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The demand for and marginal cost of air pollution abatement: An implicit market analysis

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CHAPTER I. ABSTRACT

An estimable model of the demand for and marginal cost of air pollution abatement as a public good is proposed. The model is derived from economic theory, employing median voter dominance for the demand side and cost minimizing behavior on the marginal cost side. Price and income elasticities are estimated and compared with estimates from other studies that use different approaches.

CHAPTER II. INTRODUCTION AND BACKGROUND

Air quality can be thought of in at least two ways. One, it can be viewed as the inverse of air pollution. Air pollution, in turn, can be considered an externality, in the context of joint production of a private good and a public good (or in this case, a public "bad"). Another approach, taken here, would be to consider air quality a positive public good demanded in the form of air pollution abatement. As a public good, air pollution abatement is nonrival in consumption and it is not feasible to exclude nonpayers. Under these conditions, the private market will not function. This public good is demanded by the public and provided by a figurative joint firm of the state government and private industry. By joint firm it is meant that the state government and private industry work collaboratively to abate emissions. The state government provides the inspection, monitoring and other enforcement of federal, state and local air pollution laws, while private industry, in response to governmental regulations and enforcement of those regulations, makes the necessary investment to control emissions to achieve desired air quality.

Air pollution can be considered either from the standpoint of a stock, by which abatement reduces, or a flow, in that new emissions are either abated or somehow "consumed" or dissipated. Both viewpoints are maintained in this study. That is, air pollution emissions and the attendent abatement begin each year with a soiled environment on January 1 and both the level of abatement during the year and the stock of pollution from the previous year are relevant; there are carryovers of stocks of air pollutants from year to year such that they influence people's demand for air quality. Accordingly, this way of looking at air quality is as tons of emissions abated by the state governments and private industry given the ambient air pollution level. For example, suppose that citizen preferences for clean air increase through say, some environmental awareness campaign. Industry in that state had been dumping 300,000 tons of particulates a year into the air. Now only 200,000 tons a year is considered acceptable. Through governmental action (in response to citizen demands, stricter emissions regulations are enacted and enforced) and industry investments (in new air pollution abatement equipment and workers to run it) an additional 100,000 tons per year is abated rather than be released into the atmosphere. The greater the preferences for clean air, ceteris paribus, the larger the number of tons will be abated.

The central problem with any air pollution abatement model is that there is no market for air pollution abatement. There are no prices but the amount of air pollution abatement provided can be quantified. Adding to the difficulties are the problems of public good demand revelation and the process of public good supply.

Taking the demand revelation first, Freeman (14, p. 62) catalogs three different approaches to public good demand. The first is to ask people to reveal their preferences, their willingness to pay for different quantities of a public good. This could be done with surveys or interviews. The problem with this is, of course, that there exist incentives for individuals to understate their actual demand, to be a "free rider", if they feel their responses will have an effect on how much they must pay. A second approach is to use the relationship between public and private goods in consumption (or in production) and to use the private good's market data (price and quantity) to make estimates of public goods demand. This is referred to as the hedonic price technique. The third approach is to decide the level of public good provision through voting. The different proposals put forth by political parties and candidates will, in the long run, tend to be grouped around the preferences of the median voter. Each voting district can then be taken as a sample unit, with the amount of the public good supplied approximating the median voter's preferences.

The process of public good supply is ill-understood, and no completely satisfactory models exist. This task is made more complex by the joint-production nature of air pollution abatement (government and industry).

This study will confine itself to stationary source air pollutants as the cause of degradation in air quality. Mobile source emission sources, largely automobiles, are not considered here. It is assumed therefore, that air environmental quality is a strongly separable aggregate - that the demands and supplies of different components: water pollution, land pollution, air pollution (stationary sources, e.g., industrial plants), air pollution (mobile sources, e.g., automobiles), can be considered in isolation.

CHAPTER III. REVIEW OF SELECTED RELEVANT LITERATURE

The topic of provision of air pollution abatement touches upon several areas of the economics literature. These are the previous studies on the demand for clean air, studies of the benefits of environmental improvement and the literature dealing with the demand for and supply of public goods.

Demand for Clean Air

The previous demand for clean air studies are of just two types: those using surveys and those using the hedonic price techniques. A third possibility, the median voter approach, has not been attempted.

Hedonic price analysis

Hedonic price analysis has been used most often in air quality studies to investigate the relationship between air pollution and property values. The technique is described by Freeman (14, p. 78):

> The hedonic technique is a method for estimating the implicit prices of the characteristics which differentiate closely related products in a product class. For example, houses constitute a product class differentiated by characteristics such as number of rooms and size of lot. In principle, if there are enough models with different combinations of rooms and lot size, it is possible to estimate an implicit price relationship which gives the price of any model as a function of the quantities of its various characteristics. The coefficients of the characteristics are the implicit prices. For example, the difference in price between two models with different numbers of rooms but identical in all other respects is interpreted as the implicit price of additional rooms.

In practice, an equation is set up with the house price as the dependent variable and with the independent variables being site variables (e.g., number of rooms), neighborhood variables (e.g., crime rate) and environmental variables (e.g., air quality). The equation is estimated over an urban area and the resulting variable coefficients are implicit prices. Ridker and Henning (35) pioneered this type of study and found that property values declined in response to higher pollution levels. Most air quality property value hedonic price studies go no further than measuring this implicit price. Freeman (14) lists 15 such studies; only two proceed to the next stage: estimation of the inverse demand function (where price is the independent variable instead of quantity). This stage involves regressing the implicit price for air quality against the level of air quality, income and other household variables. The two studies that do estimate the inverse demand function for air quality are Harrison and Rubinfeld (20) and Nelson (31). Both studies found estimates for price elasticity of demand for air quality to be around -1.2 and income elasticity of demand to be approximately 1.0.

When the inverse demand equation is estimated, some assumptions must be made about the supply of clean air. Harrison and Rubinfeld assume the supply to be perfectly inelastic, thus they are able to use single equation estimation methods as supply is now exogenous. Freeman (15, p. 166) examines this:

> The question of which assumption, exogenous or endogenous supply, is more appropriate boils down to the speed of the supply side adjustment . . . .

For single-year hedonic models, air quality is necessarily fixed as state governments and private industry move slowly in changing the level of abatement. Thus, supply is thought of in terms of the supply of clean air houses, whose stock would change very slowly. Therefore, in single-year hedonic models making the assumption of inelastic supply is a realistic one. However, if a demand model is examined using a pooled data set of several years, then the assumption of institutional rigidity in supplying air pollution abatement and hence clean air is not appropriate. Looking ahead, just such a data sample is used in this study and therefore an appropriate supply model is formulated.

Survey method

Survey techniques have been used to value visibility (Randall et al. (34), Rowe et al. (37)), and other aesthetic preferences (Brookshire, Ives, and Schulze (8)). There have always been some questions (strategic bias, hypothetical bias, instrument bias) about surveys. Thus, although surveys may be internally consistent, there is a need for independent confirmation of the results. Brookshire, Thayer, Schulze and d'Arge (9) make such a comparison for an area of southern California using survey and hedonic approaches for valuing air quality. Within the theoretical construct of their model, they were unable empirically to reject the dual hypotheses that specify (p. 176) ". . . that survey responses will be bounded below by zero [hypothesis 1] and above by rent differentials derived from the estimated hedonic rent gradient [hypothesis 2]." This test provides ". . . evidence for the validity of survey methods as a means of determining the value of public goods."

Median voter approach

No previous studies of the demand for air quality have used as their theoretical framework the median voter approach. The reasons for not pursuing this theoretic method are given by Freeman (14, p. 104)

> If some portion of pollution control costs is borne by the private sector, then the link between a vote on quantity and tax share or price is broken, and the vote can not be interpreted as revealing anything about the economic demand for pollution control. Also, the voting approach would only be applicable where both the benefits and the costs of the pollution control program fall entirely within the applicable political jurisdiction. If pollution spills across jurisdictional boundaries, some of the benefits of pollution control will be realized outside the jurisdiction. No voting measure could capture these interjurisdictional spillovers.

The model formulated in later chapters will deal with Freeman's objections by dealing explicitly with private sector costs and transboundary effects.

