Least-Cost Air Pollution Control: A CGE Joint Production Framework

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Abstract

This study proposes a new, more flexible approach to modeling pollution abatement activities within the CGE framework, one that treats the problem as an issue of the joint production of "good" and "bad" outputs. More specifically, this study employs a joint production technology to derive the production possibilities frontier for those industries producing both "good" and "bad" outputs. This avoids some of the difficulties associated with attempting to model separate technologies for production of the good output and pollution abatement activities. We demonstrate an application of the CGE model by estimating the cost associated with not pursuing least-cost strategies for abating air pollutants in the United States.

I. Introduction

Application of computable general equilibrium (CGE) models to environmental policy analysis has become commonplace (see Atkins and Garbaccio 1999, Conrad 1999, 2002). CGE models appeal to policymakers because of their ability to capture distributional consequences and identify sectors disproportionately affected by environmental standards. For example, CGE analyses of the economic consequences of measures to reduce greenhouse gas emissions has played a key role in understanding the potential economic consequences of policies aimed at reducing greenhouse gas reductions.

In this study, we develop a CGE model that extends previous work by specifying a flexible approach to incorporating emissions and pollution abatement processes. More specifically, we follow a two-step process. The production technology associated with those sectors producing both good and bad outputs are specified is modeled as a joint production technology through the use of distance functions. We specify and estimate the joint production technology as a translog distance function (see Färe et al 1993). The distance function is a multi-output production technology that specifies the technical relationship between good outputs and bad outputs. Once the distance function is estimated, it can be used to calculate producer shadow prices for emissions for any point on the production frontier.[1] These shadow prices reflect the opportunity cost (i.e., marginal abatement costs) in terms of foregone revenue to the producer of reducing emissions by one unit. Using a data set for 1970 through 1996 which consists of inputs, marketable outputs ("good" outputs), emissions of sulfur dioxide (SO_2) and particulate matter less than ten microns in diameter (PM-10), we estimate the joint production

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[1] Throughout this study, the "good" output is the marketed output produced by an industry and the "bad" outputs are pollutants emitted by an industry.

technology for the manufacturing sector. This allows us to establish a joint production technology based on observed data as opposed to engineering data for each polluting sector. The important advantage of this approach is that it avoids the problem of modeling pollution abatement technologies separately from the technologies used to produce the good output. This is interesting from a policy perspective because in recent years there has been an increasing use of changes in the production process as opposed to using end-of-pipe abatement technology as a means of reducing emissions.[2] This makes modeling separate pollution abatement technologies an increasingly difficult task. We demonstrate how to model joint production technologies within a CGE framework by calculating the least cost policy to reducing air pollutants in the U.S.

The remainder of this study is organized as follows. Section II reviews previous CGE analyses of environmental regulation and describes how they modeled emissions and pollution abatement. Section III briefly outlines the distance function approach to specifying the joint production technology, while Section IV describes the features of our CGE model of the U.S. economy. Section V presents the results of our analysis and Section VI presents conclusions.

II. Modeling Emissions and Pollution Abatement Activities within an Applied General

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[2] Studies that estimate the economic effects of environmental regulations typically use estimates of the pollution abatement costs incurred by the manufacturing and electric utility sectors. One difficulty associated with these data is measuring “change in production process” capital expenditures for pollution abatement (i.e., the built-in pollution abatement features of a production process). These expenditures for pollution abatement have become increasingly important relative to “end-of-pipe” capital expenditures. For example, “change in production process” as a share of manufacturing air pollution abatement capital expenditures increased from 17.4 percent in 1973 to 48.3 percent in 1994 (U.S. Bureau of the Census, 1976, p. 47 and 1996, p. 25).

Equilibrium Framework: Review of the Literature

The first efforts to incorporate emissions and pollution abatement activities into general equilibrium models were primarily theoretical. Ayres and Kneese (1969) represents the first effort to incorporate emissions and abatement activities into a theoretical general equilibrium framework. Empirical work on this topic originates in the input-output literature (see Leontief, 1970). Pearson (1989) surveyed environmental applications of input-output analysis and Hafkamp (1991) surveyed studies incorporating emissions into economic models.

