mathbb{R}^N_+$

We distinguish between good or desirable outputs $y^g = (y^g_1, \ldots, y^g_G)$ and bad or undesirable outputs $y^b = (y^b_1, \ldots, y^b_B)$, so that $y = (y^g, y^b) \in \mathbb{R}^M_+$. Emissions of sulfur dioxide (SO_2) and particulate matter (PM-10), are undesirable byproducts of producing the good output - kilowatt-hours (kWh) - and therefore will be modeled as such. In particular we say that the good and bad outputs are nulljoint or byproducts if

(2) $(y^g, y^b) \in P(x)$ and $y^b = 0$ imply $y^g = 0$.

Equation (2) states that if no bad outputs are produced (y^b=0) then none of the good outputs are produced (y^g=0). Equivalently, if some good outputs are produced then some bad outputs must also be produced. We impose this assumption on our “regulated” model. Moreover, in our regulated model we assume that outputs (y^g, y^b) are weakly disposable, i.e.,

(3) $y = (y^g, y^b) \in P(x), 0 \leq \theta \leq 1$ imply $(\theta y^g, \theta y^b) \in P(x)$

This assumption states that proportional reduction of good and bad outputs is feasible, but reduction of bads alone may not be.

In addition to assumptions (2) and (3) we impose standard properties on P(x), including: inputs and good outputs are freely disposable and P(x) is a compact, convex set (see Färe and Primont, 1995, for details).

Prior to formally showing how to calculate the output loss due to regulation, we provide some intuition based on a simple diagram. In Figure 1, the *regulated* output set, $P^R(x)$, is bounded by the line segments 0BCf0. This output set has the properties that good and bad outputs are weakly disposable and nulljoint. The *unregulated* output set, $P^U(x)$, is bounded by 0eCf0, and includes the regulated technology in our example as a proper subset.

In Figure 1, the production frontiers are derived from observed production processes. Points A, B, and C represent different combinations of good and bad outputs actually produced by a given input vector. These two points can be interpreted as representing different production processes used by producers. The portions of the frontier between these points are linear combinations of the observed production processes (i.e., the technology available to producer k′). Point A is an observed level of production that is technically inefficient. Points e and f are projected to the axes based on assumptions underlying the unregulated technology.

To measure the potential output loss, i.e., the difference in the two output sets, an observation (y^g, y^b) (say point A in Figure 1) is projected to the boundary of the regulated frontier (point A′ in Figure 1) by scaling the good output. The distance AA′ represents the reduced production of the good output resulting from technical inefficiency. I.e., this producer could increase production of its good output without increasing production of its bad output.

In this study, costs associated with technical efficiency are not included in MPAC. Here we assume that technical inefficiency, which is represented by the distance between an observation and the weak disposability frontier, occurs for reasons unrelated to pollution abatement activities. Hence, this study defines MPAC as the difference between the maximum feasible production of the good output when the bad output is unregulated and the maximum feasible production of the good output when the bad output is regulated. In our figure, the

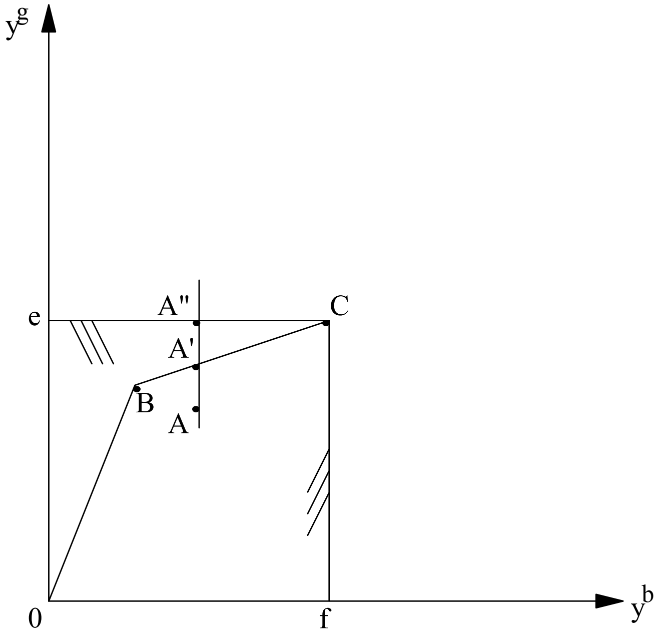

Figure 1. Measure of Potential Output Loss

distance between the two output sets - here A′A″ - gives us the potential loss due to regulation. Again, we scale only on the good output.Assuming that we have k = 1, ... , K observations of inputs x^k, fuel quality q^k, and outputs y^k, we may formulate the output sets as an activity analysis or Data Envelopment Analysis (DEA) model. The regulated model is specified as

$$
(4) \qquad P^R(x) = \{(y^g, y^b): \begin{array}{ll}
\delta \sum_{k=1}^{K} z_k y^g_{km} \geq y^g_m & m = 1, \ldots, G \\
\delta \sum_{k=1}^{K} z_k y^b_{ki} = y^b_i & i = 1, \ldots, B \\
\theta \sum_{k=1}^{K} z_k x_{kn} \leq x_n & n = 1, \ldots, N \\
\theta \sum_{k=1}^{K} z_k q_{kj} = q_j & j = 1, \ldots, J \\
\sum_{k=1}^{K} z_k = 1 & \\
z_k \geq 0 \quad k = 1, \ldots, K & \\
0 \leq \delta \leq 1 & \\
\theta \geq 1\} &
\end{array}
$$

The intensity variables, z_k, are weights assigned to each observation when constructing the technology (i.e., the production possibilities frontier). The inequality constraints in (4) on the good outputs, y^g_m, m=1,...., G imply that these outputs are freely disposable.[4] Together with the equality constraints in (4) on the bad outputs (y^b_i, i=1,..., B), good outputs and bad outputs are weakly disposable, i.e., they can be scaled down jointly to zero and hence they satisfy (3). The equality constraint on the undesirable qualities of the fuels consumed (q^k) specifies that the undesirable qualities of the fuel consumed by the reference technology must equal the

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[4] Free disposability means the good output can be disposed of without the use of any inputs. This can be stated formally as $(y^g, y^b) \in P(x)$ and $y^{g'} \leq y^g$ imply $(y^{g'}, y^b) \in P(x)$.

undesirable qualities of the fuels consumed by the observation.

This model satisfies the assumption of good and bad outputs being nulljoint provided

$$(5) \qquad (a) \quad \sum_{k=1}^{K} y_{ki}^{b} > 0 \quad i = 1,\ldots,B$$

$$(b) \quad \sum_{i=1}^{B} y_{ki}^{b} > 0 \quad k = 1,\ldots,K$$

Condition (5a) states that every bad output is produced by some plant k, and (5b) states that every plant k produces at least one bad output. To further illustrate null-jointness, assume that each $y_i^b = 0$ in the expression of the output set (4). Then, due to (5) each intensity variable z_k must be zero, implying that each good output y_m^g must be zero.

In addition, the output correspondence (4) models variable returns to scale since the intensity variables sum to unity.[5] That is, it allows for increasing, constant, and decreasing returns to scale. Since variable returns to scale is assumed, modeling weak disposability of outputs requires the left-hand portion of the constraints associated with good and bad outputs include $0 \leq \delta \leq 1$, while the left-hand portion of the constraints associated with inputs and fuel quality includes $\theta \geq 1$ to model weak disposability of inputs and fuel quality.

The unregulated model is obtained from (4) by allowing for the free disposability of bad outputs, i.e., by changing the i = 1,..., B equalities to inequalities, and removing the δs.

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[5] If there is no constraint on the summation of the intensity parameters (i.e., the z_k), constant returns to scale is imposed.

$$(6)\qquad P^U(x) = \{(y^g, y^b)\colon\ \begin{aligned}[t] &\sum_{k=1}^{K} z_k y_{km}^g \geq y_m^g \qquad m = 1,\ldots,G \\ &\sum_{k=1}^{K} z_k y_{ki}^b \geq y_i^b \qquad i = 1,\ldots,B \\ &\theta\sum_{k=1}^{K} z_k x_{kn} \leq x_n \qquad n = 1,\ldots,N \\ &\theta\sum_{k=1}^{K} z_k q_{kj} = q_j \qquad j = 1,\ldots,J \\ &\sum_{k=1}^{K} z_k = 1 \\ &z_k \geq 0 \qquad k = 1,\ldots,K \\ &\theta \geq 1\} \end{aligned}$$

To measure the output loss due to regulation we apply a directional distance function. This function makes it possible to define the difference between the two frontiers, see equation (12). In particular we choose a directional vector $d \in \mathbb{R}_+^G$ to be d= (1,...,1) then for each observation ($x^{k'}$, $y^{k'}$) we compute

$$(7)\qquad \vec{D}^R(y^{k'}, x^{k'}; 1) = \max\{(y_{k'}^g + \beta\cdot 1, y_{k'}^b) \in P^R(x^{k'})\}$$

In our case with one good output the "efficient" output relative to the regulated technology is

$$(8)\qquad y_{k'}^g + \vec{D}^R(y^{k'}, x^{k'}; 1)\cdot 1$$

$y_{k'}^g$ corresponds to point A in Figure 1. When y is a scalar $\vec{D}^R(y^{k'}, x^{k'}; 1)$ corresponds to AA′, and the sum of $y_{k'}^g$ and $\vec{D}^R(y^{k'}, x^{k'}; 1)$ corresponds to the production of the good output represented by point A′.

The corresponding directional distance function of the unregulated technology is

(9) $$\vec{D}^U(y^{k'},x^{k'};1) = \max\{(y^g_{k'} + \beta \cdot 1, y^b_{k'}) \in P^U(x^{k'})\}$$

and the efficient output relative to the unregulated technology is

(10) $$y^g_{k'} + \vec{D}^U(y^{k'},x^{k'};1)\cdot 1$$

where $\vec{D}^U(y^{k'},x^{k'};1)$ corresponds to AA″, and when y is a scalar the sum of $y^g_{k'}$ and $\vec{D}^U(y^{k'},x^{k'};1)$ corresponds to the production of the good output represented by point A″.

Noting that we have a single good output, the revenue loss due to regulation is

(11) $$p^{k'}\left(y^g_{k'} + \vec{D}^U(y^{k'},x^{k'};1)\right) - p^{k'}\left(y^g_{k'} + \vec{D}^R(y^{k'},x^{k'};1)\right)$$

or

(12) $$MPAC = p^{k'}\left[\vec{D}^U(y^{k'},x^{k'};1) - \vec{D}^R(y^{k'},x^{k'};1)\right]$$

where $p^{k'}$ is the observed price (i.e., revenue per kWh) of the good output for producer k′. The difference inside the square brackets in (12) corresponds to the distance (A′A″) in Figure 1, which is our estimate of the loss in output due to regulation.

We may compute the total loss of potential revenue by summing (12) over all k′:

(13) $$\Sigma MPAC = \sum_{k'}\left[p^{k'}\left(\vec{D}^U(y^{k'},x^{k'};1) - \vec{D}^R(y^{k'},x^{k'};1)\right)\right]$$

For feasible output vectors, the directional distance function is greater than or equal to zero. It equals zero if and only if the observation vector $y^{k'}$ is on the production possibilities frontier (i.e., the observation vector is technically efficient), while a point inside the production frontier has a value greater than zero. Hence, the value of the directional distance function represents the expansion of the good output required to project an observation $y^{k'}$ from inside the production frontier to the frontier.

The directional distance functions can be calculated as solutions to LP problems. In order to determine MPAC, one LP and one NLP problem is solved for each producer. As an example, we have for observation k′:

$$
\begin{aligned}
(14) \qquad & \vec{D}^{R}(x^{k'}, y^{k'}) = \max \beta^{k'} \\
s.t. \quad & \delta \sum_{k=1}^{K} z_k y_{km}^{g} \geq y_{k'm}^{g} + \beta^{k'} \qquad m = 1,\ldots,G \\
& \delta \sum_{k=1}^{K} z_k y_{ki}^{b} = y_{k'i}^{b} \qquad i = 1,\ldots,B \\
& \theta \sum_{k=1}^{K} z_k x_{kn} \leq x_{k'n} \qquad n = 1,\ldots,N \\
& \theta \sum_{k=1}^{K} z_k q_{kj} = q_{k'j} \qquad j = 1,\ldots,J \\
& \sum_{k=1}^{K} z_k = 1 \\
& z_k \geq 0 \qquad k = 1,\ldots,K \\
& 0 \leq \delta \leq 1 \\
& \theta \geq 1
\end{aligned}
$$

The weak disposability reference technology relative to which $(x^{k'}, y^{k'})$ is evaluated is constructed from observed processes, i.e., the constraints are consistent with $P^R(x)$ in (4). This NLP problem assigns a value to the intensity variable, z_k, associated with each observation, which yields the solution shown by the distance AA′ in Figure 1. While the regulated technology is solved by an NLP problem, the unregulated technology is solved by an LP problem that calculates the distance A′A″ in Figure 1.