Benefits of Environmental Improvement

Benefits from air pollution abatement flow to the public from several sources. One is the improved health and reduced mortality that result from decreases in pollution-related diseases such as bronchitis, emphysema and cancer (Freeman, (14), p. 165). Different approaches have been suggested and used. Freeman prefers willingness-to-pay. He (p. 167)

> . . . proposes that increases in longevity or reductions in the probability of death due to accident or illness be valued according to what an individual is willing to pay to achieve them.

Crocker et al. (10), uses $340,000 is the willingness to pay for an expected life saved (as developed by Thaler and Rosen (39)).

A different method is the human capital approach. "It values each life lost at the present value of the expected stream of future earnings for that individual, had that individual's death been avoided" (Freeman, (14), p. 169). Lave and Seskin (24) estimate this figure to be $30,000. But this approach does not take into account a person's willingness-to-pay or in Freeman's terms, the value of a statistical death avoided. Nor does this measure account for nonmarket production.

Other benefits of clean air are the productivity benefits. Some of these benefits would be reduced agricultural damage from air pollutants, lessened materials damage, reduced water supply alteration (e.g., acid rain) and less household cleaning and soiling. Examples of the studies that examine these benefits are Waddell (49) and Heintz, Hershaft and Horak (50).

These various estimates of the benefits of air pollution abatement are not all similar (e.g., Lave and Seskin vs. Thaler and Rosen's estimate for average value of life) nor are they without statistical problems. Gerking and Schulze (16, p. 230) argue that there are three types of specification error being committed by these benefit studies. There are errors in functional form, omitted variables and simultaneity. Most models use simple linear or log-linear specification - do these accurately approximate the true function? Omitted variables can cause estimates to be biased and inconsistent, but tests have shown that this is not serious with, for example, Lave and Seskin's study. Gerking and Schulze (p. 230) argue that all the benefit studies use a reduced form (rather than a simultaneous approach) which gives misleading results:

> Simple ordinary least squares estimation, however, may lead to biased and inconsistent estimates of all regression coefficients . . . .

Demand for Public Goods

Considering only the studies that provide empirical estimates of public good demand, there are two main types: surveys and voting. Survey approaches have been covered (in part) under the survey method section so only voting will be considered here.

The predominant theoretical construct in this field is the median voter model. According to this theory, under a given set of conditions, politicians will tailor their platforms to appeal to the median voter's preferences. Therefore, the median voter's demands for governmentally provided public goods will be reflected in public expenditures for those goods. This theory is not without its critics however. Although fairly popular with economists, it is dismissed in the political science literature (18, p. 1133) as having thoroughly flawed assumptions:

> If the rule were strictly majoritarian and if each citizen had full information and an equal probability of participating in an expenditure decision (or if participation probabilities were unassociated with expenditure preferences), then the amount spent on each expenditure category would reflect exactly the citizen with median preferences. These informational, probability, and majoritarian assumptions are not, however, empirically accurate.

On the other hand, Holcombe (22) conducts an empirical test of the median voter approach and finds, for Michigan school districts, that (p. 273) ". . . the actual milage rate in the average district was not statistically different from the median voter's most preferred rate."

Romer and Rosenthal (36) review several economic studies using the median voter approach and conclude that most are flawed. These flaws consist of, in their terminology, the multiple fallacy and the fractile fallacy. Romer and Rosenthal explain (p. 150) the multiple fallacy:

> If expenditures everywhere were not those desired by the median voter but some multiple of this quantity, then the elasticity estimates would be unchanged but the multiple would be confounded in the intercept. Since there are no prior constraints on [the intercept] that allow us to determine if the multiple is unity, we cannot know whether expenditures correspond to those desired by a voter with median income.

Whether this multiple fallacy exists is mostly an empirical, not a theoretical, question. This study does not intend to explore this subject further, hence pending resolution, will assume a multiple of one.

The fractile fallacy involves two parts: one, the theoretical developments using the median voter model that suggest if one substitutes any fractile for the median income, similar empirical results would be obtained. The second part of the fractile fallacy is failing to test the median voter model against alternative specifications. The median voter model developed here will explicitly treat median income thus satisfying the first part of the fractile fallacy. Alternative specifications will not be tested against the developed model, therefore allowing it to be criticized on those grounds.

A study of particular note is one by Lovell (28), who uses the median voter approach and specifies a utility function for the median voter. Lovell also incorporates nonnormal distributions of income. Classics in the area of median voter models include studies by Bergstrom and Goodman (4) (estimating price and income elasticities for police, parks and recreation), Borcherding and Deacon (6) (demand for local public services), and Barr and Davis (2) (explaining local public expenditures). These studies however, cover only the demand side.

Supply of Public Goods

There are several descriptive economic models that attempt to explain the governmental process of providing some level of public goods. These are mostly "reduced-form" models meaning that the estimated coefficients are functions of the demand and supply parameters. In this case, only when the underlying structural model is exactly identified can values for the structural parameters be determined from reduced form estimates. But these studies do not even postulate a separate supply function.

From the political science literature there seem to be several schools of thought concerning public goods supply. One is the incrementalist school which explains governmental expenditures with simple autoregressive rules such as, quoting Romer and Rosenthal (p. 144) "last years budget plus 5 percent." Another approach is actually a controversy, socioeconomic variables vs. political variables; which has more explanatory power in explaining government expenditures? Lewis-Beck (27) comes down on the side of socioeconomic variables. Godwin and Shepard (18) postulate several "political linkage" models, using exclusively political variables.

Another approach altogether is taken by Niskanen (32) who sets up a bilateral monopoly (p. 618):

> The bureau [the government agency] 'sells' its service only to the government and the government 'buys' the service only from the bureau. This market, however, involves the exchange of some output for a budget than at a per unit price. . . . my model of bureaucratic supply determines only the bureau's preferred output based on an assumption that the bureau acts to maximize its budget.

Niskanen develops a model consisting of two parts, the first of which is a bureaucrat with a utility function which is maximized subject to a "discretionary" budget constraint yielding some optimal output. The second part is a model of a vote-maximizing legislator which also has two parts. One, oversight committees are packed with legislators whose district has a particular interest in the outcome hence increases supply past median desires and second, the legislator allocates his time between district specific activities and oversight activities. This latter yields results that a legislator whose district pays a small share of taxes spends most of his time on district specific activities. Niskanen examines several hypotheses derived from his model. The first is the overspending hypothesis: that government budgets are larger than those desired by the median voter. He concludes that (p. 635) ". . . conditions that increase the monopoly power of governments and bureaus lead to an increase in government expenditures." Second, Niskanen reviews some studies comparing the relative efficiency of government and private industry providing the same services and concludes (p. 638-9)

> Both overspending and production inefficiency appear to be a function of bureaus at the margin of their present size. . . . In summary then, these studies suggest that

> inefficiency is not a necessary characteristic of the supply of government services.

Other hypotheses discussed are the oversupply hypothesis, the overcapitalization hypothesis, and the bureaucratic structure hypothesis. Taking them in turn, Niskanen feels that bureaus supply more of a public good than is demanded (given the high costs of oversight). Overcapitalization comes about because of bureaucrats preference for current over future spending. Bureaucratic structure implies that consolidation of bureaus increases costs. Niskanen feels that empirical evidence (when available) supports the hypotheses derived from his model.

Downing (11) develops a graphical multiperiod model of the actors in the implementation of pollution laws: the control agency, the emitter, and the citizen's group. He examines the effects of policy change on the control agencies budget and hence environmental quality. One interesting feature of the model is that the supply function of environmental quality is to the left of the efficient level due to the presence of discretionary activities that the control agency bureaucrat could undertake in addition to environmental activities.

None of the above studies formulates a supply function, much less an estimable one. One related area is that of nonprofit organizations. Blair, Ginsburg and Vogel (5) studied Blue Cross-Blue Shield and estimated average cost functions. They found that there appears to be a lack of incentive to minimize cost (through utilizing economies of scale) and therefore there was administrative slack. This study provides some evidence against assuming that governments provide services at least cost.