One class of CGE models introduces bad outputs by modeling them as a constant proportion of the good output (see Robinson (1990), Robinson, Subramanian, and Geoghegan (1993), Goulder (1994), Smith and Espinosa (1996), and Lee and Roland-Holst (1997)). As a result, this approach requires either fixed input-output coefficients or it does not allow for fuel combustion emissions. Hence, for a given level of production of the good output, it does not allow for substituting away from fuel consumption toward capital may reduce emissions. If input-output coefficients are not fixed, modeling emissions as a constant proportion of good output within the CGE framework implicitly assumes all emissions are "process" emissions for which no abatement technologies exist.[3] Thus, this approach fails to allow for the possibility that industry may respond to environmental regulations by installing equipment that reduces the production of the bad output per unit of production of the good output (i.e., produce fewer emissions per unit of its marketed output). As a result, the only available abatement strategy is to reduce production of the good output.

For a CGE analysis of Costa Rica, Dessus and Bussolo (1998) link emissions to the

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[3] Manufacturing emissions are produced by either fuel combustion or processes.

consumption of polluting inputs. This specification allowed for the substitution of nonpolluting inputs for polluting inputs. This is analogous to how CO_2 emissions are modeled.

Two approaches have been employed to model pollution abatement activities within a CGE framework.[4] The first approach models pollution abatement activities separrately from the technology associated with the production of the good output. Bergman (1991) developed a CGE model that specified increasing marginal abatement costs for CO2 emissions. His strategy was followed by Conrad and Schröder (1991a, 1991b, 1993, 1994). Robinson, Subramanian, and Geoghegan (1994) assume fixed coefficient production functions for the abatement technologies with identical marginal abatement costs across sectors. Dellink (2000) and Dellink et al (2002) extended Bergman's approach by calibrating a pollution abatement function. For a CGE analysis of China, Xie and Saltzman (2000) assume production of the bad output is directly linked with production of the good output; and abatement activities are modeled separately from production of the good output. For a CGE analysis of India, Nugent and Sarma (2002) also model the production of the good output and associated generation of bad outputs separately from pollution abatement activities.

The second approach used to model pollution abatement activities involves modeling pollution control costs, but excludes explicitly modeling the generation and abatement emissions. Jorgenson and Wilcoxen (1990a and 1990b) assume that an industry's production function for pollution abatement directly mirrors the production function for its good output, or equivalently, is represented in the economy as a Hicks-neutral cost increase (see Wilcoxen,

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[4] Some of these efforts rely on engineering estimates of alternative production technologies rather than actual data; while others invoke important assumptions regarding pollution abatement processes.

1988, p. 35). Hazilla and Kopp (1990) invoke a similar assumption. Ballard and Medema (1993) assumed that pollution abatement activities involve only purchases of capital and labor. Nestor and Pasurka (1995b) use detailed data on the specific inputs used for pollution abatement, and attempt a more accurate modeling of the general equilibrium effects of pollution abatement activities in Germany. In addition, Nestor and Pasurka (1995a) investigated the consequences of difference assumptions about the inputs employed by the abatement technology. This approach has been primarily used in *ex post facto* analyses of regulations.

While the approaches to modeling pollution abatement processes separately are varied, increasingly they must confront the issues associated with the fact that an increasing share of pollution abatement activities are not “end-of-pipe.” This makes modeling a separate pollution abatement function an ever more difficult problem. In addition, survey estimates of the costs associated with pollution abatement activities are also subject to increasing scrutiny. Even when pollution abatement activities are end-of-pipe, Färe, Grosskopf, and Pasurka (2002) found substantial differences between survey (i.e., accounting) estimates of pollution abatement operation and maintenance (O&M) costs and the opportunity costs of pollution abatement activities that are derived from modeling the joint production of good and bad outputs. This study proposes a way of avoiding this problem by specifying a more flexible approach to modeling pollution abatement within a CGE framework, one that treats the problem as an issue of the joint production of good and bad outputs. The following section describes the approach specified in this study to model pollution generation and abatement activities.

III. Joint Production Model and Pollution Abatement Activities

For those industries that produce at least two outputs (one good and one bad), it is not possible to specify a traditional production function. Instead, distance functions and directional distance functions have been used to specify both the non-parametric and the parametric production technologies. In this study we calibrate the joint production technology by estimating a translog (i.e., parametric) distance function and then using those results to calibrate the CGE model.