The value of the objective function represents the difference between the observed production of the good output and the maximum potential production of the good output for a given input vector and technology. Since $\beta^{k'}$ is excluded from the constraints associated with the bad outputs, the decline in production of the good output associated with environmental regulations assumes production of the bad output remains at its observed level.

III. Data and Results

The technology modeled in this study consists of one good output, "net electrical generation" (kWh), and two bad outputs - emissions of sulfur dioxide (SO_2) and particulate matter less than ten microns in diameter (PM-10).[6] Inputs consist of the capital stock, the number of employees, and the heat content (in Btu) of the coal, oil, and natural gas consumed by a plant. Undesirable fuel qualities are the ash content of coal and the sulfur content of coal and oil. Higher sulfur or ash contents translates to a fuel with more undesirable attributes. FERC Form 1 survey collects information on the cost of plant and equipment and the average number

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[6] Although some plants abate nitrogen oxide (NO_x) emissions, the EIA-767 survey collects no information about the associated costs. Hence, we do not model NO_x emissions.

of employees for each electric power plant.[7] The EIA-767 survey collects information about fuel consumption, fuel quality, and net generation of electricity, while the National Emission Inventory provides estimates of PM-10 and SO_2 emissions (see U.S. EPA, 2001, for an explanation of how the emission estimates are derived). We calculate production frontiers for two samples, which consist of 111 power plants in 1994 and 1995. The reference production frontiers consist solely of observations from the year being investigated. Hence, production frontiers for 1994 observations are calculated using only 1994 observations. In order to model a homogeneous production technology, a power plant may consume coal, oil, or natural gas;

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[7] The FERC 1 survey only collects data on cost of plant and equipment. It does not collect data on investment expenditures. Hence changes in the value of plant and equipment reflect the value of additional plant and equipment minus the value of retired plant and equipment. For this study, we assume changes in cost of plant and equipment reflect net investment (NI). The next step is converting the historical cost of plant data into constant dollar values using the Handy-Whitman Index (HWI) (Whitman, Requardt & Associates, 2002). This is the same procedure employed by Yaisawarng and Klein (1994, p . 453, footnote 30) and Carlson et. al (2000, p. 1322). The net constant dollar capital stock (CS) for year n, in constant 1973 dollars, is calculated in the following manner:

$$CS_n = \sum_{t=1}^{n} \frac{NI_t}{HWI_t}$$

In the first year of its operation, the net investment of a power plant is equivalent to the total value of its plant and equipment. Appendix A contains a more detailed discussion of the derivation of the capital stock.

however, coal must provide at least 95 percent of the Btu of fuels it consumes.[8] Table 1 presents summary statistics of the data and Appendix A contains a detailed discussion of the data.

The EIA- 861 (U.S. Department of Energy 1999, 2001b) survey provides information on sales of electricity and its associated revenue from sales to ultimate consumers and sales for resale by each utility. In our study, revenue per kWh is assumed to be identical for each power plant operated by a utility. When a plant is owned by more than one utility, it is assigned the revenue per kWh of its principal owner.

The EIA-767 survey requests information on operation and maintenance (O&M) expenditures associated with both the collection and disposal of fly ash, bottom ash, and flue gas desulfurization (FGD). Hence, six categories of expenditures in the EIA-767 survey are relevant for this study. The instructions for the EIA-767 survey (U.S. Department of Energy, 2001a, Plant Information -- Financial Information) state that operation and maintenance (O&M) expenditures "... should exclude depreciation expense, cost of electricity consumed, and fuel differential expense (i.e., extra costs of cleaner, thus more expense fuel)."[9] Expenditures

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[8] Several plants are excluded due to their consumption of petroleum coke and other types of fuel (i.e., blast furnace gas, coal-oil mixture, fuel oil #2, methanol, propane, wood and wood waste, and refuse, bagasse and other nonwood waste). Although a number of plants consume fuels other than coal, petroleum, and natural gas, these other fuels represent very small percentages of total fuel consumption (in Btu). For the purposes of the technologies modeled in this study, it was decided to exclude those plants whose consumption of these other fuels represented more than 0.0001 percent of its total consumption of fuel (in Btu). The consumption of other fuels by those plants whose consumption represents less than 0.0001 percent of its fuel consumption is ignored when modeling the production technology.

[9] The *Pollution Abatement Costs and Expenditures* survey (U.S. Department of Commerce 1996, p. A-9) of manufacturing plants included the cost of electricity used for pollution abatement activities.

associated with collection activities are included in the SPAC-1 estimates reported in this study, whereas SPAC-2 includes expenditures associated with collection and disposal activities.

While Yaisawarng and Klein (1994) interpret the sulfur content of fuels as a bad input, we view the sulfur and ash content as qualities of the fuels. By assuming no change in the sulfur and ash content of the coal and oil consumed and no change in the ash content of the coal consumed by the power plant, we exclude the costs associated with switching to fuels with fewer undesirable qualities (e.g., coal with a lower sulfur level). Since pollution abatement costs collected by the EIA-767 survey exclude costs associated with fuel switching, the constraint on the ash and sulfur content of the fuels forces the reference technology to consume the same quality of fuel as the observation.[10] This allows us to focus solely on comparing the estimates from our model with the stated costs of environmental protection activities reported in the EIA-767 survey.

Table 2 presents results for each electric power plant in 1995, while Appendix C reports the results for 1994. Column (1) lists the reduced production of electricity (in kWh) which is the following component of equation (12): $\left[\vec{D}^{U}(y^{k'}, x^{k'};1) - \vec{D}^{R}(y^{k'}, x^{k'};1)\right]$. Column (2) lists the $p^{k'}$ observed for each power plant. Column (3), which is calculated using equation (12), is the product of columns (1) and (2). Column (4) is the ratio of the reduced production of electricity,

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[10] The constraint imposed on the "bad" inputs by Yaisawarng and Klein (1994) specifies that the reference technology can use fuels of equal or lower quality than the observation whose efficiency is being estimated. Hence, the bad input is modeled as being freely disposable. In this case the observation is able to switch to a higher quality fuel (e.g., lower sulfur coal). Using that specification in this study would result in MPAC including the cost of fuel switching. Appendix B contains a discussion of BEA's use of the EIA-767 survey and how BEA estimated costs associated with consuming cleaner fuels.

which is reported in column (1), to the observed production of electricity. Column (5) reports SPAC-1, which is the estimate of SPAC for producer k' - $c^{k'}$ - which includes only collection expenditures. Column (6) reports SPAC-2, $c^{k'}$, which includes collection and disposal expenditures.

The results in Table 2 reveal substantial variation among the MPAC estimates and between the MPAC and SPAC-2 estimates. In Table 2, 85 observations have zero MPAC. In contrast, 9 observations report no SPAC-1 and only 1 observation reports no SPAC-2. There are 7 observations in which both MPAC and SPAC-1 are nil, and no observation for which MPAC and SPAC-2 are zero. Of the 23 observations for which MPAC is greater than SPAC-1 and 18 observations for which MPAC is greater than SPAC-2, both MPAC and SPAC-1 are positive for 21 of these observations, while MPAC and SPAC-2 are positive for 17 observations. Of the 81 observations for which MPAC is less than SPAC-1, MPAC and SPAC-1 are both positive for 3 observations. In addition, of the 93 observations for which MPAC is less than SPAC-2, both MPAC and SPAC-2 are positive for 8 observations. We find a significant positive correlation between SPAC-1 and SPAC-2, while the negative correlation between SPAC-2 and MPAC is insignificant.[11] Because of the significant positive correlation between SPAC-1 and SPAC-2, the remainder of our analysis of survey estimates reported in Table 2 is restricted to SPAC-2.

There are two obvious explanations for the variation in pollution abatement costs among the power plants in our two samples. First, increased regulatory stringency results in higher MPAC. This can be seen by observing Figure 1. For a given vector of inputs, stricter

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[11] In order to simplify the discussion, all statistical tests are one-tail and use a 10 percent level of significance. Appendix D contains the regression results that are the basis of the correlations discussed in this section.

regulations are associated with reduced production of the bad output which is associated with an increase in the vertical distance between the regulated and unregulated frontiers (i.e., an increase in MPAC). This reflects the fact that an increase in pollution abatement activities reduces the amount of inputs available to produce the good output. Second, for a given level of regulatory stringency we expect MPAC to increase with the scale of a plant's operation. The rationale for this explanation is linked to the fact that MPAC is the difference in production of the good output by the regulated and unregulated technologies.

We will now analyze the association between regulatory stringency and pollution abatement costs for the results presented in Table 2. Because two bad outputs are modeled in this study, it is difficult to develop a single measure of regulatory stringency. Instead, we use the ratio of SO_2 emissions per kWh and PM-10 emissions per kWh produced as proxies for regulatory stringency. While we find negative correlations between both ratios and MPAC, only the PM-10 ratio is statistically significant. Hence, stricter regulations are associated with increased MPAC. These results are confirmed when we look at the power plants with the largest MPAC (column 1 in Table 2) or the largest percentage reduction in net generation of electricity (in kWh) associated with pollution abatement activities (column 4 in Table 2). Virtually all plants with high MPAC have relatively low ratios of PM-10 emissions per kWh. However, the link between plants with high MPAC and their rate of SO_2 emissions per kWh is not as clear.

SPAC-2 is positively correlated with the ratio of PM-10 emissions per kWh and negatively correlated with the ratio of SO_2 emissions per kWh. While both are statistically significant, the ratio of SO_2 emissions per kWh is more significant. In addition to the counterintuitive relationship between SPAC-2 and PM-10 emissions, this result is interesting because in 1995 the collection and disposal expenditures associated with fly ash and bottom ash accounts for 53.6 percent of SPAC-2, while FGD collection and disposal expenditures account for 46.4 percent of SPAC-2.

We find an inverse relationship between the net generation of electricity (in kWh) and PM-10 emissions per kWh and SO_2 emissions per kWh. While the net generation of electricity (in kWh) is not significantly correlated with the ratio of PM-10 emissions per kWh, it is significantly correlated with the ratio of SO_2 emissions per kWh. Hence, it appears larger plants use less emission intensive processes. This result leads us to expect that we would find a positive correlation between net generation of electricity and pollution abatement costs.

In our analysis of the association between plant size and pollution abatement costs, we use the net generation of electricity (in kWh) as a proxy for the scale of operation. The empirical evidence for the association between plant size and SPAC-2 and MPAC is surprising. The scatter plot in Figure 2 reveals the expected positive association between kWh and SPAC-2; however, the scatter plot in Figure 3 reveals an inverse relationship between kWh and MPAC. These scatter plots are confirmed by using simple regressions with MPAC, SPAC-2 and kWh. As expected, we find a positive statistically significant correlation between SPAC-2 and kWh, while we find a non-significant negative correlation between kWh and MPAC. One possible explanation for this unexpected result is our use of net generation of electricity (in kWh), which is our measure of good output production, as a proxy for the scale of operation. The negative correlation between kWh and MPAC may simply reflect that for a given vector of inputs, good output production declines when MPAC increases.