CHAPTER IV. IMPLICIT MARKETS AND TRANSBOUNDARY EFFECTS

Implicit Markets and Transboundary Effects

Implicit market describes a situation when a good or service is provided, but not through the normal market mechanism of exchange involving prices and quantities. Even in private goods markets, except for highly organized and visible ones such as agricultural commodities markets or the stock market, transactions data (prices and quantities) are well known only to individuals directly involved. For public goods, there are no markets in terms of observable transactions. Often there are expenditure data, but defining quantities, especially for pure public goods, can be elusive.

There are data on expenditures for air pollution abatement by government and private industry. If one had a good measure of the "level" of air quality provided, then using the identity: expenditures are equal to price times quantity, the per unit price theoretically could be determined. This price is implicit, hence the term implicit market.

Symbolically, these relations may be shown as follows

Let:

e = total expenditures on air pollution abatement, by state government and private industry,

e_g = total expenditures on air pollution abatement by state governments,

e_i = total expenditures on air pollution abatement by private industry.

Starting with the obvious:

4.01 $e = e_g + e_i.$

The quantity of air pollution abatement by each state is Q_a. The per unit cost or implicit price facing the firm is P_{ai}. The price facing the government is P_{ag}. The aggregate per unit cost is P_a and can be shown to be:

4.02 $P_a = P_{ai} + P_{ag}.$

Transboundary Effects

Transboundary effects refer to the fact that air pollution and the impact of air pollution abatement cross political boundaries, in this case, from one state to another.

In physical terms, air pollution can be generated in one state and not affect that state's residents because it is exported across state lines. Air pollution that does affect state residents is also exported but this is already figured into the generating state's demand for clean air calculus. Likewise, the polluting state itself may be receiving unwanted imports of air pollution from other states.

In monetary terms, if the instate emitter industries are abating air pollution, then the cost of this abatement is factored into the price of their goods. From the consumer's viewpoint, the cost increases of emitter goods due to air pollution abatement can be considered a consumption tax. Therefore, to the degree that a state exports its emitter goods, it can shift part of the burden of paying for air pollution abatement to other states or countries.

CHAPTER V. AIR POLLUTION ABATEMENT EXPENDITURES

To develop a model that allows for transboundary effects the expenditure side should be (1), distinguished from the financing of those expenditures and (2), broken down in sufficiently fine detail to expose the transboundary components and their relationship to aggregate expenditures. It should be noted that the actual expenditure data have all these cross-state line considerations embedded in it. As before, the total expenditure (e) for air pollution abatement within a state comprises two parts: state government expenditure (e_g) and private industry expenditure (e_i).

State Government Expenditures

State government expenditures are hypothesized to comprise two parts:

(1) The cost of state governmental monitoring, inspection, enforcement and administration necessary to control the load of air pollution generated within the state.

(2) The cost of additional air pollution arriving across state lines. This may cause negotiation/litigation costs with those states exporting to this state and/or may cause the state to require additional abatement by in-state emitter industries to help offset the effects of the imported air pollution.

To develop a mathematical model of these expenditures, consider the following:

Let:

Q_a: actual abated emissions in the state,

ψQ_a: the level of abatement needed to handle the instate generated air pollution.

For any state, a given amount of air pollution is "abated" by sending it across state lines. Conversely, the air pollution load in-state is increased by pollutants coming in from other states. The sum of these two effects is captured by the parameter μ:

5.01 $$(\psi Q_a)^{\mu}.$$

If, for example, $\mu > 1$, then imports of pollution exceed exports. It is assumed that additions to the air pollution load of a state through imports causes the state to enforce existing regulations more strictly or pass additional regulations in order to compensate for imports of air pollution on a one-for-one basis through increased instate abatement. Similarly, if exports of air pollution exceed imports, then $\mu < 1$, and less abatement need be undertaken instate than otherwise.[1] Therefore, the actual abatement of air pollution in a state incorporates these import/export factors and is shown by

5.02 $$Q_a = (\psi Q_a)^{\mu}.$$

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[1]See Appendix A for numerical example.

Total state expenditures are simply

5.03 $$e_g = P_{ag}\ Q_{ag} = P_{ag}\ (\psi\ Q_a)^{\mu}.$$

Private Industry Expenditures

The private industry expenditures for air pollution abatement are hypothesized to comprise the per unit cost to private industry for abatement (P_{ai}) times the quantity of air pollution emissions abated (Q_a):

5.04 $$e_i = P_{ai} \cdot Q_a.$$

Total Expenditures

Putting the two relevant expenditure equations together, that for state government (equation 5.03), and that for private industry (equation 5.04), gives total expenditures:

5.05 $$e = e_g + e_i = P_{ag}\ (\psi\ Q_a)^{\mu} + P_{ai}\ Q_a.$$

The expenditures side then is fairly straightforward and provides the baseline for the financing side which is the key to any estimable model of demand.

CHAPTER VI. FINANCING AIR POLLUTION ABATEMENT EXPENDITURES

The financing of air pollution abatement expenditures is crucial to the modelling of demand in the later theoretical model chapters.

Background and Assumptions

How do the state governments and private industry finance these expenditures for air pollution statement?

The state governments finance air pollution abatement expenditures out of general revenue. These funds are raised primarily through proportional income taxes and general sales taxes. To finance the necessary administration, monitoring and enforcement tasks of the state in air pollution abatement, one could think of imposing higher income and/or sales tax rates, assuming that the needed funds are not diverted from other state programs or procured through federal grants. At the level of income being considered here, that of the median voter, the impact or incidence of the two different types of taxes is about the same. This is important for modelling purposes as several states do not have state income taxes, some have only sales taxes while others have both state income and sales taxes. As more states have income taxes than not, it is assumed in this study that states' finance air pollution abatement with higher income tax rates. Those states without state income taxes are assumed to make changes in their sale taxes such that the effects (on the median voter) are the same as if additional income taxes are imposed.

Most of private industry, in producing its output of goods, also produces air pollution. Those industries producing emissions are called emitter industries. Likewise, those goods produced by emitter industries are called emitter goods. In this study, emitter industries are assumed to add the cost of abatement to the price of their products to cover the cost of air pollution abatement. This price increase due to the cost of abatement could be considered a "consumption tax" in that the consumers are being forced to pay some share (depending on the elasticities of demand for and supply of the emitter goods) of the cost of air pollution abatement by the emitter industries. If the demand for emitter goods is perfectly inelastic, then the consumers will pay the entire amount of the air pollution abatement-caused cost increase or consumption tax. If demand is not completely inelastic, but less than perfectly elastic, then the elasticities of the demand for and supply of emitter goods determine the cost shares of the consumption tax allocated to consumers and emitter goods producers. If demand is completely elastic, then the producers must absorb the entire cost increase.

State residents, for the purposes of this study are assumed to be all consumer-taxpayer-voters (CTVs). They realize that any additional air pollution abatement, requested through the political process will be paid, at least in part, by them and that part of this payment will be through higher prices for emitter goods (air pollution abatement-caused goods prices increases) and part through higher taxes (higher income tax rates).

State Government Financing

The state government, ignoring intergovernmental transfers, finances the cost of abatement administration, monitoring and enforcement through taxes on state CTVs. There is no way the CTVs can shift this part of the cost of air pollution abatement to out-of-state residents. Therefore, state CTV's finance e_g worth of abatement activities, helping to abate Q_a tons at a per unit equilibrium price of P_{ag}. This is summarized in equation 5.03 and shown here as

6.01 $$e_g = P_{ag} Q_a = P_{ag} (\psi Q_a)^{\mu}.$$

Private Industry Financing

Consider the financing of private industry expenditures for instate air pollution abatement by consumers of emitter goods. These include both in-state and out-of-state categories and are hypothesized to comprise three parts:

(1) The total amount of consumption tax paid by in-state residents through consumption of in-state produced emitter goods.

(2) The total amount of consumption tax paid by out-of-state residents through consumption of in-state produced emitter goods.

(3) The total amount of consumption tax paid by in-state emitter industries when consumer demand for emitter goods is other than perfectly inelastic.

Putting these parts together in mathematical form:

Let:

$P_{ai} \cdot Q_a^{\nu}$: the amount of air pollution abatement costs paid by all consumers of in-state produced emitter goods.