There are several advantages of modeling the joint production of good and bad outputs. One advantage is that it does not require information on pollution abatement technologies and their associated costs. Hence, there is no need to estimate the inputs associated with a particular pollution abatement activity nor is it necessary to estimate the quantity of emissions abated as a consequence of that pollution abatement activity. Instead, the cost of pollution abatement activities is captured by the reduced production of the good output that occurs as a result of inputs being reallocated to pollution abatement activities. Another advantage of modeling the joint production of good and bad outputs is that it avoids the difficulties encountered by survey efforts to measure the costs associated with "change in production process" pollution abatement techniques. In the joint production model, the synergies in the abatement process of two or more pollutants are automatically handled by the production technology. Pollution abatement functions require information on the synergies that exist among various pollution abatement processes. Finally, the distance function methodology estimates the joint production technology and associated producer shadow prices based on the actual behavior producers and not on engineering estimates.[5]

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[5] Kolstad and Turnovsky (1998, p.445, footnote #1) expressed concern that the endogenity and simultaneous equation bias problems associated with the econometric estimation of production functions also apply to the LP estimation of distance functions. However, such biases may not be

There are two approaches to modeling the joint production of good and bad outputs. One approach assumes a non-parametric piece-wise linear production technology (see Färe, Grosskopf, and Pasurka (1986 and 1989)). The joint production framework was first used by Kohn (1975, pp. 29-37) to investigate the costs of pollution abatement activities. Brännlund, et al. (1998) specified a non-parametric distance function (i.e., an activity analysis) within a partial equilibrium framework in order to estimate the cost savings associated with an emissions trading program. Willett (1985) had already specified a theoretical general equilibrium model that incorporated emissions into the CGE model by using an activity analysis specification of the production technology. Using a CGE model, Komen and Peerlings (2001) specified input-output vectors representing three technologies (two active and one latent) that are available to the dairy farming sector representing different mixes of good and bad outputs.

Figure 1 illustrates the simplified case where the production process generates one good output (Q) and one bad output (e) from a vector of inputs. When using an activity analysis framework, a finite number of production processes exist for a given vector of inputs. Each process is represented by a ray from the origin that represents different combinations of good and bad outputs which can be produced by a given technology. In Figure 1, three processes (T1, T2, and T3) are available to the producer. Steeper rays (e.g., T1) represent production technologies that allocate relatively more inputs to pollution abatement activities, while a relatively flat ray (e.g., T2) represents a production technology with fewer inputs devoted to

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as significant as previously believed. For example, Coelli (2000) provides evidence that the simultaneous equation bias associated with the OLS estimation of production functions may notbe as severe as previously believed and Coelli and Cuesta (2001) provide evidence that the simultaneous equations bias of the econometric estimation of distance functions is no worse than the bias associated with estimation of production functions in general.

pollution abatement activities. Once the vector of inputs is known, it is possible to determine the combination of good and bad outputs that a process can produce (i.e., points a, b, c).

The points on the frontier represent the different combinations of good and bad outputs that can be produced with a given vector of inputs. It is possible to construct linear combinations of the different production processes. For the case of one good output, one bad output, and a single input, the production unit will use the two processes to efficiently produce a given combination of good and bad outputs. In Figure 1, process T1 can be used to produce bundle represented by point x and process T2 can be used to produce bundle represented by point y. Combining these two output bundles yields point z on ray ab (adopted from Kohn, 1975).

In our model, emissions decrease as inputs are shifted from production of the good output to pollution abatement activities. The "output" of the pollution abatement activities is the reduced production of the bad output (i.e., emissions) for a given vector of inputs. In Figure 1, the line segments labeled 0abc represent the economically relevant portion of the piece-wise linear production-possibilities frontier consisting of the good and bad outputs. A consequence and limitation of specifying an activity analysis framework is that the production possibility frontier for the good and bad outputs is piece-wise linear.

A second approach used to model the joint production of good and bad outputs specifies a parametric production technology. Most empirical studies that specify a parametric distance function have used a translog function (see Färe et al., 1993); however, recently a quadratic production technology was specified (see Färe, Grosskopf, and Weber 2001) . The advantage of specifying a translog distance function is that the production frontier is smooth.

While McKitrick (1998) and Perroni and Rutherford (1998) discuss the merits of different functional forms used in CGE models with good outputs, there is no comparable discussion regarding the proper modeling of the joint production of good and bad outputs within a CGE framework. Perroni and Rutherford (1995) describe an n input production technology can be approximated by a nonseparable nested constant elesticity of substitution (NNCES) functional form.[6] Perroni (1999) extends Perroni and Rutherford (1995) by describing an m output n input production technology can be approximated by a NNCES / constant elasticity of transformation (CET) restricted profit function. Jensen, Kristensen, and Nielsen (1999) estimated a multiple good output NNCES cost function. However, there has been no investigation of the feasibility of extending the NNCES technology to the case of the joint production of good and bad outputs.