Figure 2. kWh vs. MPAC

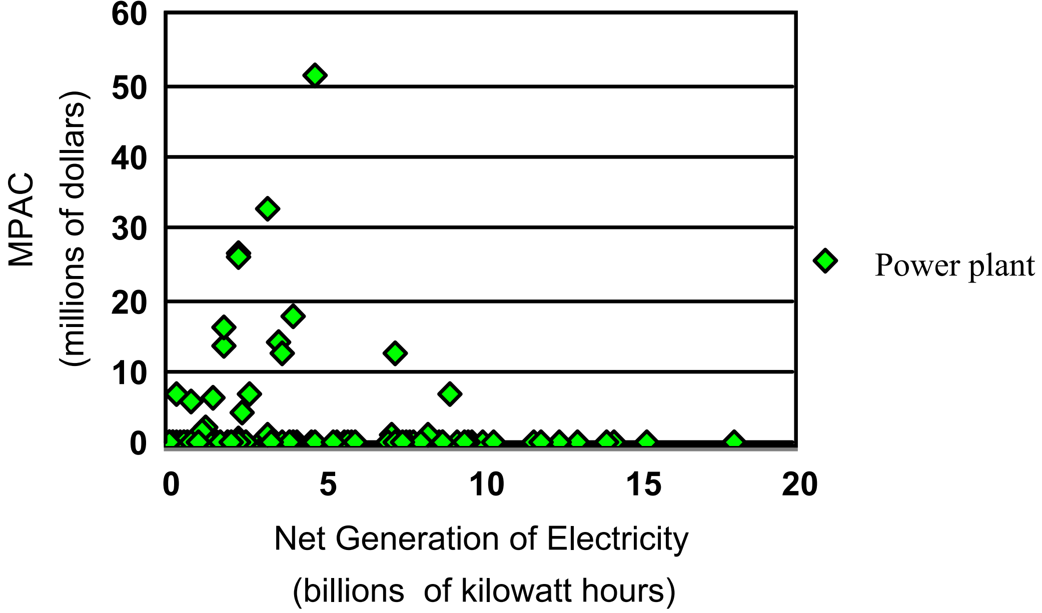

Figure 3. kWh vs. SPAC-2

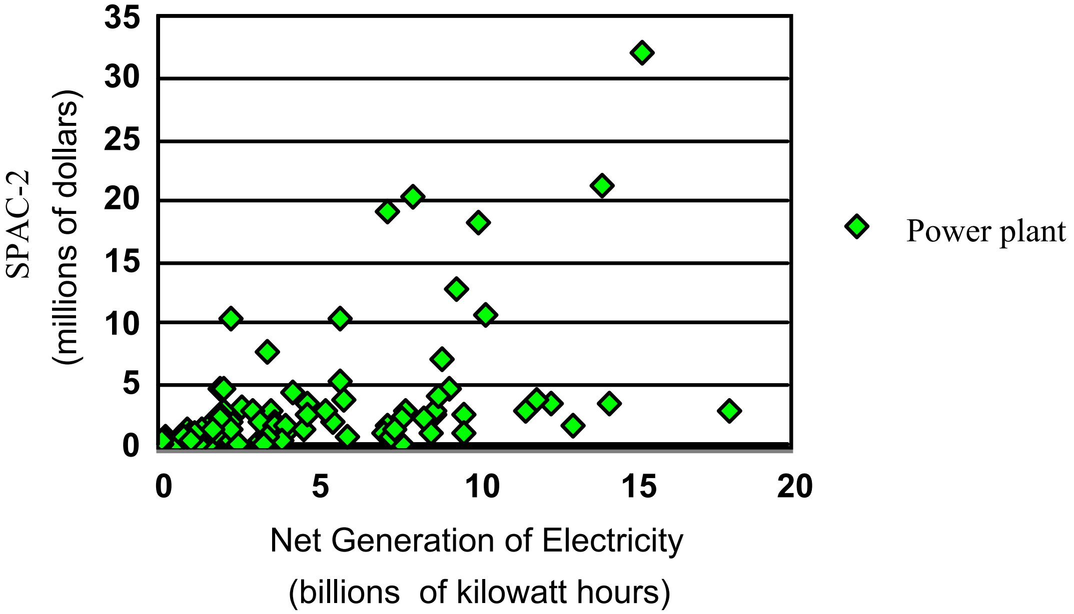

Table 3 presents summary statistics of MPAC and SPAC estimates. For 1995, ΣMPAC is \$273 million, while ΣSPAC-1 is \$223 million and ΣSPAC-2 is \$314 million (i.e., ΣMPAC and ΣSPAC refer to the sum of the modeling and survey estimates of pollution abatement costs for all power plants in the sample). In 1994, ΣMPAC is \$125 million, while ΣSPAC-1 is \$162 million and ΣSPAC-2 is \$314 million. If we exclude the 10 power plants with MPAC in excess of \$10 million in 1995, ΣMPAC declines to \$47 million, while excluding the 3 power plants with MPAC in excess of \$10 million in 1994 results in ΣMPAC declining to \$36 million. Finally, it is worth noting that in terms of the observed net electric production of electricity by all power plants in our samples the reduced production of electricity (in KWh) associated with environmental regulations is 0.48 percent in 1994 and 0.97 percent in 1995.

Figure 4 shows that the 10 plants with MPAC in excess of \$10 million in 1995 have some interesting characteristics relative to the average power plant in the sample. Their production of the good output ranges from 45 to 170 percent of the mean plant. The PM-10 emissions per kWh of these plants range from 6 to 73 percent of the mean ratio for the sample, while SO_2 emissions per kWh range between 31 and 145 percent of the average plant in the sample. This provides further evidence that relative to SO_2 emissions, reductions in PM-10 emissions are more closely associated with higher MPAC. In addition, the negative statistically significant correlations between (1) MPAC and kWh and (2) MPAC and PM-10 emissions per kWh may be explained by the fact that 5 of the10 plants with MPAC in excess of \$10 million plants have rates of SO_2 emissions per kWh that are greater than the average plant in the sample.

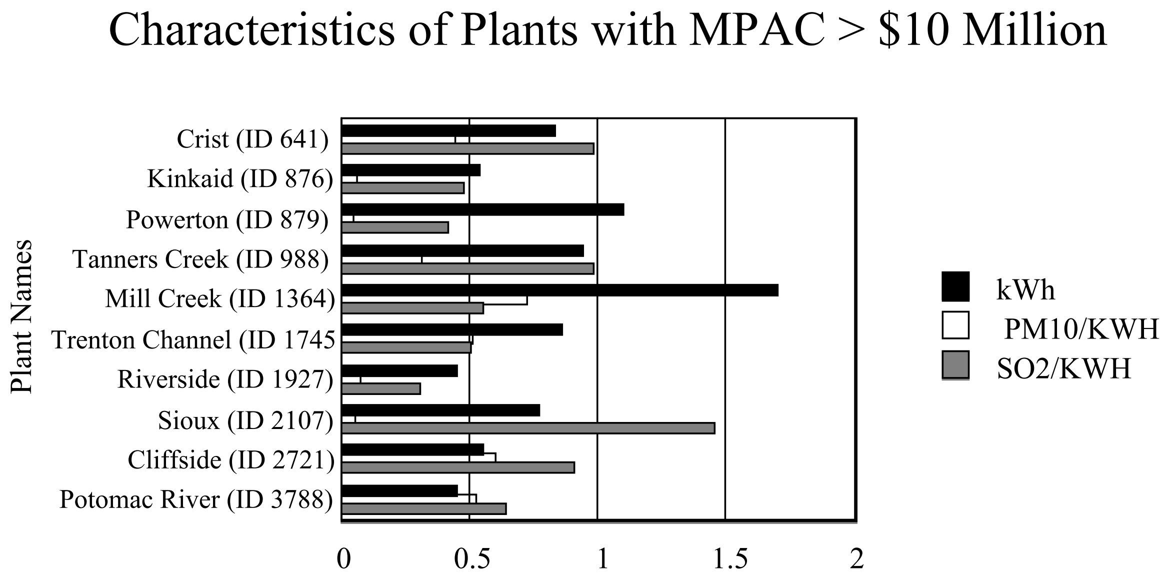

Figure 4. Plant Performance
(relative to average plant)

The results in Tables 2 and 3 show that while ΣMPAC exceeds ΣSPAC-1 this is due to a relatively small number of observations with relatively large values for MPAC. The skewness of the MPAC results is illustrated by observing the relative size of the means and medians. While the mean MPAC is greater than the mean of SPAC-1, the median of SPAC-1 is greater than the median of MPAC.

There are two readily apparent explanations for why ΣMPAC is greater than ΣSPAC. First, the ΣMPAC estimates may exceed the ΣSPAC estimates due to outliers in the data used to estimate ΣMPAC. There are two ways to address this problem. One approach involves eliminating a certain percentage of outliers. Although there is no statistical theory justifying such a procedure, it provides insights into the effect of outliers. A more sophisticated approach involves using a bootstrap procedure to test the sensitivity of the results to outliers. Finally, Simar (2003) has proposed an easy and fast method that can be applied to the problem of detecting outliers when using the DEA approach.

A second possible explanation is that MPAC measures opportunity costs of pollution abatement activities (e.g., paperwork costs) excluded from SPAC estimates. Hence, the divergence between the MPAC and SPAC estimates may represent the difference between the opportunity cost measure employed by economists and the accounting cost measure employed by the EIA-767 survey.

There are several additional explanations for why MPAC might exceed SPAC. First, MPAC estimates include the costs of electricity consumption associated with pollution abatement activities, while the EIA-767 survey excludes these costs. The inputs used to produce the electricity consumed for pollution abatement activities are part of the joint production technology, while electricity consumed for pollution abatement activities is excluded from the measure of production of the good output (i.e., net generation of electricity).[12] As a result, MPAC estimates include the cost of electricity consumed for pollution abatement activities. Information collected by the EIA-767 survey on electricity consumed by FGD systems provides some insights into this issue. Of the 111 power plants in our 1995 sample, 19 plants had at least one operational FGD unit (i.e., FGD unit in service during the year). While all 19 plants report SPAC-2 expenditures, and 18 report FGD collection and disposal expenditures, which are part of SPAC-2 expenditures, only 2 have positive MPAC. The 19 plants account for 7 percent of ΣMPAC expenditures, 60 percent of ΣSPAC-2 expenditures, and 93 percent of the FGD collection and disposal expenditures included in ΣSPAC-2. The electricity consumed by FGD units is 0.51 percent of the net generation of electricity of all power plants in our 1995 sample and 2.04 percent of the net generation of electricity by the 19 plants reporting estimates of FGD electricity consumption.[13] The plants with the largest quantities of electricity consumed by FGD units relative to their net generation of electricity include the 19 percent by Cherokee (plant ID 469) and 10.8 percent by Elrama (plant ID 3098). Sly Laskin (plant ID 1891) reports FGD

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[12] According to the instructions for "Generator Information" (Schedule IV, Item 4) of the EIA-767 survey, "net electrical generation" consists of the total amount of electrical energy generated minus electricity consumed at the plant.

[13] Petersburgh (plant ID 994) and Milliken (plant ID 2535) each report the electricity consumed by both FGD units but report the O&M expenditures associated with only 1 of its FGD units, while Martin Lake (plant ID 6146) reports the electricity consumed by all three of its FGD units, but the O&M expenditures associated with only 1 of its FGD units.

electricity consumption, but no FGD collection or disposal expenditures.[14] Finally, 12 plants report FGD collection and disposal expenditures, but no electricity consumed by FGD units.

Second, respondents to the EIA-767 survey may perceive environmental regulations as less binding constraints than the DEA model used to generate the MPAC estimates. The respondents to the EIA-767 survey may perceive either a different baseline technology than the unregulated technology specified by the DEA methodology used to derive the MPAC estimates or that the options available to electric utilities in an unregulated world are more limited than assumed by economic models.

Third, for the purposes of the SPAC estimates used in this study, nonreponses to questions regarding O&M expenditures for pollution abatement activities associated with reducing sulfur dioxide and PM-10 emissions in the EIA-767 survey are treated as zeros. The electronic files containing the results of the EIA-767 survey do not indicate whether the zeros represent zeros or nonresponses to questions associated with O&M expenditures. When a nonreponse represents a failure to report pollution abatement expenditures, this creates a downward bias in the estimates from the EIA-767 survey.[15]

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[14] According to the instructions of the EIA-767, the collection and disposal expenditures associated with FGD units from Schedule I, Section C, item 1 of the survey, which is the source of the survey estimates used in this study, should include the totals for O&M expenditures for FGD from Schedule VII, Section A, item 8e of the survey. Sly Laskin (plant ID 1891) is the only plant that deviates from this instruction.