Q_a^{ν}: amount of air pollution abatement "charged" to all consumers of emitter goods. When $\nu = 1$, demand for emitter goods is perfectly inelastic and consumers pay all the mark-up or consumption tax. When $0 < \nu < 1$, the cost is shared. When $\nu = 0$, emitter industries pay the entire tax (demand for emitter goods is perfectly elastic).

P_{ai}: per unit cost of abatement by private industry

$\hat{\psi} P_{ai} Q_a^{\nu}$: portion of consumer paid abatement cost paid by in-state consumers.

ψ: percentage of in-state produced emitter goods consumed in-state.

$(1 - \hat{\psi}) P_{ai} Q_a^{\nu}$: portion of consumer paid abatement cost paid by out-of-state consumers.

$P_{ai} (Q_a - Q_a^{\nu})$: the consumption tax paid by state emitter industries. Q_a is abated emissions, Q_a^{ν} are those emissions "charged" to all consumers thus $Q_a - Q_a^{\nu}$ are those emissions "charged" to in-state emitter industries.

Therefore, the in-state financed portion of in-state air pollution abatement paid through consumption taxes is

6.02 $$e_{it} = \hat{\psi} P_{ai} Q_a^{\nu} + P_{ai} (Q_a - Q_a^{\nu}).$$

Total Air Pollution Abatement Financing

Aggregate air pollution abatement financing is undertaken by state governments (6.01) and consumers plus industry (6.02). This is shown by

6.03 $$e_g + e_{it} = P_{ag} (\hat{\psi} Q_a)^{\mu} + \psi P_{ai} Q_a^{\nu} + P_{ai} (Q_a - Q_a^{\nu}).$$

The in-state financing aggregate equation 6.03 more complex than the expenditure aggregate 5.05 because of the cost sharing of the consumption tax between in-state consumers and instate emitter goods producers.

There are two cases of interest.

Case 1

The assumptions for Case 1 are the most restrictive:

(a) that in-state consumers purchase all in-state produced emitter goods (hence $\hat{\psi} = 1$),

(b) that all abatement is in response to instate emissions (hence $\psi = 1$) which implies that imports of air pollution equal exports ($\mu = 1$),

(c) that the demand for emitter goods is perfectly inelastic ($\nu = 1$).

As a result of these assumptions, the financing aggregate equation 6.03 collapses to the expenditure identity:

6.04 $$e = e_g + e_{it} = e_g + e_i = P_{ag}\ Q_a + P_{ai}\ Q_a.$$

Case 2

Case 2 allows out-of-state purchases of in-state emitter goods ($\psi \neq 1$), abatement in response to nonzero net exports ($\psi \neq 1$, $\mu \neq 1$), but maintains the assumption of perfectly inelastic demand for emitter goods ($\nu = 1$). As a result, the financing aggregate equation 6.03 becomes

6.05 $$e_g + e_{it} = P_{ag}\ (\psi\ Q_a)^{\mu} + \hat{\psi}\ P_{ai}\ Q_a.$$

Recall 5.02: $Q_a = (\psi\, Q_a)^{\mu}$ and substitute into 6.05 which yields

6.06 $$e_g + e_{it} = P_{ag}\ (\psi\, Q_a)^{\mu} + \hat{\psi}\, P_{ai}\ (\psi\, Q_a)^{\mu}.$$

To get 6.06 in terms of aggregate air pollution abatement per unit cost or implicit price P_a, recall 4.02: $P_a = P_{ai} + P_{ag}$. For each state, define some k such that

6.07 $$k\, P_a = P_{ai},$$

6.08 $$(1 - k)\, P_a = P_{ag}.$$

Substitute 6.07 and 6.08 into 6.06 and let:

6.09 $$Z = \psi^{\mu}\ [k + (1 - k)\ \hat{\psi}],$$

then

6.10 $$e_g + e_{it} = Z\, P_a\, Q_a^{\ \mu}.$$

Equation 6.10 represents the financing of air pollution abatement from the point of view of the state's CTVs, accounting for transboundary costs and benefits. When a budget constraint is formulated for the median voter in later sections, 6.10 will prove to be an integral part.

CHAPTER VII. THEORETICAL MODEL

The model has two sides to it, a demand side and a marginal cost side.

Demand Side

The demand for air pollution abatement is being modeled by using what is called the median voter approach. As explained by Holcombe (22, p. 261,) median voter models all have a common starting point.

> A single political issue is to be determined by a simple majority voting rule, via some election process. The alternatives may all be ranked along a single-dimensioned continuum, and all voters have single peaked preferences.

It can be shown that the median voter will dominate by combining with one of the other majorities-less-one. Downs (12) suggested that the two-party system provides an opportunity and incentive for politicans to shape their platforms to match the preferences of the median voter. The assumption used here is that the state's expenditures for monitoring and enforcing air pollution standards are a direct reflection of the platform of the political party in power. That platform reflects the preferences for air quality of the median voter. By making these assumptions, it greatly simplifies the problem of determining demand. Instead of having to aggregate all individuals' demands, each one necessarily having been previously disclosed through some demand revealing process (such as surveys), a utility function for the median voter can be assumed and ordinary demand functions derived from it.

Utility function

The following utility function is specified for the median voter and maximized subject to his/her budget constraint. This process will produce ordinary (Marshallian) demand curves.

Consider a strongly separable, linearly homogeneous utility function such as the venerable Cobb-Douglas:

7.01 $$U_m = a\ C^{\zeta}\ G^{\xi}\ Q^{\gamma},$$

where

U_m: utility of the median voter,

a: some constant,

C: composite consumption good,

G: composite of all public goods other than air pollution abatement,

Q: air pollution abatement. Air pollution abatement is dealt with in the expenditure and financing chapters in terms of Q_a^{μ} - where Q_a is the quantity of air pollution abatement and μ is the "net exports" parameter. Smaller values of μ ($\mu < 1$) indicate exports exceed imports of air pollution, hence the amount of Q_a actually paid for is less than Q_a achieved. Therefore, Q_a will be incorporated into the utility function to the power $1/\mu$, so that values of μ less than one raise the impact of a given level of air pollution abatement. For consistency of notation, Q_a raised to the $1/\mu$ will be incorporated in the utility function in the following manner:

7.03 $$Q = (Q_a)^{\frac{1}{\mu}} = (Q_a^{\mu})^{\frac{1}{\mu^2}}.$$

The utility function, substituting 7.03 into 7.01, would read:

7.04 $$U_m = a\ C^{\zeta}\ G^{\xi}\ [(Q_a^{\mu})^{\frac{1}{\mu^2}}]^{\gamma}.$$

Continuing with parameter and definitions:

ζ, ξ, γ: distribution parameters

In addition,

7.05 $$\gamma = ATT_a^{\alpha} E^{\mu}.$$

with

ATT_a: median voters ideological attitude about air quality. ATT_a is an index with a possible range from zero to 100, with low values indicating no preference or even hostility towards air quality and higher values indicating stronger preferences for air quality. See Chapter VII, Data Definitions and Sources, for the series used. The index is monotonically scaled so that all values lie in the range zero to two. Thus the index, which appears in the utility function exponentially, can be given concrete meaning:
$ATT_a = 1.0$ connotes an median preference,
$ATT_a < 1$ indicates a weaker than median preference for air quality,
$ATT_a > 1$ indicates a stronger than median preference for air quality.

α: activism parameter. This gages the intensity with which the attitudes about air quality are held. Intensely held feelings are often translated into attempts to influence decision makers, whereas weakly held feelings results in less influence:
$\alpha = 1$ indicates a median level of activism,
$\alpha > 1$ indicates a greater than median level of activism,
$\alpha < 1$ indicates a less than median level of activism.

E^{μ}: stock of air pollution existing in the state.

- E: point source instate emissions in the previous year
- μ: net exports parameter. The stock of pollutants is increased or decreased depending on whether the state is a net importer or exporter of air pollution.