We specify a parametric translog distance function in order to obtain parameter estimates for those industries that produce good and bad outputs (see Färe et al., 1993, for a detailed discussion of the application of distance functions to model good and bad outputs). In particular, we consider a production unit that produces outputs $Q = (Q_1, Q_2, ..., Q_m)$ using inputs $X = (X_1, X_2, ..., X_n)$ at each period of time $t = 1, ..., T$. Of the outputs, $i = 1, ..., k$ represent emissions (bad outputs) while $i = k+1, ..., m$ represent good outputs. We assume weak disposability of outputs and constant returns to scale. Thus, the technology is represented as an output distance function:[7]

$$(1) \qquad D_o(X, Q) = \min_{\omega} \left\{ \omega : \frac{Q}{\omega} \in G(X) \right\}$$

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[6] Rutherford (1995) provides insights into calibrating an NNCES function.

[7] See Shephard (1970) or Färe (1988)

where G(X) is the set of technically feasible output vectors that employ input vector X and Q 0 G(X) when $D_o(X, Q)$ # 1. The output distance function measures the greatest possible radial expansion of output bundle Q to the production possibilities frontier for a given input bundle X. When $D_o(X, Q) = 1$, the producer is maximizing the production of the good and bad outputs for a given level of inputs. Hence, the producer is technically efficient. When $D_o(X, Q) < 1$, then the producer is producing "inside the frontier," or is technically inefficient. One advantage to using the output distance function as opposed to a production function representation of technology is that it easily models the joint production of multiple outputs.

The duality between the output distance function and the revenue function allows the derivation of producer shadow prices for the bad outputs. Since the distance function is equivalent to the revenue function at the revenue maximizing output price vector, applying Shephard's dual lemma yields revenue deflated (i.e., normalized) output shadow prices (P^*) as follows

$$(2) \qquad \frac{\mathrm{M}D_o(X,\ Q)}{\mathrm{M}Q_i} = P_i^{(}(X,\ Q), \quad i = 1,\ ...,\ m$$

The undeflated (i.e., absolute) shadow prices (P) can be expressed as the product of the revenue function and the deflated shadow price (P*). Hence, when the revenue function is known, P can be computed. The difficulty in computing P is the revenue function depends on P, which are unknown. However, if we assume the observed price for the good output is equal to its undeflated shadow price, then the revenue function is the ratio of its undeflated and deflated shadow prices. It is assumed that the undeflated shadow price of Q_m, which represents a good output, is equal to its observed market price (P_m).[8] The remaining undeflated shadow prices (P_1, P_2, ..., P_{m-1}) are calculated

$$(3)\ \ P_i \ = \ \frac{P_m}{P_m^{(}(X,\ Q)} P_i^{(}(X,\ Q) \ = \ P_m \frac{\partial D_o(X,\ Q)/\partial Q_i}{\partial D_o(X,\ Q)/\partial Q_m}, \quad i \ = \ 1,\ ...,\ m\text{-}1$$

Equation (3) states the undeflated shadow price of an bad output equals/is the product of the actual product of the price of the good output (P_m) and the marginal rate of transformation (MRT). The MRT is the quantity of the good output that must be foregone in order to reduce the quantity of an bad output by one unit. The undeflated shadow price of an bad output is negative, which reflects the opportunity cost (i.e., in terms of foregone revenue) of reducing production of the bad output.

According to equation (3), the absolute shadow price of the bad output for an inefficient producer is determined by making a radial projection to the production possibilities frontier from the observation.[9] The shadow prices of the bad outputs associated with that observation are calculated at that point on the frontier. Hence, the absolute shadow price reflects the actual proportions of good and bad outputs produced by an inefficient producer.

Figure 2 provides a representation of these concepts for the case of the production of one good output (Q_2) and one bad output (Q_1). Figure 2 illustrates that the firm cannot decrease production of Q_1 without decreasing Q_2, and that technology satisfies weak disposability. The

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[8] To the extent that markets are not perfectly competitive, or there are subsidies or taxes, the assumption that the price of the good output equals its shadow price is inaccurate.

[9] The radial projection assumes a proportional expansion of all good and bad outputs for a given input vector until the production possibilities frontier is attained.

output distance function measures the proportion by which both Q_1 and Q_2 can be increased with the original input vector, while using the original production process (i.e., this radial projection maintains the initial ratio of the good to bad outputs). For the combination of output depicted by point a, the value is given by the ratio 0a/0b. Figure 2 illustrates the condition for optimality, or that the ratio of the output prices P_1 and P_2 must equal the slope of the distance frontier. This condition holds even if an observation is inefficient, so the methodology for assigning shadow prices is not sensitive to the existence of technical inefficiency.