[15] Blanks in the PACE survey of U.S. manufacturers are treated as zeros for the purpose of generating the published statistics and in estimating standard errors (see Streitwieser,1996, p. 23; 1997, p. 12). In addition, unpublished data from the BEA suggest it treated nonresponses from the EIA-767 survey as zeros. Appendix C contains a more detailed discussion of this issue.

Finally, the regulated technology specified in this study is valid if producers are engaged in pollution abatement activities. If free disposability characterizes the "true" technology, then the observations used to construct the regulated technology are simply inefficient producers relative to the unregulated production frontier. In this case observations used to construct the regulated frontier are in fact inefficient, and the MPAC estimates are biased in an upward direction.

Although there are numerous reasons to expect ΣMPAC to exceed ΣSPAC, arguments have been set forth in support of the belief that SPAC estimates will be greater than MPAC estimates. We will now summarize some of these hypotheses. First, respondents might have an incentive to overstate the costs associated with pollution abatement activities.[16] Second, respondents to the EIA-767 survey may perceive environmental regulations as more binding than the joint production model used to generate the MPAC estimates. Third, because some O&M disposal expenditures in the EIA-767 survey may represent expenditures for materials and services not included as inputs in the production technology modeled in this study, the SPAC estimates may exceed the MPAC estimates.[17]

Finally, pollution abatement activities have been undertaken by power plants for several decades (see U.S. Department of Commerce, 1982). As a result, using only observations from 1994 or 1995 is unlikely to result in modeling the true unregulated technology. Instead of an

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[16] The first page of "General Information" about the EIA-767 survey contains a paragraph describing the possible sanctions the government can bring against those utilities failing to respond to the survey.

[17] The EIA-767 estimates include "... all contract and self-service pollution abatement O&M expenditures..." (U.S. DOE, "General Information" for Form EIA-767, 2001, "Plant Information -- Financial Information," Schedule I, Section C, Item 1).

unregulated technology, it is more accurate to describe the free disposability technology as the least regulated technology available in that year. Hence, the failure to model the true unregulated technology results in a downward bias in the MPAC estimates. In fact, if a power plant operates a pollution abatement device (e.g., a scrubber) and the plant produces more of the good output with a given input vector than any other plant, the DEA model will determine there are no pollution abatement costs - MPAC - even though SPAC reports expenditures associated with the operation of the pollution abatement device.

IV. Conclusions

This study investigated the relationship between “stated” cost estimates of pollution abatement activities and the costs of pollution abatement activities “revealed” by the actual behavior of the regulated entities through a comparison of SPAC and MPAC estimates for U.S. coal-fired power plants. The latter views pollution abatement costs as the value of the reduced production of the good output due to environmental regulations. This alternative method is based on a DEA model, which allows us to model joint production with and without regulations and estimate pollution abatement costs as the difference in production in the two models. We compare these estimates with the survey estimates of the pollution abatement costs borne by power plants in 1994 and 1995.

In estimating pollution abatement costs using our DEA approach, we model the unregulated and regulated technologies using notions of free and weak disposability, respectively. Hence, the joint production model represents an example of the advantage of establishing the link between pollution abatement costs and production technologies. This study illustrates the potential of using a joint production model to assess the costs of reducing air pollutants emitted into the atmosphere.

Specifying joint production models to estimate the costs associated with pollution abatement activities follows in the tradition of using economic models to estimate the costs of regulations. When using a joint production framework, costs now depend on the specification of the production technology (i.e., the functional form and the associated elasticities of substitution) which is comparable to efforts that estimate the costs of other types of economic policies. For example, this model could be estimated parametrically-- either a parametric cost or distance function can be specified and estimated as a frontier model (see for example Färe et al., 1993). This involves estimating one regulated and one unregulated function for all observations. In fact, CGE models such as Jensen and Rasmussen (2000) specify a special case of the joint production of good and bad outputs when estimating the costs associated with proposed reductions in CO_2 emissions.

We believe joint production models provide a useful complement to survey methods used to identify pollution abatement costs. If pollution abatement activities consist primarily of end-of-pipe technologies, then surveys should provide an adequate means of estimating these costs. However, as an increasing share of the activities associated with abating air pollutants involve integrated technologies, surveys become an exercise in “stated” costs. In that case, economic models, which are more closely tied to production theory, represent a means of estimating the costs associated with pollution abatement activities.

Future investigations using the joint production model specified in this study might include: additional bad outputs, incorporation of the revenue from the sale of byproducts, and expansion of the sample to include observations from earlier years in order to more accurately depict the unregulated technology.

It is important to remember that all data employed in this study are collected by surveys. This study did not investigate the accuracy of responses to all types of questions included in surveys, instead it was concerned with the accuracy of responses to survey questions that require respondents to make judgement calls when the data required to answer a question are not readily observed. For example, fuel consumption, fuel quality, and the number of employees at a power plant are relatively easy to determine. However, estimating either the capital expenditures or O&M expenditures associated with pollution abatement activities provides a greater challenge to survey respondents. In order to provide answers to those questions, the respondent must ascertain the unobservable unregulated technology. Determining the unregulated technology is especially challenging if producers employ technologies in which the abatement activities are embedded in the production process.

Since the EIA-767 survey excludes expenditures associated with fuel switching, the expenditures reported in the EIA-767 survey are associated with end-of-pipe pollution abatement activities, survey estimates of the costs of these activities are likely to be more accurate than cost estimates associated with change in production process abatement techniques. Hence, the divergence between the “stated” and “revealed” costs estimates reported in this study should be smaller than a study comparing model estimates of pollution abatement costs with survey estimates of the costs associated with change in process abatement technologies.

Färe and Grosskopf (1983) and Färe, Grosskopf, and Pasurka (1986) specified a joint production function to measure the costs of pollution abatement activities when a producer is restricted to maintaining its observed mix of the good output and the bad output. This approach produces MPAC values that would be similar or smaller than those found in this study. Alternatively, Färe et al. (1989) proposed a hyperbolic efficiency measure of pollution abatement costs that assumed the simultaneous proportional expansion of good output production and contraction of bad output production. This approach yields values of MPAC that will be similar or larger than those found in this study. Which of the three formulation of MPAC is appropriate depends on how respondents to the EIA-767 survey implicitly assess the costs of pollution abatement activities. Because emission regulations on electric power plants are specified in terms of fuel consumption, we believe the directional distance function specified in this study is the closest representation of the perceptions of the respondents to the EIA-767 survey.

Although this study is concerned with the costs of pollution abatement activities, it is possible to speculate on whether the results of this study are relevant to the discussion about the relative accuracy of the "stated" and "revealed" methods used to estimate the benefits of environmental controls. It seems reasonable to assume the individuals responsible for completing the EIA-767 survey are more familiar with the costs of pollution abatement activities than the typical respondent to a contingent valuation survey. Hence, the divergence between the "stated" and "revealed" costs of this study is likely to be less than the divergence found by a comparable study of benefits.

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Table 1
Summary Statistics
(111 coal-fired power plants, 1994)

	Units	Mean	Sample Std. Dev.	Maximum	Minimum
Electricity	kWh	4,174,079,775.35	3,729,413,836.57	16,492,472,000.00	193,800,000.00
PM10	short tons	607.13	892.14	5,680.47	11.89
SO2	short tons	48,582.66	64,439.64	382,892.88	1,032.41
Capital stock	dollars	227,398,978.38	148,072,784.60	743,500,676.10	34,448,002.87
Employees	workers	184.09	112.14	535.00	36.00
Heat content of coal	Btu	42,441,504,318,918.90	36,792,966,822,567.30	177,809,737,200,000.00	2,574,430,000,000.00
Heat content of oil	Btu	106,398,828,994.59	167,373,086,883.45	1,125,953,770,200.00	0.00
Heat content of gas	Btu	117,810,209,909.91	372,834,528,952.53	2,860,199,800,000.00	0.00
Sulfur content of coal	short tons	27,642.82	34,810.30	171,674.43	853.20
Sulfur content of oil	short tons	8.14	12.97	82.18	0.00
Ash content of coal	short tons	206,362.74	276,447.94	1,560,669.96	8,783.60

Table 1 (cont.)
Summary Statistics
(111 coal-fired power plants, 1995)

	Units	Mean	Sample Std. Dev.	Maximum	Minimum
Electricity	kWh	4,331,653,735.36	3,965,028,404.63	18,212,069,000.00	43,132,000.00
PM10	short tons	623.91	924.49	5,886.58	6.17
SO2	short tons	36,051.22	40,197.84	265,995.43	455.00
Capital stock	dollars	229,543,726.26	149,228,791.73	750,024,803.65	34,503,302.14
Employees	workers	174.25	110.12	535.00	33.00
Heat content of coal	Btu	43,576,895,425,225.20	38,929,334,447,356.80	173,436,781,000,000.00	726,537,600,000.00
Heat content of oil	Btu	90,726,680,989.19	148,995,824,520.17	1,168,644,552,600.00	0.00
Heat content of gas	Btu	126,381,115,315.32	384,435,129,482.14	2,678,259,900,000.00	0.00
Sulfur content of coal	short tons	24,625.16	33,173.81	186,213.12	230.40
Sulfur content of oil	short tons	7.04	11.51	61.99	0.00
Ash content of coal	short tons	206,913.84	281,533.96	1,695,301.47	2,442.50

Table 2

Pollution Abatement Costs of 111 Coal-fired Power Plants in 1995

Plant Name	Plant ID code	Lost Good Output (kWh)	$/ KWH	MPAC ($1,000)	Lost Good Output / Net Generation (in percent)	SPAC-1 ($1,000)	SPAC-2 ($1,000)
Barry	3	0	0.0504	0	0.00	2,560	2,570
Gadsden	7	134,500,000	0.0504	6,778	34.98	183	183
Gorgas	8	0	0.0504	0	0.00	2,457	2,457
Limestone	298	0	0.0578	0	0.00	10,012	18,277
Araphoe	465	0	0.0588	0	0.00	0	1,243
Cherokee	469	0	0.0588	0	0.00	0	7,657
Comanche	470	0	0.0588	0	0.00	0	259
Brandon Shores	602	112,700,000	0.0608	6,854	1.24	837	7,032
Crist	641	256,100,000	0.0559	14,327	7.10	416	2,846
Hammond	708	76,200,000	0.0600	4,576	3.02	83	136
Harliee Branch	709	0	0.0600	0	0.00	932	932
Yates	728	116,700,000	0.0600	7,008	4.32	2,142	3,061
E.D. Edwards	856	0	0.0547	0	0.00	601	1,043
Coffeen	861	0	0.0497	0	0.00	1,839	2,920
Grand Tower	862	0	0.0497	0	0.00	319	687
Hutsonville	863	0	0.0497	0	0.00	178	313
Meredosia	864	0	0.0497	0	0.00	201	321
Kinkaid	876	356,400,000	0.0749	26,693	15.17	1,401	2,071
Powerton	879	690,200,000	0.0749	51,694	14.44	2,335	3,548
Will County	884	0	0.0749	0	0.00	2,819	4,421
Joppa	887	0	0.0187	0	0.00	244	244
Baldwin	889	0	0.0615	0	0.00	1,018	1,018
Havana	891	102,000,000	0.0615	6,273	6.70	61	61
Hennepin	892	0	0.0615	0	0.00	341	341
Wood River	898	0	0.0615	0	0.00	193	193
Clifty Creek	983	0	0.0159	0	0.00	2,909	4,542
Tanners Creek	988	437,000,000	0.0407	17,804	10.68	672	1,086
H.T. Pritchard	991	0	0.0493	0	0.00	240	240
Petersburgh	994	0	0.0493	0	0.00	10,631	10,631
Edwardsport	1004	0	0.0404	0	0.00	557	557
Gallagher	1008	0	0.0404	0	0.00	237	237
F.B. Culley	1012	0	0.0441	0	0.00	2,165	2,938
Lansing	1047	0	0.0497	0	0.00	190	299
Milton Kapp	1048	0	0.0497	0	0.00	174	1,106
Lawrence	1250	0	0.0465	0	0.00	1,707	2,088
Big Sandy Stream	1353	38,100,000	0.0313	1,194	0.52	1,049	1,511