Multiply the stock of air pollution E^{μ} by

7.06 $$\frac{SQMI^{\mu}}{SQMI^{\mu}},$$

where SQMI is state area in square miles, thus giving

7.07 $$\gamma = \frac{ATT_a^{\alpha}\ E^{\mu}\ SQMI^{\mu}}{SQMI^{\mu}}.$$

Let

7.08 $$(E/SM)^{\mu} = \frac{E^{\mu}}{SQMI^{\mu}},\ \text{thus}$$

7.09 $$\gamma = ATT_a^{\alpha}\ (E/SM)^{\mu}\ SQMI^{\mu}.$$

Budget constraint

The median voter will pay for this abatement of air pollution through taxes and through higher prices for goods produced by those industries that emit air pollutants. The sum of abatement income taxes and higher emitter goods prices constitutes the air pollution abatement portion of the budget constraint.

Taxes Consider the payment for abatement through taxes. Part of the following development follows that of Lovell (28). Assume that the air pollution abatement tax is a proportional income tax, then the average taxpayer pays:

7.10 $\bar{T} = t \cdot \bar{Y}$,

where

$\bar{T}$: taxes paid by average voter for air pollution abatement,

t: air pollution abatement tax rate,

$\bar{Y}$: income of the average voter (assumed to be average income).

The cost of abating emissions that can be ascribed to the state government is, recalling equation 6.01:

6.01 $e_g = P_{ag} Q_a = P_{ag} (\psi Q_a)^{\mu}$

The average taxpayer's share of this expenditure is calculated by dividing the total expenditure by the number of CTVs which is N:

7.11 $\frac{P_{ag}(\psi Q_a)^{\mu}}{N}$.

Setting equal the abatement tax paid by the average taxpayer (7.1^) and the average taxpayer's cost share of abating emissions (7.11) and solving for the air pollution abatement tax rate t gives:

7.12 $t = \frac{P_{ag}(\psi Q_a)^{\mu}}{\bar{Y}N}$.

The air pollution abatement taxes paid by the median voter (T_m) are based on the air pollution tax rate (t) and median voter income (assumed to be median income Y_m).

7.13 $$T_m = t \cdot Y_m.$$

Substituting in the tax rate (7.12) into 7.13 yields:

7.14 $$T_m = \frac{P_{ag} (\psi\, Q_a)^{\mu}}{\bar{Y}N} \cdot Y_m.$$

Rearranging terms gives the tax price for air pollution abatement for the median voter:

7.15 $$T_m = \frac{P_{ag}}{N} \cdot \frac{Y_m}{\bar{Y}} \cdot (\psi\, Q_a)^{\mu}.$$

<u>Higher prices for emitter goods</u> Now consider the payment for abatement through increased prices for emitter industry produced goods. Recall from Chapter VI, equation 6.02, the financing of air pollution abatement through the consumption of emitter goods:

6.02 $$e_{it} = \hat{\psi}\, P_{ai}\, Q_a^{\nu} + P_{ai}\, (Q_a - Q_a^{\nu})$$

Following Case 2 as developed in Chapter VI, assume that the demand for emitter goods is perfectly inelastic and thus consumers pay the entire amount of the cost increase in emitter goods due to air pollution abatement. In terms of 6.02 above, inelastic demand is represented when $\nu = 1$, and recalling 5.02: $Q_a = (\psi\, Q_a)^{\mu}$ and yields

7.16 $$e_{it} = \hat{\psi}\, P_{ai}\, (\psi\, Q_a)^{\mu}.$$

Now e_{it} represents the amount of air pollution abatement-caused emitter goods price increases paid by state CTVs.

To determine the share of cost/price increases that is paid by the median voter, let

C_t: total consumption of in-state produced emitter goods by all CTVs in the state,

C_m: total consumption of in-state produced emitter goods by the median voter,

$\frac{C_m}{C_t}$: the median voters percentage consumption of in-state emitter goods.

The portion of the total abatement cost of in-state emitter goods passed on to the median voter is:

7.17 $$E_m = \frac{C_m}{C_t} \cdot e_{it} = \frac{C_m}{C_t} \cdot \hat{\psi} P_{ai} \; (\psi \, Q_a)^{\mu}.$$

But total consumption of emitter goods, C_t, is the number of CTVs, N, times average consumption $\bar{C}$.

7.18 $$C_t = \bar{C}N$$

Making the appropriate substitution of 7.18 into 7.17 gives

7.19 $$E_m = \frac{C_m}{\bar{C}N} \cdot \hat{\psi} P_{ai} \; (\psi \, Q_a)^{\mu}.$$

It is hypothesized that the median income individual and the mean income individual will spend similar proportions of their incomes on emitter goods. Let this proportion of income spent on emitter goods be δ, so that

7.20 $C_m = \delta Y_m$,

7.21 $\bar{C} = \delta\bar{Y}$.

Substituting in 7.20 and 7.21 into 7.19 eliminates the consumption terms and the δ's cancel:

7.22 $$E_m = \hat{\psi}\frac{P_{ai}}{N} \cdot \frac{Y_m}{\bar{Y}} \cdot (\psi\, Q_a)^{\mu},$$

which is cost to the median voter of air pollution abatement through increased emitter good prices/consumption tax.

<u>Taxes plus higher prices for emitter goods</u> Combining the two means of paying for air pollution abatement: through taxes (T_m) and through increased prices for emitters goods (E_m) yields the budget constraint for air pollution abatement (APA_m):

7.23 $$APA_m = T_m + E_m.$$

Substituting in 7.23 for taxes with 7.15 and for higher prices with 7.22, rearranging and factoring gives:

7.24 $$APA_m = \frac{Y_m}{\bar{Y}} \frac{Q_a^{\mu}}{N} \psi^{\mu} \left[P_{ag} + \hat{\psi}\, P_{ai}\right].$$

Recall the development of the relationship between P_a, P_{ai}, P_{ag}, specifically equations 6.07-6.09, which, when incorporated into 7.24 yields:

7.25 $$APA_m = Z \cdot \frac{Y_m}{\bar{Y}} \cdot \frac{P_a Q_a^{\mu}}{N}$$

By definition in this study, gross personal income Y is equal to average personal income $\bar{Y}$, times the number of CTVs N. Substituting in for $\bar{Y}$ yields

7.26 $$APA_m = Z \cdot \frac{Y_m}{Y} \cdot P_a Q_a^{\mu}.$$

Let:

7.27 $$P_a' = Z \cdot \frac{Y_m}{Y} \cdot P_a,$$ therefore

7.28 $$APA_m = P_a' Q_a^{\mu}.$$

The complete budget constraint for the median voter Based on the utility function described earlier, the median voter's budget constraint would be as follows:

7.29 $$Y_m = P_c C + P_g G + P_a' Q_a^{\mu}.$$

Maximization

Maximizing the median voter's utility function (7.04) subject to his/her budget constraint (7.29) begins with forming the lagrangian

7.30 $$L = a\, C^{\zeta}\, G^{\xi}\, \left[(Q_a^{\mu})^{\frac{1}{\mu^2}}\right]^{\gamma} + \lambda\left[Y_m - P_c\, C - P_g\, G - P_a'\, Q_a^{\mu}\right].$$

Let:

7.31 $$\eta = \frac{\gamma}{\mu^2} .$$

Substituting 7.31 in 7.30 gives

7.32 $$L = a\ C^{\zeta}\ G^{\xi}\ (Q_a^{\mu})^{\eta} + \lambda[Y_m - P_c\ C - P_g\ G - P_a'\ Q_a^{\mu}].$$

By assumption of linear homogeneity:

7.33 $$\zeta + \xi + \eta = 1.$$

The first order conditions are calculated by differentiating the lagrangian function of 7.32 with respect to the choice variables C, G and Q_a^{μ}:

7.34 $$\frac{\partial L}{\partial C} = \frac{\zeta U}{C} + \lambda(-P_c) = 0,$$

7.35 $$\frac{\partial L}{\partial G} = \frac{\xi U}{G} + \lambda(-P_g) = 0,$$

7.36 $$\frac{\partial L}{\partial Q_a^{\mu}} = \frac{\eta U}{Q_a^{\mu}} + \lambda(-P_a') = 0.$$

The first order conditions are solved simultaneously to get the demand functions in C and G in terms of Q_a^{μ} and P_a':

7.37 $$C = \frac{\zeta P_a'}{\eta P_c}\ Q_a^{\mu},$$

7.38 $$G = \frac{\xi P_a'}{\eta P_g}\ Q_a^{\mu}.$$

To get the demand function for Q_a, substitute 7.37 and 7.38 into the budget constraint:

7.39 $$Y_m = P_c \left[\frac{\zeta P'_a}{\eta P_c} Q^\mu_a\right] + P_g \left[\frac{\xi P'_a}{\eta P_g} Q^\mu_a\right] + P'_a Q^\mu_a.$$

Cancelling the P_c's and P_g's and factoring out $P'_a Q^\mu_a$ out of each of the terms yields:

7.40 $$Y_m = P'_a Q^\mu_a \left[\frac{\zeta}{\eta} + \frac{\xi}{\eta} + 1\right].$$

Substituting η/η for 1 and putting the term in brackets over a common denominator gives

7.41 $$Y_m = P'_a Q^\mu_a \left[\frac{\zeta + \xi + \eta}{\eta}\right].$$

Impose the constraint of linear homogeneity on the demand function with equation 7.33: $\zeta + \xi + \eta = 1$.