For purposes of estimating the shadow prices, we follow Färe et al. (1993) and specify a translog output distance function. For a panel consisting of s=1,. . ., S industries observed over t=1,. . ., T years the distance function has the form:

$$\begin{aligned}\ln D_o^t(X^{s,t},\ Q^{s,t}) \ &= \ \alpha_0 + \sum_{j=1}^{n} \beta_j \ln X_j^{s,t} + \frac{1}{2}\sum_{j=1}^{n}\sum_{j=1}^{n} \beta_{jj} \ln X_j^{s,t} \ln X_j^{s,t} + \sum_{i=1}^{m} \omega_i \ln Q_i^{s,t} \\ (4) \qquad &+ \frac{1}{2}\sum_{i=1}^{m}\sum_{i=1}^{m} \omega_{ii} \ln Q_i^{s,t} \ln Q_i^{s,t} + \sum_{i=1}^{m}\sum_{j=1}^{n} \varphi_{ij} \ln X_j^{s,t} \ln Q_i^{s,t} + \nu_t t + \frac{1}{2}\nu_{tt} t^2 + \sum_{j=1}^{n} \beta_{jt} t \ln X_j^{s,t} \\ &+ \sum_{i=1}^{m} \omega_{it} t \ln Q_i^{s,t} + \sum_{k=1}^{s} \tau_k DI_k \ , \qquad s = 1,...,S;\ t = 1,...,T.\end{aligned}$$

where X_1, X_2, X_3, represent capital, labor and an aggregate intermediate input, respectively. Q_1, Q_2, Q_3, represent production of the good output, PM-10 emissions and SO_2 emissions, respectively. Finally, the industry dummy variables, DI_s, capture industry-specific effects and t is a time trend variable. Since a single distance function is estimated, input and output substitution possibilities are constant over time and across industries.

We estimate (11) as a linear programming (LP) problem. Specifically, for observations t = 1, ..., T, and s = 1,..., S, we maximize:

$$(5) \qquad \sum_{t=1}^{T} \ln D_o^t(X^{s,t}, Q^{s,t})$$

subject to the following constraints:

$$(6i) \quad \ln D_o^t(X^{s,t}, Q^{s,t}) \le 0, \quad s = 1,\dots,S; \quad t = 1,\dots,T$$

$$(6ii) \quad \frac{\partial \ln D_o^t(X^{s,t}, Q^{s,t})}{\partial \ln Q_i^{s,t}} \le 0, \ \ \mathrm{i = 1, ..., k; \ \ s = 1,...,S; \ \ t = 1,...,T}$$

$$(6iii) \quad \frac{\partial \ln D_o^{s,t}(X^t, Q^{s,t})}{\partial \ln Q_i^{s,t}} \ge 0, \ \ \mathrm{i = k+1, ...m; \ \ s = 1,...,S; \ \ t = 1,...,T}$$

$$(6iv) \quad \frac{\partial \ln D_o^{s,t}(X^t, Q^{s,t})}{\partial \ln X_j^{s,t}} \le 0, \ \ \mathrm{j = 1, ...n; \ \ s = 1,...,S; \ \ t = 1,...,T}$$

$$(6v) \quad \sum_{i=1}^{m} \omega_i = 1, \ \sum_{i=1}^{m} \omega_{ii'} = \sum_{i=1}^{m} \beta_{ij} = \sum_{i=1}^{m} \omega_{it} = 0, \ \ \mathrm{i=1,...,m; \ \ j=1,...,n; \ \ t = 1,...,T}$$

$$(6vi) \quad \begin{array}{l} \beta_{jj'} = \beta_{j'j}, \quad j = 1,\dots,n, \quad j' = 1,\dots,n \\ \omega_{ii'} = \omega_{i'i}, \quad i = 1,\dots,m, \quad i' = 1,\dots,m \end{array}$$

The first constraint forces observations to fall on or within the production frontier. Constraint (6ii) restricts the shadow prices of the bad outputs must be non-positive while constraint (6iii) restricts the shadow prices of the good outputs to be nonnegative.