E.W. Brown	1355	17,100,000	0.0391	668	0.72	387	387
Ghent	1356	0	0.0391	0	0.00	2,856	2,856
Green River	1357	0	0.0391	0	0.00	660	660
Mill Creek	1364	284,700,000	0.0452	12,881	3.86	18,947	19,132
R.P. Smith	1570	0	0.0477	0	0.00	219	271
Mt. Tom	1606	0	0.0287	0	0.00	60	697
B.C. Cobb	1695	2,400,000	0.0633	152	0.12	3,663	4,771
Marysville	1732	0	0.0732	0	0.00	0	186
Trenton Channel	1745	175,300,000	0.0732	12,840	4.70	0	1,845
Sly Laskin	1891	0	0.0373	0	0.00	20	20
Black Dog	1904	0	0.0507	0	0.00	381	665
High Bridge	1912	112,400,000	0.0507	5,701	12.30	218	383
Riverside	1927	273,900,000	0.0507	13,892	13.98	990	990
Hoot Lake	1943	0	0.0448	0	0.00	176	216
Asbury	2076	0	0.0490	0	0.00	129	129
Montrose	2080	0	0.0544	0	0.00	526	526
Labadie	2103	0	0.0543	0	0.00	1,539	1,539
Sioux	2107	607,200,000	0.0543	32,979	18.12	479	479
J.E. Corette	2187	0	0.0423	0	0.00	251	306
Goudey	2526	0	0.0809	0	0.00	84	240
Greenidge	2527	5,200,000	0.0809	421	0.76	104	186
Milliken	2535	0	0.0809	0	0.00	2,584	2,703
C.R. Huntley	2549	0	0.0850	0	0.00	0	430
Dunkirk	2554	0	0.0850	0	0.00	477	1,432
Rochester	2642	0	0.0873	0	0.00	0	637
Asheville	2706	0	0.0593	0	0.00	113	194
G.G. Allen	2718	20,000,000	0.0558	1,117	0.60	1,240	1,911
Cliffside	2721	472,500,000	0.0558	26,377	19.66	918	1,386
Marshall	2727	0	0.0558	0	0.00	1,250	3,524
R.M. Heskett	2790	0	0.0545	0	0.00	143	160
J.M. Stuart	2850	0	0.0607	0	0.00	2,667	3,392
R.E. Burger	2864	0	0.0728	0	0.00	468	888
Muskingum River	2872	0	0.0391	0	0.00	922	1,928
Kyger Creek	2876	0	0.0173	0	0.00	2,223	2,882
Muskogee	2952	0	0.0508	0	0.00	883	2,837
Elrama	3098	0	0.0756	0	0.00	6,290	10,345
Seward	3130	0	0.0601	0	0.00	872	872
Shawville	3131	0	0.0601	0	0.00	1,574	1,574
New Castle	3138	7,700,000	0.0625	481	0.51	423	606
Brunner Island	3140	0	0.0631	0	0.00	1,418	2,278
Montour	3149	0	0.0631	0	0.00	1,698	4,120
Armstrong	3178	0	0.0484	0	0.00	999	1,285
Silas McMeekin	3287	3,500,000	0.0561	196	0.23	59	731
Watertree	3297	0	0.0561	0	0.00	190	1,048

Big Brown	3497	0	0.0632	0	0.00	3,430	5,338
Carbon	3644	0	0.0427	0	0.00	433	583
Clinch River	3775	0	0.0430	0	0.00	1,009	1,799
Glen Lyn	3776	0	0.0430	0	0.00	72	1,441
Potomac River	3788	242,200,000	0.0674	16,332	12.28	1,494	2,169
Bremo	3796	39,500,000	0.0622	2,457	2.98	0	0
Kanawha	3936	38,200,000	0.0430	1,641	3.17	631	1,043
Rivesville	3945	0	0.0479	0	0.00	195	351
Willow Creek	3946	0	0.0479	0	0.00	762	866
Kammer	3947	0	0.0391	0	0.00	531	1,239
Mitchell	3948	35,900,000	0.0391	1,404	0.43	1,000	2,121
Nelson Dewey	4054	0	0.0459	0	0.00	270	325
Pulliam	4072	0	0.0442	0	0.00	683	1,299
Dave Johnston	4158	0	0.0427	0	0.00	2,650	3,736
Naughton	4162	0	0.0427	0	0.00	2,505	2,508
James Miller	6002	0	0.0504	0	0.00	2,569	2,771
Pleasants	6004	0	0.0479	0	0.00	18,161	20,287
Duck Creek	6016	0	0.0547	0	0.00	3,996	4,649
Newton	6017	0	0.0497	0	0.00	9,493	10,441
Sooner	6095	0	0.0508	0	0.00	697	933
Welsh	6139	0	0.0414	0	0.00	817	817
Martin Lake	6146	0	0.0632	0	0.00	25,097	32,142
Monticello	6147	0	0.0632	0	0.00	8,960	12,780
Rush Isl	6155	0	0.0543	0	0.00	790	790
Coleto Creek	6178	0	0.0573	0	0.00	153	349
Harrington	6193	0	0.0416	0	0.00	876	1,460
Pawnee	6248	0	0.0588	0	0.00	0	708
Mountaineer	6264	0	0.0430	0	0.00	1,858	2,905
Belews Creek	8042	0	0.0558	0	0.00	1,437	3,640
Jame M. Gavin	8102	0	0.0391	0	0.00	21,302	21,302
Cheswick	8226	0	0.0756	0	0.00	135	135
TOTALS		4,657,600,000		272,741		222,809	313,643

Table 3

Summary Statistics for Pollution Abatement Costs, 1994
(thousands of dollars)

	Total	Mean	Median	Std. Dev.	Maximum	Minimum
MPAC	124,892	1,125	0	5,271	45,291	0
SPAC-1	162,210	1,461	552	2,776	20,280	0
SPAC-2	250,566	2,257	1,271	3,827	30,319	55

Summary Statistics for Pollution Abatement Costs, 1995
(thousands of dollars)

	Total	Mean	Median	Std. Dev.	Maximum	Minimum
MPAC	272,741	2,457	0	7,422	51,694	0
SPAC-1	222,809	2,007	683	4,187	25,097	0
SPAC-2	313,643	2,826	1,106	4,942	32,142	0

Appendix A to

Estimating Pollution Abatement Costs:
A Comparison of “Stated” and “Revealed” Approaches

(Not for publication)

History of EIA-767 Survey

The Federal Power Commission (FPC) Form 67 entitled “Steam-Electric Plant Air and Water Quality Control Data” collected information about the operating costs associated with the pollution abatement activities of power plants for 1969 through 1980.[18] These data were published in a series of annual reports by the U.S. Federal Power Commission (1973a, 1973b, 197x, 197x, 1976) for 1969 to 1973 and the Federal Energy Regulatory Commission (1978, 1979a, and 1979b) for 1974 to 1976 (Appendix A lists these reports). The EIA-767 survey “Steam-Electric Plant Operation and Design Report” is the successor to FPC Form 67.[19] Although Form EIA-767 was administered during 1981 to 1984, the Energy Information Administration (EIA) does not consider these data to be as accurate as the data starting in 1985.

In its annual report on pollution abatement expenditures, the Bureau of Economic Analysis (see Vogan, 1996) used data collected by FPC Form 67 to estimate the costs associated with the operation of air and water pollution abatement capital equipment of privately owned electric utilities for the years from 1972 through 1980, and data from the EIA-767 survey were used to estimate costs for the years from 1985 through 1994 (Farber and Rutledge 1989, pp. 12-13 and 16 and Vogan 1996, p. 54). Changes in related series of data were used to generate estimates for the years from 1981 to 1984.

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[18] Gollop and Roberts (1983), Tran and Smith (1983), and Färe, Grosskopf, and Pasurka (1986) are among the studies using data from the FPC Form 67.

[19] Bellas (1998) used annual flue gas desulfurization (FGD) costs from the EIA-767 survey for the years from 1985 through 1991, excluding 1988, in his study investigating the existence of technical progress in the pollution abatement activities of electric utilities.

FERC was created through the Department of Energy Organization Act on October 1, 1977. At that time, the Commission's predecessor, the Federal Power Commission (FPC), was abolished, and the new agency (FERC) inherited most of the FPC's responsibilities. (URL: http://www.ferc.fed.us/public/isd/b16gide.htm).

Data Sources

The power plants included in the sample were determined via a two step process. The initial list of power plants consisted of the 296 coal-fired power plants provided by Carlson et al. (2000, p. 1305). These plants represent most phase I coal-fired generating plants and all privately owned phase II coal-fired plants. From this initial sample, power plants were excluded due to lack of information about fuel consumed, net generation of electricity, or emissions. In addition, some power plants are excluded due to concerns about the accuracy of the data on the cost of structures and equipment. No plant was excluded due to lack of data on pollution abatement expenditures. Finally, plants for which coal constituted less than 95 percent of the BTU were excluded.

Capital Stock and Employment

The Carlson data consisted of the historical cost of plant for (1) Structures and Improvements and (2) Equipment. These data form the nucleus of the capital stock estimates used in our study. For some plants, it was necessary to locate missing observations in the Carlson data. The data were published until 1991 in the following sources:

1938-1947	Federal Power Commission	*Steam-Electric Plant Construction Cost and Annual Production Expenses, 1938-1947*
1948-1974	Federal Power Commission	*Steam-Electric Plant Construction Cost and Annual Production Expenses* (Annual Supplements)
1975-1978	Energy Information Admin.	*Steam-Electric Plant Construction Cost and Annual Production Expenses* (Annual Supplements)

1979-1981	Energy Information Admin.	*Thermal Electric Plant Construction Cost and Annual Production Expenses* (Annual Supplements)
1982-1987	Energy Information Admin.	*Historical Plant Cost and Annual Production Expenses for Selected Electric Plants* (Annual Supplements)
1988-1991	Energy Information Admin.	*Electric Plant Cost and Power Production Expenses* (Annual Supplements)

Data from FERC Form 1 are available electronically from 1994 to the present at the following URL:

http://rimsweb2.ferc.fed.us/form1viewer/

Observations that are unavailable in either published form or electronically, are available from the original FERC Form 1 survey which can be found at the FERC Public Reference Room. Data from the EIA Form 767 for the years from 1994 to the present are also available at

http://www.eia.doe.gov/cneaf/electricity/page/eia767.html

A random comparison was made of Carlson's plant cost data with published FERC data. In addition, Carlson included numerous power plants with Gas Turbines installed; however, the cost of the gas turbines were excluded from the steam electric power data for plant and equipment cost. Therefore, we excluded all power plants that reported costs for Gas Turbines generators (GT). For the same reason, we excluded all plants with installed Internal Combustion (IC) generators with the following exceptions:

(1) Hutsonville (ID 863) - 3.0 MW international combustion generator

(2) Milliken (ID 2535) - 5.6 MW internal combustion generator

(3) Huntley (ID 2549) - 0.7 MW internal combustion generator

(4) Dunkirk (ID 2554) - 0.5 MW internal combustion generator

(5) Burger (ID 2864) - 7.5 MW internal combustion generator

Although none of these five plants reported costs for their internal combustion generators on the FERC Form 1 survey, the capacity of the generators was reported in the 1994 and 1995 *Inventory of Power Plants*.

Because those plant reporting costs for internal combustion power plants on the FERC Form 1 survey reported costs of approximately $100,000 per MW, we decided to include these five plants.

There are two additional exceptions to our general rule for which power plants to include in our samples. Cherokee (ID 469) capacity consists of a Steam Internal Combustion generator. Although E.W. Brown (ID 1355) has a Gas Turbine generator, it provides separate plant cost and employment estimates for the (1) Steam and (2) Gas Turbine Generators. Therefore, E.W. Brown (ID 1355) is included in our samples.

Next, it was necessary to develop estimates of the value of plant and equipment for some older plants for years in which no estimates were reported. If cost data are not available, the procedure is followed. First, if data are reported for (1) net generating capacity and (2) cost per KW of installed generating capacity, the cost of Structures and Improvements (SI) in period n is estimated using the following expression:

$$PC_n^{SI} = IGCinMW_n \cdot (\$ / IGCinKW)_n \cdot \left(\frac{PC_t^{SI}}{PC_t^{total}} \right) \cdot 1000$$

where IGCinMW is installed generating capacity in megawatts, PC is the plant cost and t is the first year cost data are available. PC^{Total} reflects the cost of the following three components: (1) structures and improvements, (2) equipment, and (3) land and land rights. A similar procedure allows us to estimate the cost of equipment in period n. The cost of “land and land rights” is excluded from our definition of capital stock.