Substituting 7.33 into 7.41 results in

7.42 $$Y_m = \frac{P'_a Q^\mu_a}{\eta}.$$

Recall that 7.31: $\eta = \frac{\gamma}{\mu^2}$, 7.27: $P'_a = Z \cdot \frac{Y_m}{Y} \cdot P_a$ and 7.09: $\gamma = ATT^\alpha_a (E/SM)^\mu SQMI^\mu$. Substituting these in 7.38, cancelling and solving for Q^μ_a gives:

7.43 $$Q^\mu_a = \frac{Y\, ATT^\alpha_a (E/SM)^\mu SQMI^\mu}{Z \mu^2 P_a}.$$

Divide both sides by $SQMI^\mu$ and letting

$$7.44 \qquad Q^{\mu} = \frac{Q_a^{\mu}}{SQMI^{\mu}} = \left(\frac{Q_a}{SQMI}\right)^{\mu}$$

brings in the concentration factor. For instance, a given level of abatement will have more of an impact in a smaller state than in a larger one, just as removing one cigar smoker from a phone booth will have more impact on the given environemnt's air quality than removing a cigar smoker from an auditorium will. 7.43 can now be written as

$$7.45 \qquad Q^{\mu} = \frac{Y\ ATT_a^{\alpha}\ (E/SM)^{\mu}}{Z\ \mu^2\ P_a}.$$

Taking logs of both sides of 7.45 yields:

$$7.46 \qquad \mu \ln Q = -2\ln \mu - \ln P_a + \ln Y + \alpha \ln ATT_a + \mu \ln E/SM - \ln Z.$$

Dividing through by μ results in:

$$7.47 \qquad \ln Q = -\frac{2}{\mu}\ln\mu - \frac{1}{\mu}\ln P_a + \frac{1}{\mu}\ln Y + \frac{\alpha}{\mu}\ln ATT_a + \frac{\mu}{\mu}\ln E/SM - \frac{1}{\mu}\ln Z.$$

Let

$$\alpha_0 = -\frac{2}{\mu}\ln\mu,$$

$$\alpha_1 = \alpha_2 = \alpha_5 = \frac{1}{\mu},$$

$$\alpha_3 = \frac{\alpha}{\mu},$$

$$\alpha_4 = \frac{\mu}{\mu}.$$

Substituting in the above results in

7.48 $$\ln Q = \alpha_0 - \alpha_1 \ln P_a + \alpha_2 \ln Y + \alpha_3 \ln ATT_a + \alpha_4 \ln E/SM - \alpha_5 \ln Z.$$

Equation 7.48 is an estimable demand function that includes many common sense variables but has been derived from economic theory. There are no data for Z, hence in the estimation process, the variable Z would have to be dropped. The consequences for omitting a variable that is thought to belong in a regression equation is discussed in Chapter IX Estimation, Results and Conclusions.

Marginal Cost Side

The supply of air pollution abatement is produced through joint production. Instead of two products-one firm case as is normally thought of, the production of clean air (a single good) is undertaken by two divisions of a figurative single joint product firm. This "joint" production function involves the state government as one division through their monitoring and enforcement of air pollution abatement regulations and it involves private industry as the other division. Private industry responds to government regulations and enforcement by capital investment in air pollution abatement equipment (APAE) and current operating expenditure on existing APAE. The primary inputs to this production process are hypothesized to be labor and capital. The state governments provide only labor through their bureaucracy for monitoring, enforcement, administration, and R&D. Private industry provides both labor and capital for the actual technological reduction/prevention of a certain amount of emissions. If the entire joint process can be considered to be efficient (least cost) then cost minimization, subject to output constraints, can yield marginal cost (MC) functions, the inverse of which are supply functions.

Downing's model (11) shows that part of control agency's budget is spent not on providing environmental quality but rather on discretionary activities. Maximizing this discretionary part of the budget is seen as one of the bureaucrats goals - thus the marginal cost of implementation curve (MCI) which accounts for discretionary activities lies inside the efficient MCI. It is this inner curve on which points can be observed. It is postulated here that the portion of the budget used for environmental, rather than discretionary activities, is used efficiently. Consider the following homogenous form of the production function:

7.49 $$Q_a = E(L_g^{\sigma})^{\rho} L_i^{\pi} K^{\phi},$$

where

Q_a: tons of abated emissions.

E: point emissions in the previous year. This is a measure of the stock of industrial air pollution. This stock greatly influences the degree of difficulty in achieving abatement. In very dirty areas marginal abatement will be relatively inexpensive and conversely in very clean areas with extensive ongoing abatement.

L_g: labor input by the state government,

L_i: labor input by emitter industries,

K: capital stock of APAE employed by emitter industries in the current period,

ρ, π, ϕ: distribution parameters,

σ: efficiency parameter, $0 < \sigma \leq 1$. When $\sigma = 1$, discretionary activities are zero and the entire control agency budget is used for air quality control. If $\sigma < 1$, then there is that degree of discretionary activity.

The government air pollution control agency cannot minimize cost with respect L_g^σ, the effective labor input but must fund the full labor complement L_g and minimize costs with respect to that total labor input. This is because although a given percentage of labor input is used for discretionary nonabatement activities, this may come as a percentage of otherwise efficient employee time rather than having employees divided into full time discretionary or nondiscretionary groups. The following lagrangian is then formed to minimize costs subject to an output constraint:

7.50 $$C = w_g L_g + w_i L_i + r K + \lambda[Q_a - E L_g^{\sigma\rho} L_i^{\pi} K^{\phi}],$$

where

w_g: wage rate of state government workers engaged in abatement activities,

w_i: wage rate of emitter industry workers engaged in abatement activities,

r: user cost of capital,

λ: lagrangian multiplier.

In forming this lagrangian, it can be shown (25, p. 214) that the lagrangian multiplier (λ) is marginal cost (MC). The first order conditions are determined by differentiating the lagrangian 7.50 with respect to the choice variables L_g, L_i, K and the multiplier λ:

7.51 $$\frac{\partial C}{\partial L_g^{\sigma}} = w_g + \lambda\left[\frac{-\sigma\rho \cdot Q_a}{L_g^{\sigma}}\right] = 0; \qquad L_g = \frac{\lambda\ \sigma\ \rho\ Q_a}{W_g},$$

7.52 $$\frac{\partial C}{\partial L_i} = w_i + \lambda\left[\frac{-\pi \cdot Q_a}{L_i}\right] = 0; \qquad L_i = \frac{\lambda\ \pi\ Q_a}{w_i},$$

7.53 $$\frac{\partial C}{\partial K} = r + \lambda\left[\frac{-\phi \cdot Q_a}{K}\right] = 0; \qquad K = \frac{\lambda\ \phi\ Q_a}{r},$$

7.54 $$\frac{\partial C}{\partial \lambda} = Q_a - E\ L_g^{\sigma\rho}\ L_i^{\pi}\ K^{\phi} = 0.$$

Substituting each of the first order conditions involving the choice variables into the budget constraint 7.54 yields:

7.55 $$Q_a = E\left(\frac{\lambda\ \sigma\ \rho\ Q_a}{w_g}\right)^{\sigma\rho} \left(\frac{\lambda\ \pi\ Q_a}{w_i}\right)^{\pi} \left(\frac{\lambda\ \phi\ Q_a}{r}\right)^{\phi}.$$

Put emissions E on a per square mile basis to take into account the concentration of emissions

7.56 $$Q_a = SQMI \cdot \frac{E}{SQMI} \left(\frac{\lambda\ \sigma\ \rho\ Q_a}{w_g}\right)^{\sigma\rho} \left(\frac{\lambda\ \pi\ Q_a}{w_i}\right)^{\pi} \left(\frac{\lambda\ \phi\ Q_a}{r}\right)^{\phi}.$$

Divide through by square miles, SQMI, thus taking the concentration factor into account on the abatement side.