The constraints in (6iv) impose monotonicity on each input for all observations. Because the output distance function exhibits monotonicity when it is non-increasing in the inputs, for fixed quantities of the good and bad outputs, more inputs decreases the value of the distance function (i.e., decreases technical efficiency). The constraints in (6v) impose homogeneity of +1 in the outputs. This assures that as outputs expand proportionately for a given input vector and technology, the value of the distance function increases in the same proportion. This ensures the outputs are weakly disposable. The constraints in (6vi) impose the usual symmetry conditions. The specification of (4) allows for neutral and biased technical change. The effect of neutral technical change is captured by the ν_t and ν_{tt} parameters. The extent of biased technical change is estimated by the β_{jt} parameters, and the effect of changes in output (i.e., scale augmenting technical change) is estimated by the ω_{it} parameters.

In the next section, we specify a simple CGE model of the United States.

IV. The CGE Model

In many respects, our model is a standard CGE model of an open economy.[10] The United States is assumed to be a small country and there is a flexible exchange rate. We use the standard Armington assumption that imports are imperfect substitutes in both production and consumption. Elasticities of primary factor substitution and elasticities between domestic and imported goods are constructed on the basis of the elasticities presented in Harrison, Rutherford, and Wooton (1991). The economy is comprised of producing sectors, a household sector, government, and a foreign sector. All markets operate under conditions of perfect competition.

Given income from the sale of capital and labor, households choose a consumption bundle consisting of foreign and domestically produced good output and maximize utility subject to a budget constraint. We assume that environmental quality does not enter the representative

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[10] The details of the formal model and data sources are provided in an appendix available upon request from the authors.

household's utility function. The allows us to avoid issues involved with incorporating the benefits of pollution abatement activities into the model.

Nested Cobb-Douglas and CES functions are specified for the energy, materials, and services components of the estimated KLEMS production technology for each sector of the economy. Wilcoxen (1988, pp. 122-123) discusses which intermediate input industries are contained in the energy and materials components of the KLEM model specified in his study. The energy, materials, and services sectors consist of nested Cobb-Douglas and CES functions.

For non-polluting sectors, production is represented as a hierarchy of Cobb-Douglas and CES production functions. The distinguishing feature of our CGE model is calibrating distance functions to model the joint production of good and bad outputs. As with Willett (1985), we specify a model in which each polluting sector has available a production technology that allows different combinations of good and bad outputs to be produced by a given vector of inputs. However, Willett assumed a piece-wise linear production technology in which difference processes are represented by different coefficients associated with the inputs and outputs. In this study, we employ a translog distance function in order to accomplish the same effect.

In addition to modifying the production technology, a separate constraint establishes limits on production of the bad output whose production is regulated. These constraints show the maximum amount of the bad output that the economy is allowed to produce. Initial ownership of permits can be established by either grandfathering ownership of the permits or allowing the government to auction the permits to polluters and then distribute the revenues to the representative household as a lump-sum transfer.

V. Data and Results

In order to provide greater flexibility in our specification of the joint production technology, we specify and estimate a translog distance function for nineteen two-digit SIC manufacturing industries using data from 1970 to 1996.[11] Aiken and Pasurka (2002) estimated translog distance functions with two bad outputs (SO_2 and PM-10) and three inputs: capital, labor, and an aggregate intermediate input. In this study, we estimate a translog distance function with two bad outputs (SO_2 and PM-10) and the three inputs: capital, labor, and an aggregate intermediate input consisting of energy, materials, and services. A translog distance function is estimated using panel data for nineteen of the twenty two-digit SIC manufacturing industries for 1970 to 1996. The parameters of translog distance function are used to calibrate the joint production technology of those industries producing good and bad outputs in the CGE model.

Aiken and Pasurka (2002) discuss the estimation of the translog distance function in greater detail.

The 1992 benchmark input-output table and the associated SO_2 and PM-10 emissions serve as the basis of the CGE model calibrated in this study. For sectors that emit SO_2 and PM-10, translog production technologies are specified. Non-polluting sectors are assumed to produce the good output using nested Cobb-Douglas and CES production functions as described above. In the simulations, it is assumed that ownership of the permits to pollute are given to the representative household which sells the permits to the polluting sectors. An alternative distribution of the permits is to grandfather ownership of the permits based on observed level of

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[11] There are actually twenty two-digit SIC manufacturing industries; however, the U.S. Bureau of Labor Statistics (BLS) does not publish productivity data for SIC 21 (tobacco products).

emissions. The industries would then be allowed to buy and sell the permits among themselves. Since there is no connection between emissions and consumer welfare, there households have no demand function for the permits.