Second, if the installed generating capacity associated with the first year plant cost data are available is the same for all previous years, we assume the plant cost value is identical for those years. Hence, we assume all plant costs are incurred in the initial year of operation and no net investment occurred in subsequent years in which the installed generating capacity was constant and no cost data were reported.

Third, if the net generating capacity varies in the years prior to which plant cost data are reported, we assume the cost (in constant dollars) of each MW installed generating capacity is constant. Hence, plant costs are incurred in the year in which generating capacity increases at a constant dollar amount for MW. For years in which there is no change in installed generating capacity, we assume no change in plant costs (i.e., no net investment). Finally, if cost estimates exist for two years (0 and t) with identical installed generating capacity but estimates of plant cost (PC) for the intervening years (n) are missing, current dollar cost estimates are derived for the missing observations using the following expression (a simply interpolation procedure using current dollar values):

$$PC_n = PC_0 + \left(PC_t - PC_0\right)\left(\frac{n-1}{t-0}\right), for\ n = 1,\ldots,t-1$$

Power plants were excluded if data were not collected on a consistent basis. For example, in some years information for a subset of the generators for some power plants were reported. In other years, data from all generators were reported on the FERC Form 1. Those power plants are excluded from our sample. In some years, power plants with multiple owners report data associated with a subset of its owners. Those power plants were also excluded from our sample. The FERC 1 survey only collects data on the total historical cost of plant and equipment - no data are collected on investment expenditures. Hence changes in the value of plant and equipment reflect the value of additional plant and equipment plus the value of retired plant and equipment. For this study, we assume changes in Cost of Plant reflect net investment (NI), which is the same assumption employed by Yaisawarng and Klein (1994, p . 453, footnote 30) and Carlson et. al (2000, p. 1322).

The next step is converting the historical cost of plant data into constant dollar values using the Handy-Whitman Index (HWI). Cost indexes are available for six geographic regions in the United States. Hence, each power plant was assigned to a region based on its location. The cost index for "Total Steam Production Plant" (line 6) in "The Handy-Whitman Index of Public Utility Construction Costs - Trends in Construction Costs" (Whitman, Requardt & Associates, LLP, 2002) is used to convert the historical cost data into constant 1973 dollar values. Cost index (CI) estimates for 1987 to 1995 are presented for January 1 and July 1. These values are converted into annual cost indexes for year t using the following four-point average equation:

$$CI_t = \frac{CI_t^{Jan.1} + (2 \cdot CI_t^{Jul.1}) + CI_{t+1}^{Jan.1}}{4}$$

Hence, the constant dollar capital stock (CS) for year n is calculated in the following manner:

$$CS_n = \sum_{t=1}^{n} \frac{NI_t}{HWI_t}$$

Obviously, in the first year of its operation the net investment of a power plant is equivalent to the total value of its plant and equipment.

<u>Other Inputs and Outputs</u>

Page 6 of the EIA-767 survey requests information on fuel consumption (heat content) and fuel quality (sulfur content and ash content), while page 9 requests information on net electricity generation (kWh). In this study, information about fuel consumption and fuel quality is taken from the BOILER data files compiled by the EIA, and net generation of electricity is from the TURBINE data files compiled by the

EIA. The data in the BOILER and TURBINE files are from the EIA-767 survey. The EIA created one BOILER file and one TURBINE file for each year.

In developing the power plant data, we followed the strategy of aggregating data for all boilers associated with a power plant (BOILER data) and aggregating data for all generators associated with a power plant (TURBINE) data in order to develop data on fuel consumption and electricity generation for each power plant.

Emission data are provided by the U.S. EPA. The procedure to estimate the quantity of bad outputs has evolved over the years. The U.S. FPC (1973, pp. ix-xvi) specified the procedure used by to estimate emissions for the years from 1969 to 1976. The U.S. DOE (1999, pp. 115-117 and 122) uses the Compilation of Air Pollutant Emission Factors (U.S. EPA 1999) when it generates estimates of SO_2, NO_x, and CO_2 emissions from electric utilities (in BOILER file). Emission estimates are derived using the algorithms described in *National Air Pollutant Emission Trends, Procedures Document, 1900-1996* (U.S. EPA 1998a, pp. 4-25 to 4-26 and 4-32 to 4-34).

Data on pollution abatement costs were extracted from files provided by the EIA, which contain all information reported on the EIA-767 survey. Page 4 of the EIA-767 survey requests information on operation and maintenance expenditures associated with abating fly ash, bottom ash, and FGD (flue gas desulfurization). These estimates exclude depreciation expense, cost of electricity consumed, and fuel differential expense (i.e., extra costs of cleaner, thus more expense fuel). It is possible to determine whether or not a blank represents no pollution abatement costs or a missing observation by using information on the number of inservice hours of flue gas particulate collectors (requested on page 12) and the number of inservice hours of flue gas desulfurization units and electrical energy consumed during the year to operate those units (requested on page 13).

The Form EIA- 861 survey provides information on sales of electricity and its associated revenue from sales to ultimate consumers and sales for resale by each utility. In this study, the revenue per kWh is identical for each power plant operated by a utility. When a power plant is owned by more than one utility, it is assigned the revenue per kWh of its principal owner.

The revenue per kWh is estimated by using the following information collected by the EIA-861 survey:

$$\frac{\text{"}\mathit{Field}\ 44\text{, }\mathrm{Re}\mathit{venue\ from\ Sales\ to\ Ultimate\ Consumers}\text{"} + \text{"}\mathit{Field}\ 45\text{, }\mathrm{Re}\mathit{venue\ from\ Sales\ for}\ \mathrm{Re}\mathit{sale}\text{"}}{\text{"}\mathit{Field}\ 38\text{, }\mathit{Sales\ to\ Ultimate\ Consumers}\text{"} + \text{"}\mathit{Field}\ 39\text{, }\mathit{Sales\ for}\ \mathrm{Re}\mathit{sale}\text{"}}$$

The utility codes from the TURBINE and BOILER files are matched with the utility codes from the EIA-861 data when assigning revenue per kWh to each plant. There are some instances in which the TURBINE/BOILER utility codes do not match the EIA-861 utility codes. In those instances, the following concordances/assignments are specified:

1) Montana-Dakota Utilities (utility code 12819) is a division of MDU (utility code 12199).

2) Western Resources (utility code 22500) was formed in 1992 from the merger of The Kansas Power and Light Company (utility code 10015) with the Kansas Gas and Electric Company (utility code 10005).

3) Texas Utilities Generating Company (utility code 18716) is now the Texas Utilities Electric Company (utility code 44372).

4) Iowa Southern Utilities, Inc. (utility code 9432) merged with Iowa Electric Light and Power Company (9423) to form IES Utilities, Inc. (utility code 9162).

5) In 1992, Iowa Public Service Company (utility code 9435) merged with Iowa Power Inc. (utility code 9429) to form Midwest Power Systems (utility code 23333 in 1994 EIA-861 survey). Midwest Power Systems was later renamed Mid-American Energy (utility code 12341 in 1995 EIA-861 survey).

The sulfur content of petroleum is expressed as a percentage of weight. In order to convert it to barrels, the following procedure is followed. According to the European Natural Gas Vehicle Association (ENGVA) http://www.engva.org/view.phtml?page=127.phtml, the following conversion factors exist: (1) to convert from tonnes of petroleum (t) to barrels of petroleum (bbl), multiply tonnes of petroleum by 0.135 (i.e., a barrel of petroleum weighs 0.135 tonnes). A long ton (British) is 2,240 pounds, a tonne (metric) is 2,205 pounds, and a short ton is 2,000 pounds. Hence, multiply tonnes by 0.907 to obtain short tons (i.e., a short ton is 0.907 of a tonne) and multiply tonnes by 1.016 to obtain long tons. Hence, to convert from barrels (bbls) of petroleum consumed to short tons (ST) of petroleum consumed:

$$ST = (bbls \times 0.135) \times \left(\frac{1}{0.907}\right)$$

The following expression is used to determine the weight of sulfur (in short tons) in the petroleum consumed:

$$ST_{sulfur} = (bbls \times 0.135) \times \left(\frac{1}{0.907}\right) \times (\%\, of\ sulfur\, in\, petroleum)$$

For example, a 1,000 barrels of petroleum weighs 135 tonnes which equals 148.8 short tons of petroleum. Multiplying the 148.8 short tons of petroleum by the percent of sulfur in the petroleum (by weight) yields the sulfur content (in short tons) of the petroleum consumed by the power plant.

Hours of operation of pollution abatement equipment

It seems reasonable to expect plants with operational flue gas desulfurization units or flue gas particulate collectors should report operation and maintenance (O&M) pollution abatement expenditures.

One method of determining which zeros might represent nonresponses is to compare the PACS estimates for ash and sulfur collection with the kWh associated with operating FGD systems and the number of in-service hours of any flue gas particulate collectors or flue gas desulfurization units employed by the power plant. The assumption is an inservice FGD system will require electricity and will result in O&M expenditures associated with sulfur collection. Similarly, an inservice flue gas particulate collector will result in O&M expenditures associated with ash collection.

By-product sales revenues

In its annual report on pollution abatement expenditures, the Bureau of Economic Analysis used data collected by the FPC Form 67 to estimate the by-product sales revenues associated with sulfur and flyash recovered from air pollution abatement activities and bottom ash from solid waste collection and disposal for 1972 through 1980, and data from the EIA-767 survey were used to estimate the by-product sales revenue for 1985 through 1987 (Farber and Rutledge 1989, pp. 16-17). Changes in related series of data were used to generate estimates for 1981 to 1984.

Other Sources of Emission Estimates

The U.S. Department of Energy provided its estimates of SO_2, CO_2, and NO_x emissions. These emission estimates are calculated using a different set of engineering equations (see U.S. DOE 1999, pp.115-117 and 122) than the emission estimates published by the Federal Power Commission and Federal Energy Regulatory Commission for 1969 to 1976 (Federal Power Commission, 1973a, pp. ix-xvi).

Since neither CO_2 nor PM-2.5 were regulated in 1994 or 1995 - the U.S. EPA (1998b, p. 30) announced its PM-2.5 standard on July 18, 1997 - they are not included among the bad outputs.

Background Capital Expenditures for Pollution Abatement not used in this Study

There were two sources of data for the capital expenditures associated with the pollution abatement activities of electric utilities. Although the FPC Form 67 and Form EIA-767 surveys included questions on capital expenditures, during the years from 1973 to 1987 the BEA conducted its own survey of electric utilities in order to estimate capital expenditures by electric utility companies (see Farber and Rutledge 1989, pp. 7-8). The results of this survey were published in an annual article in the Survey of Current Business. For the years after 1988, the BEA survey was conducted by the U.S. Bureau of the Census. These results were initially published starting with the 1990 PACE report, which reported estimates of nonmanufacturing capital expenditures for the years from 1987 to 1990. In 1992, the "Plant and Equipment Survey Supplement for Pollution Abatement" (Form PA-2) replaced the survey entitled "Structures and Equipment Expenditures Survey: Supplement for Pollution Abatement" (Form PA-1) (see U.S. Bureau of the Census 1994, pp. 5-6). An advantage of the EIA-767 data on capital expenditures is their public availability on a plant-by-plant basis; since, the BEA survey results for individual companies are confidential, they are only available in aggregate form.

The BEA developed a procedure using information about corporate utility capital expenditures for pollution abatement to estimate pollution abatement capital expenditures by electric utility cooperatives (Farber and Rutledge, p. 8).

The BEA (Farber and Rutledge 1989, p. 16) estimated the operating costs associated with the pollution abatement activities of government enterprise electric utilities in conjunction with developing its estimates of the operating costs of pollution abatement activities of private and cooperatively owned electric utilities.