Let

$Q = Q_a/SQMI$ and

$E/SM = E/SQMI$ then

7.57 $$Q = (E/SM) \left(\frac{\lambda\ \sigma\ \rho\ Q_a}{w_g}\right)^{\sigma\rho} \left(\frac{\lambda\ \pi\ Q_a}{w_i}\right)^{\pi} \left(\frac{\lambda\ \phi\ Q_a}{r}\right)^{\phi}.$$

Solving for λ and letting

7.58 $$m = \sigma\ \rho + \pi + \phi, \text{ and}$$

7.59 $$s = (\sigma\ \rho)^{\sigma\rho}\ \pi^{\pi}\ \phi^{\phi}, \text{ gives}$$

7.60 $$\lambda = \frac{Q^{\frac{1-m}{m}}\ w_g^{\frac{\sigma\rho}{m}}\ w_i^{\frac{\pi}{m}}\ r^{\frac{\phi}{m}}}{(E/SM)^{\frac{1}{m}}\ s^{\frac{1}{m}}}$$

Assuming that this joint firm behaves as if it were a perfect competitor, that is, sets price equal to marginal cost then:

7.61 $$P^{mc} = MC = \lambda.$$

Substituting in P for λ and taking logs of both sides gives:

7.62 $$\ln P^{mc} = -\frac{1}{m}\ln s + \frac{1-m}{m}\ln Q + \frac{\sigma\rho}{m}\ln w_g + \frac{\pi}{m}\ln w_i + \frac{\phi}{m}\ln r - \frac{1}{m}\ln E/SM.$$

Let:

$$\beta_0 = -\frac{1}{m}\ln s,$$

$$\beta_1 = \frac{1-m}{m},$$

$$\beta_2 = \frac{\sigma\rho}{m},$$

$$\beta_3 = \frac{\pi}{m},$$

$$\beta_4 = \frac{\phi}{m},$$

$$\beta_5 = \frac{1}{m}.$$

Substituting these into 7.62 gives

7.63 $$\ln P^{mc} = \beta_0 + \beta_1 \ln Q - \beta_2 \ln w_g - \beta_3 \ln w_i - \beta_4 \ln r - \beta_5 \ln E/SM.$$

Equation 7.63 is the marginal cost function.

Once all the coefficients have been estimated, then some of the parameters can be determined using the coefficient estimates. It can be shown[1] that the relationships between the parameters and the model coefficients are:

7.64 $$\pi = \frac{\beta_2\beta_4}{\beta_2\beta_3 + \beta_2\beta_4 + \beta_3\beta_4 + \beta_2\beta_3\beta_4},$$

[1]See Appendix B for solution of distribution and efficiency parameters in terms of the coefficients.

7.65 $$\phi = \frac{\beta_2\beta_3}{\beta_2\beta_3 + \beta_2\beta_4 + \beta_3\beta_4 + \beta_2\beta_3\beta_4},$$

The parameter of most interest would be the efficiency parameter σ. Unfortunately, there are an insufficient number of independent equations to solve for σ, only the product $\sigma\rho$ can be determined. Several elasticities would also be available: price elasticity with respect to abatement, the elasticity of price of abatement with respect to wage rates, the elasticity of abatement price with respect to the user cost of capital, and the price of elasticity with respect to the existing stock of air pollution.

The Complete Model

The complete model brings together the demand side and the marginal cost of abatement. The supply and demand decisions are assumed to be made at the same time, thus simultaneous equations techniques are called for. The model consists of a demand equation, a marginal cost equation and an equilibrium condition linking the two:

7.66 Demand: $$\ln Q^d = \alpha_0 - \alpha_1 \ln P_d + \alpha_2 \ln Y + \alpha_3 \ln ATT_a + \alpha_4 \ln E/SM - \alpha_5 \ln Z$$

7.67 Marginal Cost: $$\ln P^{mc} = \beta_0 + \beta_1 \ln Q^s - \beta_2 \ln w_g + \beta_3 \ln w_1 + \beta_4 \ln r - \beta_5 \ln E/SM$$

7.68 Equilibrium Condition: $\ln P^{d} = \ln P^{mc}$

The unit of observation is the state thus the estimation will be a cross-sectional analysis. Data from 1974 through 1978 will be pooled to form the sample. Simultaneous regression technqiues such as two and three stage leasts squares will be used to analyze the data.

CHAPTER VIII. DATA DEFINITIONS AND SOURCES

The critical data necessary for the empirical estimation of the model are air pollution abatement by state and private industry and state government expenditures on air pollution abatement. These data are necessary to calculate the implicit per unit cost or price of air pollution abatement.

The sample period is 1974-1978. This was chosen for two reasons. First, the passage of the Clean Air Act in 1970 in which national air quality standards were set and the individual states were charged with monitoring and enforcing these standards, meant that both states and private industry would be attempting to reach during the middle 1970s some equilibrium level of spending supportable by the CTVs. Second, the availability of data given the model construction. Consistent data series on air pollution abatement expenditures do not start until 1972-3; the same being true for quantities of air pollutants abated. The year 1974 was the most feasible starting date. The data for quantities abated are consistent for the years 1974-76, then in 1977 and 1978 changes were made. In 1977, estimates of air pollution abatement were derived from a sample consisting of firms with 20 or more employees instead of all firms. In 1978, there were additional changes, in that data entries with standard errors larger than 20 percent were not reported. The expenditure data were consistent throughout the sample period but not beyond. To extend the sample period beyond 1978 proved to be impractical for this study. Data (such as value-added by standard industrial classification code by state) necessary for the construction of air pollution abatement data series were not available and therefore the consistency of the series would be at risk if extended over a longer period. Abatement expenditure data are similarly affected.

One quirk in the data must be mentioned. Major industry Group 23, Apparel and Other Textile Products was not included in any of the Bureau of Census abatement quantity or expenditure surveys and therefore is excluded from the state totals.

The variables are defined below by equation; first, demand for air pollution abatement, then the marginal cost of air pollution abatement.

Demand for Air Pollution Abatement

The demand equation is

$$\ln Q = \alpha_0 - \alpha_1 \ln P + \alpha_2 \ln Y + \alpha_3 \ln ATT_a + \alpha_4 \ln E/SM$$

$$- \alpha_5 \ln Z,$$

where

$$0 = \frac{Q_a}{SOMI} \quad \text{and}$$

Q_a: tons of air pollution emissions abated in each state. These are aggregate emissions abated, the sum of particulates, sulfur oxides, nitrogen oxides, hydrocarbons, carbon monoxide, heavy metals, toxic and nuclear air pollutants.

SQMI: state area in square miles.

Data on air pollution abatement are available (42) by pollutant, state and standard industry classification (SIC) code. However, many state-pollutant-SIC data positions were omitted, generally to preserve confidentiality of an industry or a particular firm. To overcome this problem, the ratio of emissions abated to value-added (40) was calculated, where data were available, for each pollutant class, state and SIC code. For each pollutant class, these ratios were summed over all states within each SIC code and then divided by the number of nonzero ratios in each code. That is, the average emissions abated per dollar of value-added was calculated for each SIC code for every class of pollutants. The classes of pollutants are (1) particulates, (2) sulfur oxides, (3) nitrogen oxides + hydrocarbons + carbon monoxide, and (4) heavy metals + toxic + nuclear.