Table 2 presents the results.[12]

VI. Summary and Directions for Future Research

The study represents an initial investigation into the feasibility of modeling the joint production of good and bad outputs within a CGE framework. The translog distance function specification provides flexibility in modeling the production technologies while avoiding the somewhat arbitrary nature of specifications of the production technology employed by previous studies. As an increasing percentage of pollution abatement efforts involve change in production processes, the advantages associated with specifying a joint production model in order to depict the production technology for a sector becomes apparent.

In order to provide insights into the consequences of specifying an alternative production technology, we could estimate the least cost solution when we assume a fixed bad-good output ratios for all polluting sectors and a CES production technology for all sectors are employed to determine the least cost results. The results of this simulation is representative of previous modeling efforts and provides a means of comparing the results of the model employed in this study with an alternative specification of the joint production technology.

The joint production modeling approach allows us to undertake a retrospective study of the cost of environmental regulations without using survey estimates of pollution abatement costs. We accomplish this by solving the model under the assumption “bad” outputs are freely

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[12] We solve the model using GAMS (see Rutherford 1999).

disposable. We calculate the cost of environmental regulations in terms of the reduction in the level of the "good" output. In addition, we use the model to compare that cost with the good output lost due to the allocative inefficiency of environmental regulations. Allocative inefficiency is the increased cost of attaining a given level of emissions using a command and control strategy instead of a least cost strategy (i.e., through permits). This provides an estimate of the percentage reduction in pollution abatement costs that can be achieved simply by pursing a least-cost strategy.

This study demonstrates pollution abatement activities and emissions can be incorporated into a CGE model. In fact, the joint production of good and bad outputs has been specified in CGE models such as Jensen and Rasmussen (2000) to estimate the costs associated with proposed reductions in CO_2 emissions. The treatment of CO_2 emissions in CGE models are revealed to be a special case of the more general model specified in this study.

Incorporating a translog parametric distance function that represents the joint production technology presents problems for the solution of CGE models. Unfortunately, solutions to CGE models with translog distance functions are not guaranteed. In order to make this approach practical, it will be necessary to determine which parametric specification of the production function will be well behaved and will allow CGE models to converge to meaningful results. One possible solution to the convergence problem is extending Peronni (1999) to develop nonseparable nested CES (NNCES) functions for the case when multiple outputs includes good and bad outputs. This would allow GAMS/MPSGE to solve the joint production CGE model developed in this study.

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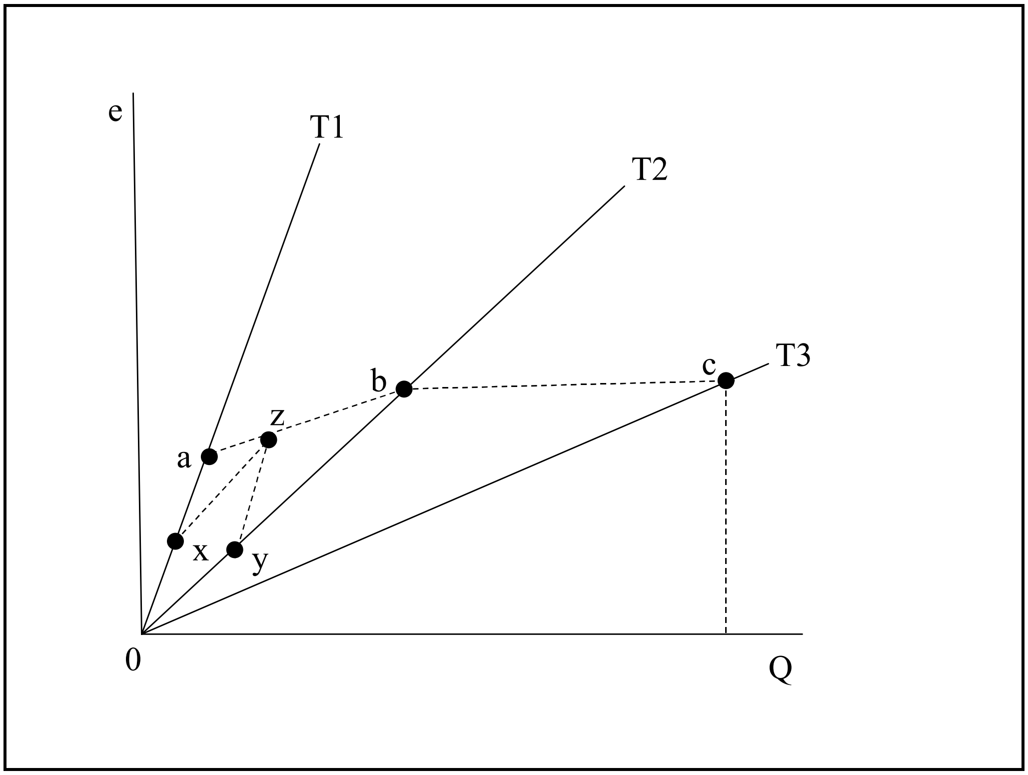
Figure 1
Piece-wise Linear Joint production Technology