The BEA (Farber and Rutledge 1989, p. 19) obtained an estimate of PA capital expenditures by government enterprise electric utilities by taking the ratio of PA capital stock owned by government enterprise electric utilities relative to PA capital stock owned by private and cooperative utilities and multiplying this ratio by the PA capital expenditures of private and cooperative utilities. This calculation is performed separately for capital expenditures associated with air and water pollution abatement activities.

Background: Depreciation data not used in this study

The BEA (Farber and Rutledge 1989, pp. 22-23) explain how the BEA estimated the capital consumption allowances associated with air and water pollution abatement activities for ten manufacturing industries three nonmanufacturing categories. Cremeans (1977) reported these estimates for 1972 and 1973; however, for its annual survey of pollution abatement expenditures, the BEA did not report their estimates of capital consumption associated with pollution abatement plant and equipment. The BEA (U.S. Department of Commerce, 1994, p. 47) did report estimates for the depreciation of the capital stock associated with pollution abatement activities for 1987.

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Appendix B to

Estimating Pollution Abatement Costs:
A Comparison of “Stated” and “Revealed” Approaches

(Not for publication)

Treatment of blanks in surveys

Blanks in the PACE survey are treated as zeros for the purpose of generating the published statistics and in estimating standard errors. The occurrence of blank fields in responses to the PACE survey doubled from 28.8 percent during the years from 1984-86 to 57.2 percent for the years from 1988-92 (see Streitwieser,1996, p. 23; 1997, p. 12). Streitwieser also discussed the use of imputation at the U.S. Bureau of the Census’ Center for Economic Studies when the PACE data are linked to other data in the Longitudinal Research Database (LRD).

Unfortunately, the BEA did not publish separate estimates of the O&M expenditures associated with the efforts of electric utilities to abate air pollutants. However, unpublished data from the BEA (October 4, 1993 fax sent by Mo Mowabi of the Environmental Economics Division of the BEA) provides information on BEA’s estimates of O&M expenditures by electric utilities for 1979 to 1990. In order to provide some insights into BEA’s treatment of nonresponses, Table B.1 reports its estimates for 1988-1990 and estimates we collect from the EIA databases. The EIA estimates are operation and maintenance expenditures (O&M) for (1) fly ash collection and disposal (Schedule I, Section C, Item 1a) and (2) FGD, nitrogen oxide control and all other air pollution abatement (Schedule I, Section C, Item 1b). The difference (column 3) between the BEA estimate of total O&M expenditures for air pollution abatement (column 1) and its estimate of the cost of the fuel differential (column 2) should be close to the estimate from the EIA-767 survey for the costs associated with abating ash and sulfur emissions (column 4). Since the estimates are close, it appears the BEA treated nonresponses from the EIA-767 survey as zeros.

Table B.1
O&M Expenditures Associated with Air Pollution Abatement Activities
(millions of current dollars)

	BEA Estimates			EIA-767 Estimates (4)
Year	Total O&M Expenditures (1)	Fuel Differential Expenditure (2)	Difference between Total O&M Expenditures and Fuel Differential (3) = (1) - (2)	
1988	2,031.1	874.5	1,156.6	1,154.2
1989	1,862.8	881.9	980.9	980.7
1990	2,010.4	823.1	1,187.3	1,031.9

NOTE: BEA estimates are from an unpublished set of tables (dated May 31 and June 1, 1994). The EIA -767 estimates are from Schedule I, Section C, Item 1.

NOTE: The electric utility expenditures were part of the "operation of plant and equipment" category which was part of the private (line 9) category of "Business, current account" (line 8) in the BEA estimates of pollution abatement expenditures published in the *Survey of Current Business* (see Vogan, 1996).

NOTE: BEA would revise O&M estimates associated with air pollution abatement activities.

In addition to leaving a cell empty, the EIA-767 survey allows respondents to answer EN (estimate is not available) or NA (item is not applicable) An EN is employed if collection and disposal costs cannot be separated (instructions fo Schedule I, Section C, Item 1). In that case, the total cost is placed under collection and the EN is placed in the disposal column. Since some power plants respond with EN to some inquiries about cost, it is likely this results in some underestimate of pollution abatement costs by the EIA-767 survey.

According to the EIA-767 instructions (Schedule VII, Section A): "FGD O&M expenditures should include the costs of continuous emissions monitoring, raw and byproduct material handling, limestone milling and storage, dewatering facilities, contracted labor and all other auxiliary FGD support facilities..." These expenditures include: (a) feed materials and chemicals, (b) labor and supervision, (c) waste disposal, and (d) maintenance, materials, and all other costs.

BEA use of EIA-767 Estimates

The BEA estimate of operating expenditures associated with the pollution abatement activities of electric utilities included an estimate of the cost of the "fuel differential" borne by the electric utilities (see Farber and Rutledge 1989, p. 13). The BEA defined the fuel differential to be the increased cost associated with purchasing low-sulfur coal instead of high sulfur coal. Using data on the sulfur content of fuels contained in the 1969 FPC report, the BEA assumed changes in the sulfur content of fuel after 1969 were the consequence of policies aimed at reducing emissions of sulfur oxides (Farber and Rutledge 1989, p. 13). The BEA used pollution abatement expenditures "... for the collection and disposal of flyash, bottom ash, sulfur and sulfur products, and other products from flue gases. (Farber and Rutledge,1989, p. 12). Hence, it is likely BEA used cost estimates from Schedule 1 (Section C) of EIA-767.

Electricity Consumption of Pollution Abatement Equipment

While the EIA-767 survey provides estimates of electricity consumed by flue gas desulfurization units, there are two potential difficulties with introducing electricity consumed for pollution abatement activities as an additional constraint in the LP problem. First, the electricity consumed by flue gas desulfurization units does not account for all electricity consumed for pollution abatement activities. For example, the EIA-767 survey provides no estimates of the electricity consumed to operate flue gas particulate collectors. Second, the use of a separate constraint associated solely with pollution abatement activities violates this study's objective of specifying a joint production methodology that is capable of estimating the costs associated with pollution abatement activities and not requiring separate information on pollution abatement activities.

In order to provide a sense of the relative significance of the electricity consumed for pollution abatement activities in 1995, column 5 in Table B.1 reports the ratio of the electricity consumed (in kWh) by flue gas desulfurization units of a plant to its net generation.

Table B.1

Electricity Consumption (in kWh) of FGD Systems

Plant Name	plant ID	FGD kWh Consumption	Net Generation (in kWh)	FGD kWh / Net Generation
Barry	3	0	9,814,575,000	0.00
Gadsen	7	0	384,491,000	0.00
Gorgas	8	0	8,853,639,000	0.00
Limestone	298	70,100,000	10,207,568,000	0.69
Araphoe	465	0	953,067,000	0.00
Cherokee	469	671,514,000	3,539,614,000	18.97
Comanche	470	0	4,023,033,000	0.00
Brandon Shores	602	0	9,091,443,000	0.00
Crist	641	0	3,609,457,000	0.00
Hammond	708	0	2,521,650,000	0.00
Harliee Branch	709	0	8,697,459,000	0.00
Yates	728	28,501,000	2,702,823,000	1.05
E.D. Edwards	856	0	3,473,843,000	0.00
Coffeen	861	0	3,091,145,000	0.00
Grand Tower	862	0	323,597,800	0.00
Hutsonville	863	0	299,892,100	0.00
Meredosia	864	0	1,066,306,900	0.00
Kinkaid	876	0	2,350,041,000	0.00
Powerton	879	0	4,778,160,000	0.00
Will County	884	0	4,287,310,000	0.00
Joppa	887	0	7,821,165,000	0.00
Baldwin	889	0	9,752,835,000	0.00
Havana	891	0	1,523,231,700	0.00
Hennepin	892	0	1,322,163,100	0.00
Wood River	898	0	1,675,138,100	0.00
Clifty Creek	983	0	9,340,285,000	0.00
Tanners Creek	988	0	4,093,609,000	0.00
H.T. Pritchard	991	0	688,587,000	0.00
Petersburgh	994	109,313,000	10,519,333,000	1.04
Edwardsport	1004	0	176,041,000	0.00
Gallagher	1008	0	2,645,753,000	0.00

F.B. Culley	1012	63,665,000	2,111,457,500	3.02
Lansing	1047	0	775,610,820	0.00
Milton Kapp	1048	0	1,050,504,200	0.00
Lawrence	1250	71,480,000	1,826,733,000	3.91
Big Sandy Stream	1353	0	7,317,567,000	0.00
E.W. Brown	1355	0	2,378,139,000	0.00
Ghent	1356	106,427,000	11,790,910,000	0.90
Green River	1357	0	738,493,000	0.00
Mill Creek	1364	121,783,000	7,368,357,000	1.65
R.P. Smith	1570	0	197,208,000	0.00
Mt. Tom	1606	0	949,827,599	0.00
B.C. Cobb	1695	0	1,984,754,000	0.00
Marysville	1732	0	43,132,000	0.00
Trenton Channel	1745	0	3,730,602,000	0.00
Sly Laskin	1891	12,667,200	279,000,000	4.54
Black Dog	1904	0	1,411,253,000	0.00
High Bridge	1912	0	913,863,000	0.00
Riverside	1927	0	1,959,852,000	0.00
Hoot Lake	1943	0	395,616,200	0.00
Asbury	2076	0	1,317,169,000	0.00
Montrose	2080	0	2,380,121,800	0.00
Labadie	2103	0	13,239,359,000	0.00
Sioux	2107	0	3,350,084,000	0.00
J.E. Corette	2187	0	1,131,915,000	0.00
Goudey	2526	0	550,566,200	0.00
Greenidge	2527	0	685,440,906	0.00
Milliken	2535	30,974,400	1,987,739,900	1.56
C.R. Huntley	2549	0	3,343,543,000	0.00
Dunkirk	2554	0	3,509,966,000	0.00
Rochester	2642	0	1,200,409,000	0.00
Asheville	2706	0	2,609,136,000	0.00
G.G. Allen	2718	0	3,349,714,000	0.00
Cliffside	2721	0	2,403,835,000	0.00
Marshall	2727	0	12,561,314,000	0.00
R.M. Heskett	2790	0	225,761,800	0.00
J.M. Stuart	2850	0	14,397,656,000	0.00
R.E. Burger	2864	0	1,509,691,000	0.00

Muskingum River	2872	0	5,580,898,000	0.00
Kyger Creek	2876	0	7,953,432,000	0.00
Muskogee	2952	0	8,818,000,000	0.00
Elrama	3098	260,860,000	2,411,631,000	10.82
Seward	3130	0	1,131,014,000	0.00
Shawville	3131	0	3,780,447,000	0.00
New Castle	3138	0	1,502,285,000	0.00
Brunner Island	3140	0	7,764,372,000	0.00
Montour	3149	0	8,945,801,000	0.00
Armstrong	3178	0	1,481,879,000	0.00
Silas McMeekin	3287	0	1,518,441,000	0.00
Watertree	3297	0	4,127,259,000	0.00
Big Brown	3497	0	5,781,047,000	0.00
Carbon	3644	0	1,352,883,000	0.00
Clinch River	3775	0	4,081,107,000	0.00
Glen Lyn	3776	0	1,500,298,000	0.00
Potomac River	3788	0	1,972,332,000	0.00
Bremo	3796	0	1,327,251,000	0.00
Kanawha	3936	0	1,203,444,000	0.00
Rivesville	3945	0	166,616,000	0.00
Willow Creek	3946	0	856,091,000	0.00
Kammer	3947	0	4,709,260,000	0.00
Mitchell	3948	0	8,441,366,000	0.00
Nelson Dewey	4054	0	1,098,532,000	0.00
Pulliam	4072	0	1,755,690,000	0.00
Dave Johnston	4158	476,562	5,956,956,000	0.01
Naughton	4162	26,403,298	4,772,109,000	0.55
James Miller	6002	0	18,212,069,000	0.00
Pleasants	6004	186,487,000	8,165,553,000	2.28
Duck Creek	6016	67,470,240	2,168,113,000	3.11
Newton	6017	69,603,000	5,827,031,000	1.19
Sooner	6095	0	7,208,426,000	0.00
Welsh	6139	0	7,441,328,000	0.00
Martin Lake	6146	99,000,000	15,443,100,000	0.64
Monticello	6147	41,706,500	9,577,486,000	0.44
Rush Isl	6155	0	6,105,649,000	0.00
Coleto Creek	6178	0	3,991,045,000	0.00

Harrington	6193	0	7,559,039,000	0.00
Pawnee	6248	0	3,479,430,000	0.00
Mountaineer	6264	0	5,410,832,000	0.00
Belews Creek	8042	0	12,063,195,000	0.00
Jame M. Gavin	8102	430,705,000	14,135,869,000	3.05
Cheswick	8226	0	3,431,402,000	0.00

Appendix C to

Estimating Pollution Abatement Costs:
A Comparison of “Stated” and “Revealed” Approaches
(Not for publication)

Pollution Abatement Costs of 111 Coal-fired Power Plants in 1995

Plant Name	Plant ID Code	Lost Good Output (kWh)	$/kWh	MPAC ($1,000)	Lost Good Output / Net Generation (in percent)	SPAC-1 ($1,000)	SPAC-2 ($1,000)
Barry	3	0	0.0504	0	0.00	2,560	2,570
Gadsen	7	134,500,000	0.0504	6,778	34.98	183	183
Gorgas	8	0	0.0504	0	0.00	2,457	2,457
Limestone	298	0	0.0578	0	0.00	10,012	18,277
Araphoe	465	0	0.0588	0	0.00	0	1,243
Cherokee	469	0	0.0588	0	0.00	0	7,657
Comanche	470	0	0.0588	0	0.00	0	259
Brandon Shores	602	112,700,000	0.0608	6,854	1.24	837	7,032
Crist	641	256,100,000	0.0559	14,327	7.10	416	2,846
Hammond	708	76,200,000	0.0600	4,576	3.02	83	136
Harliee Branch	709	0	0.0600	0	0.00	932	932
Yates	728	116,700,000	0.0600	7,008	4.32	2,142	3,061
E.D. Edwards	856	0	0.0547	0	0.00	601	1,043
Coffeen	861	0	0.0497	0	0.00	1,839	2,920
Grand Tower	862	0	0.0497	0	0.00	319	687
Hutsonville	863	0	0.0497	0	0.00	178	313
Meredosia	864	0	0.0497	0	0.00	201	321
Kinkaid	876	356,400,000	0.0749	26,693	15.17	1,401	2,071
Powerton	879	690,200,000	0.0749	51,694	14.44	2,335	3,548
Will County	884	0	0.0749	0	0.00	2,819	4,421
Joppa	887	0	0.0187	0	0.00	244	244
Baldwin	889	0	0.0615	0	0.00	1,018	1,018
Havana	891	102,000,000	0.0615	6,273	6.70	61	61
Hennepin	892	0	0.0615	0	0.00	341	341
Wood River	898	0	0.0615	0	0.00	193	193
Clifty Creek	983	0	0.0159	0	0.00	2,909	4,542
Tanners Creek	988	437,000,000	0.0407	17,804	10.68	672	1,086
H.T. Pritchard	991	0	0.0493	0	0.00	240	240
Petersburgh	994	0	0.0493	0	0.00	10,631	10,631
Edwardsport	1004	0	0.0404	0	0.00	557	557
Gallagher	1008	0	0.0404	0	0.00	237	237
F.B. Culley	1012	0	0.0441	0	0.00	2,165	2,938

Lansing	1047	0	0.0497	0	0.00	190	299
Milton Kapp	1048	0	0.0497	0	0.00	174	1,106
Lawrence	1250	0	0.0465	0	0.00	1,707	2,088
Big Sandy Stream	1353	38,100,000	0.0313	1,194	0.52	1,049	1,511
E.W. Brown	1355	17,100,000	0.0391	668	0.72	387	387
Ghent	1356	0	0.0391	0	0.00	2,856	2,856
Green River	1357	0	0.0391	0	0.00	660	660
Mill Creek	1364	284,700,000	0.0452	12,881	3.86	18,947	19,132
R.P. Smith	1570	0	0.0477	0	0.00	219	271
Mt. Tom	1606	0	0.0287	0	0.00	60	697
B.C. Cobb	1695	2,400,000	0.0633	152	0.12	3,663	4,771
Marysville	1732	0	0.0732	0	0.00	0	186
Trenton Channel	1745	175,300,000	0.0732	12,840	4.70	0	1,845
Sly Laskin	1891	0	0.0373	0	0.00	20	20
Black Dog	1904	0	0.0507	0	0.00	381	665
High Bridge	1912	112,400,000	0.0507	5,701	12.30	218	383
Riverside	1927	273,900,000	0.0507	13,892	13.98	990	990
Hoot Lake	1943	0	0.0448	0	0.00	176	216
Asbury	2076	0	0.0490	0	0.00	129	129
Montrose	2080	0	0.0544	0	0.00	526	526
Labadie	2103	0	0.0543	0	0.00	1,539	1,539
Sioux	2107	607,200,000	0.0543	32,979	18.12	479	479
J.E. Corette	2187	0	0.0423	0	0.00	251	306
Goudey	2526	0	0.0809	0	0.00	84	240
Greenidge	2527	5,200,000	0.0809	421	0.76	104	186
Milliken	2535	0	0.0809	0	0.00	2,584	2,703
C.R. Huntley	2549	0	0.0850	0	0.00	0	430
Dunkirk	2554	0	0.0850	0	0.00	477	1,432
Rochester	2642	0	0.0873	0	0.00	0	637
Asheville	2706	0	0.0593	0	0.00	113	194
G.G. Allen	2718	20,000,000	0.0558	1,117	0.60	1,240	1,911
Cliffside	2721	472,500,000	0.0558	26,377	19.66	918	1,386
Marshall	2727	0	0.0558	0	0.00	1,250	3,524
R.M. Heskett	2790	0	0.0545	0	0.00	143	160
J.M. Stuart	2850	0	0.0607	0	0.00	2,667	3,392
R.E. Burger	2864	0	0.0728	0	0.00	468	888
Muskingum River	2872	0	0.0391	0	0.00	922	1,928
Kyger Creek	2876	0	0.0173	0	0.00	2,223	2,882
Muskogee	2952	0	0.0508	0	0.00	883	2,837
Elrama	3098	0	0.0756	0	0.00	6,290	10,345
Seward	3130	0	0.0601	0	0.00	872	872
Shawville	3131	0	0.0601	0	0.00	1,574	1,574
New Castle	3138	7,700,000	0.0625	481	0.51	423	606
Brunner Island	3140	0	0.0631	0	0.00	1,418	2,278

Montour	3149	0	0.0631	0	0.00	1,698	4,120
Armstrong	3178	0	0.0484	0	0.00	999	1,285
Silas McMeekin	3287	3,500,000	0.0561	196	0.23	59	731
Watertree	3297	0	0.0561	0	0.00	190	1,048
Big Brown	3497	0	0.0632	0	0.00	3,430	5,338
Carbon	3644	0	0.0427	0	0.00	433	583
Clinch River	3775	0	0.0430	0	0.00	1,009	1,799
Glen Lyn	3776	0	0.0430	0	0.00	72	1,441
Potomac River	3788	242,200,000	0.0674	16,332	12.28	1,494	2,169
Bremo	3796	39,500,000	0.0622	2,457	2.98	0	0
Kanawha	3936	38,200,000	0.0430	1,641	3.17	631	1,043
Rivesville	3945	0	0.0479	0	0.00	195	351
Willow Creek	3946	0	0.0479	0	0.00	762	866
Kammer	3947	0	0.0391	0	0.00	531	1,239
Mitchell	3948	35,900,000	0.0391	1,404	0.43	1,000	2,121
Nelson Dewey	4054	0	0.0459	0	0.00	270	325
Pulliam	4072	0	0.0442	0	0.00	683	1,299
Dave Johnston	4158	0	0.0427	0	0.00	2,650	3,736
Naughton	4162	0	0.0427	0	0.00	2,505	2,508
James Miller	6002	0	0.0504	0	0.00	2,569	2,771
Pleasants	6004	0	0.0479	0	0.00	18,161	20,287
Duck Creek	6016	0	0.0547	0	0.00	3,996	4,649
Newton	6017	0	0.0497	0	0.00	9,493	10,441
Sooner	6095	0	0.0508	0	0.00	697	933
Welsh	6139	0	0.0414	0	0.00	817	817
Martin Lake	6146	0	0.0632	0	0.00	25,097	32,142
Monticello	6147	0	0.0632	0	0.00	8,960	12,780
Rush Isl	6155	0	0.0543	0	0.00	790	790
Coleto Creek	6178	0	0.0573	0	0.00	153	349
Harrington	6193	0	0.0416	0	0.00	876	1,460
Pawnee	6248	0	0.0588	0	0.00	0	708
Mountaineer	6264	0	0.0430	0	0.00	1,858	2,905
Belews Creek	8042	0	0.0558	0	0.00	1,437	3,640
Jame M. Gavin	8102	0	0.0391	0	0.00	21,302	21,302
Cheswick	8226	0	0.0756	0	0.00	135	135

Appendix D

Estimating Pollution Abatement Costs:
A Comparison of “Stated” and “Revealed” Approaches

(Not for publication)

Regression results:
(1) lower SPAC-2 are associated with lower SPAC-1

			dep. variable =	SPAC-1
			indep. variable =	SPAC-2
Constant		-293.4215		
Std Err of Y Est		1162.8997		
R Squared		0.9236		
No. of Observations		111		
Degrees of Freedom		109		
X Coefficient(s)	0.8142			
Std Err of Coef.	0.0224			
t-stat	36.2918			
	SPAC-2			

(2) lower SPAC-2 are associated with higher MPAC

			dep. variable =	MPAC
			indep. variable =	SPAC-2
Constant		2473941.763517		
Std Err of Y Est		7456178.752218		
R Squared		0.000016		
No. of Observations		111		
Degrees of Freedom		109		
X Coefficient(s)	-5.9503			
Std Err of Coef.	143.8517			
t-stat	-0.0414			
	SPAC-2			

(3) lower PM-10/kWh and SO_2/kWh are associated with higher MPAC

			dep. variable =	MPAC	
			indep. variable =	PM10/KWH	SO2/KWH
Constant		4164224.7711			
Std Err of Y Est		7375074.8615			
R Squared		0.0306			
No. of Observations		111			
Degrees of Freedom		108			
X Coefficient(s)	-42881681.7531	-1034432.3022			
Std Err of Coef.	29385263.2274	985407.7355			
t-stat	-1.4593	-1.0498			
	PM10/KWH	SO2/KWH			

(4) higher PM-10/kWh and lower SO_2/kWh are associated with higher SPAC-2

			dep. variable =	SPAC-2	
			indep. variable =	PM10/KWH	SO2//KWH
Constant		4103.3953			
Std Err of Y Est		4797.6903			
R Squared		0.0747			
No. of Observations		111			
Degrees of Freedom		108			
X Coefficient(s)	25851.5461	-1728.1248			
Std Err of Coef.	19115.9269	641.0350			
t-stat	1.3524	-2.6958			
	PM10/KWH	SO2/KWH			

(5) lower PM-10/kWh and SO_2/kWh are associated with higher kWh

			dep. variable =	KWH	
			indep. variable =	PM10/KWH	SO2/KWH
Constant		5739782319.0843			
Std Err of Y Est		3885559603.2861			
R Squared		0.0571			
No. of Observations		111			
Degrees of Freedom		108			
X Coefficient(s)	-11188035687.5794	-1251332517.8541			
Std Err of Coef.	15481631559.3934	519162254.1815			
t-stat	-0.7227	-2.4103			
	PM10/KWH	SO2/KWH			

(6) higher SPAC-2 are associated with higher kWh

			dep. variable =	SPAC-2 =
			indep. variable =	KWH
Constant		-37.1062		
Std Err of Y Est		4209.2862		
R Squared		0.2811		
No. of Observations		111		
Degrees of Freedom		109		
X Coefficient(s)	0.000001			
Std Err of Coef.	0.000000			
t-stat	6.529188			
	KWH			

(7) lower kWh are associated with higher MPAC

			dep. variable =	MPAC
			indep. variable =	KWH
Constant		3028259.9166		
Std Err of Y Est		7437718.4443		
R Squared		0.0050		
No. of Observations		111		
Degrees of Freedom		109		
X Coefficient(s)	-0.000132			
Std Err of Coef.	0.000179			
t-stat	-0.737200			
	KWH			