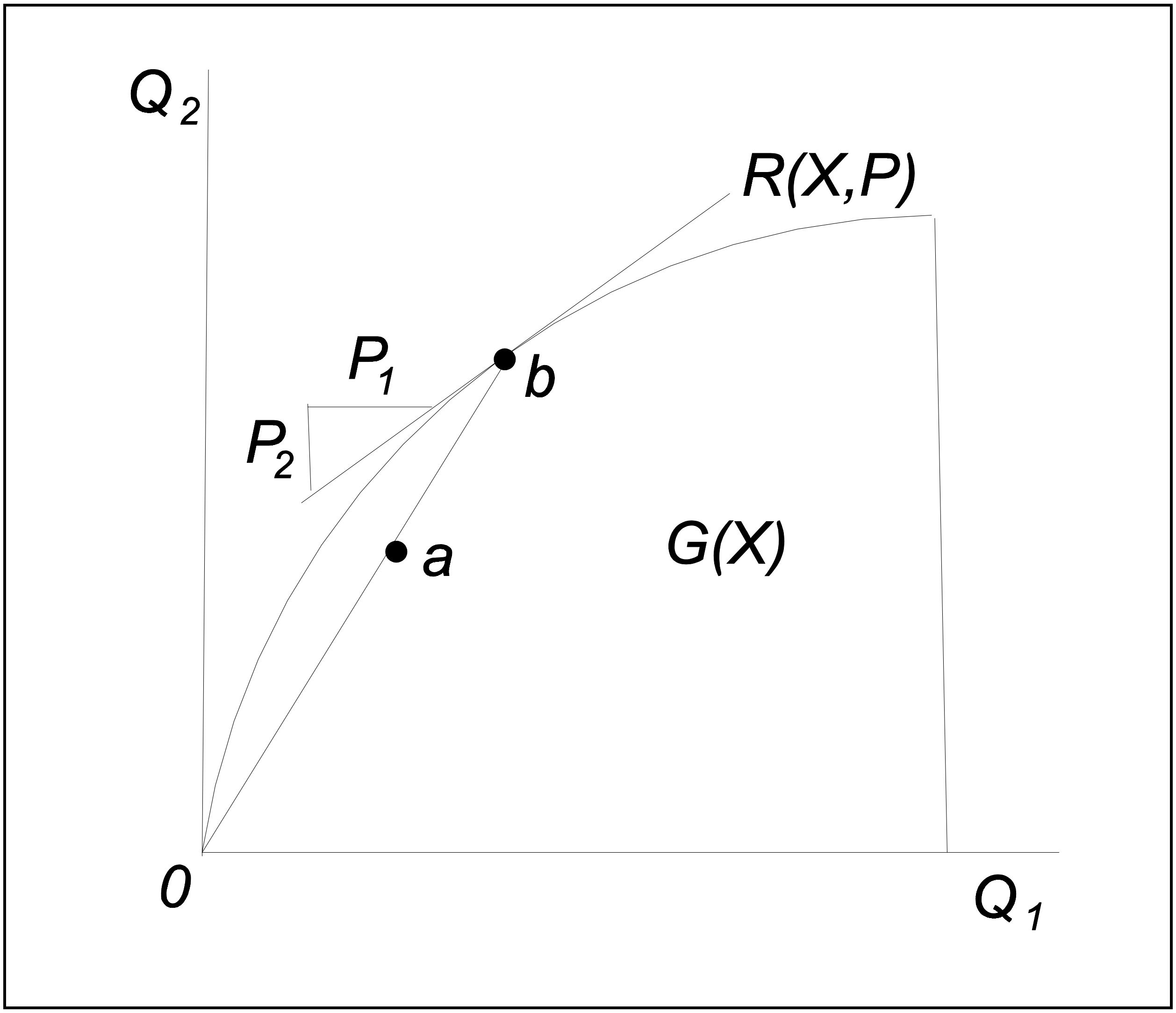


Figure 2

Shadow Price of Bad Output