The original census abatement data matrices (50 states by 19 SIC codes for four classes of pollutants) were then examined for zero abatement entries. Upon discovering a zero abatement level for a pollutant-state-SIC data position, the average (over all states) emissions abated per dollar of value-added ratio for that SIC code and pollutant was multiplied by the value-added in that SIC code in that state, thus generating an "average" level of abatement for the state, SIC code and pollutant data position. This average level was substituted for the zero value. If the state had little or no value added in a particular SIC classification, it generally would not have much emissions nor abatement from that SIC code. Therefore, there is little chance of this estimation procedure providing estimates of nonexistent abatement.

After the original census abatement data matrices have been "filled-in" with estimates for the omitted values, then for each pollutant the total amount abated for each state is calculated by summing over all SIC codes. The state totals of abatement by pollutant are themselves summed over pollutants to give an aggregate total of air pollution abatement by state. This aggregate total of abatement is used for Q_a - the tons of air pollution abatement in each state.

This procedure was used for years 1974-1977. For 1978, the number of SIC abatement entries for each state was reduced by the Bureau of Census by one-half or in many cases, much more. The procedure used for 1974-77 could not be used, thus the tabular totals were used instead. Further, in the few states where abatement totals (as listed) dropped by 50% or more in 1978, totals for 1977 were substituted.

Data on state area are readily available. One source is the Statistical Abstract of the United States (46).

P: per unit cost or price of abating one ton of air pollutant per square mile.

Data on per unit costs are not available so P is an implicit price, determined by using the expenditure identity: expenditures equals price times quantity. The expenditures on air pollution abatement is the sum of expenditure by state government (41) and by private industry (42). There are several categories of expenditure by both government and private industry, but only selected categories are used. On the government side, capital investment and intergovernmental grants were ignored. Investment is extremely lumpy, for example in one year one state made 90% of the capital investment. Intergovernmental transfers were not used for similar reasons and for the fact that they are not locally originating, hence are not reflective of demand. What remains is current operating expenditure which is taken to be largely labor input. On the private industry side, both categories, current operating expenditure and investment were included, although investment was lagged one year. All these categories were summed to give total expenditure on air pollution abatement. The per unit cost was then calculated as total expenditure on abatement divided by total abatement per square mile.

Y: gross personal income.

Data for gross personal income are readily available. This particular series, State Personal Income was found in the Survey of Current Business (48).

ATT_a: attitudes of state CTVs environmental quality lagged one year. The lag is necessary as spending in the current year is decided in the previous year, hence it is attitudes in the past year that influence current spending levels. This is proxied by the votes of the state congressional delegation on environmental issues. An index is constructed, 0 to 100, with higher values indicating greater pro-environmental stance. This index is scaled to fall within limits 0 to 2 to conform with the model.

The League of Conservation Voters (26) provides a scorecard for the U.S. Congress on environmental issues. Each year since 1971, the House of Representatives has been graded, member by member, by the League on environmental issues. Thus, a delegation environmental average score can be determined and this is held to be reflective of a state's CTVs attitudes about air quality.

E/SM: Total point emissions of air pollutants per square mile for the previous year

Data on emissions by air pollutant by state by year are available (51). Data for the year 1976 were unavailable and thus the average of 1977 and 1975 was used.

A mixed term: $Z = \psi^{\mu} \left[k + (1 - k)\hat{\psi}\right]$,

where

ψ: percentage that instate generated air pollution abatement requirement is of actual abatement.

$\hat{\psi}$: percentage of instate produced emitter goods consumed instate,

k: the percentage of total expenditures on abatement that is state government expenditures.

Of all the variables in the mixed term, only k is known. Hence, this term cannot be used in the regression analysis. For the consequences of omitting a variable from a correctly specified regression equation, see the discussion in Chapter IX, Estimation, Results and Conclusions.

Marginal Cost of Air Pollution Abatement

The marginal cost equation is:

$$\ln Q = \beta_0 + \beta_1 \ln P - \beta_2 \ln w_g - \beta_3 \ln w_i - \beta_4 \ln r + \beta_5 \ln E/SM,$$

where

Q: defined previously under Demand for Air Quality,

P: defined previously under Demand for Air Quality.

E/SM: defined previously under Demand for Air Quality.

w_g: wage rates of state government employees engaged in air pollution abatement activities.

There are published data (43) on state governmental payrolls and employment by function. Air quality control is not separately identified as a function therefore the "general control" category was selected. By dividing the monthly payroll for "general control" by the number of full time equivalent employees in that category a monthly wage is calculated.

w_i: wage rates of private industry employees engaged in air pollution abatement activities.

There are published data (40) on SIC payroll and employment for production workers in each state. For each SIC industry in each state, payroll is divided by employment to yield a monthly wage rate. Then for each state the percentage of total abatement by each SIC code (42) is multiplied by the wage rate in that SIC code. These weighted wage rates are summed to get a weighted average wage rate for private industry abatement workers in the state.

r: user cost of capital

Capital in this model is all purchased capital so that r represents the user cost of owning and employing capital goods rather than just a flow of capital services as would be the case if the capital goods were leased. User cost of capital consists of three parts: (a) the opportunity cost, (b) depreciation, (c) appreciation. See (Branson (7), p. 230ff) for details. These are proxied as follows: The opportunity cost by the prime rate (13) times the cost of the air pollution abatement equipment (APAE) ordered. There are data on number of units of APAE shippped and value of shipment (44) for particulate and gaseous abatement. The price of the new capital is determined by dividing value of shipments by units shipped for each type of particulate and gaseous abatement equipment. The price for each type is then weighted by the percentage by that type of total value shipped under each class (particulate, gaseous). All types under each class are then summed to give a weighted price for particulate equipment purchases and a weighted price for gaseous equipment purchases. These two prices are then weighted by percentage that each class is of the sum of abatement of the two classes (42). The price of new air pollution abatement consists of the sum of the weighted prices for particulate and gaseous abatement equipment for each state. Depreciation is calculated as an arbitrary 10 percent of the new cost of air pollution abatement equipment. Appreciation was calculated from an index of new plant and equipment prices (38) times the cost of new abatement equipment.

All these data series were collected for all 50 states for the years 1974-78, with the exception of investment attitudes, and emissions which were collected for 1973-77.

Price Indexes

The model is estimated in constant 1972 dollars. This required deflating all the monetary series. The following deflators were used:

Personal Consumption Expenditures Index (47) is used to deflate gross personal income.

Wages of Manufacturing Workers Index (47) is used to deflate private industry abatement workers wage rate.

Air Pollution Abatement Plant and Equipment Index (38) is used to deflate private industry investment in air pollution equipment.

Regulation and Monitoring of Pollution Abatement Index (38) is used to deflate state government abatement employees wage rate.

Pollution Abatement and Control Index (38) was used to deflate current operating expenditure for air pollution abatement by private industry.

CHAPTER IX. ESTIMATION, RESULTS AND CONCLUSIONS

A theoretical model of the demand for air pollution abatement and the marginal cost of supplying air pollution abatement was developed in Chapter VII. In the same chapter, it was shown how this model could be put in such a form that it could be estimated statistically. Chapter VIII laid out the definitions of the data, described how different series were constructed and gave the data sources. This chapter will describe the empirical model, its limitations, the econometric techniques used, the results obtained and what new knowledge can be drawn from this research.

Estimation Model

The model, as previously developed, consists of a demand equation of the median voter for air pollution abatement, a marginal cost equation for providing air pollution abatement and an equilibrium condition linking the two. For reference, the model and its variable definitions are listed below:

9.01 Demand: $$\ln Q^d = \alpha_0 - \alpha_1 \ln P^d + \alpha_2 \ln Y + \alpha_3 \ln ATT_a + \alpha_4 \ln E/SM - \alpha_5 \ln Z,$$

where

Q^d: air pollution abatement demanded, measured in terms of abatement per square miles ('000 tons/square mile),

P^d: implicit per unit cost or price of abatement ('000\$/('000 tons/square mile)), the price CTVs are willing to pay,

Y: gross personal income ('000\$),

ATT_a: index of ideological attitudes in the previous year about environmental quality, pro-environmental > anti-environmental,

E/SM: emissions per square mile in the previous year - a measure of the stock of air pollution ('000 tons/square mile),

Z: a mixed term of several variables relating to transboundary effects.

9.02 Marginal Cost: $P^{mc} = \beta_0 + \beta_1 \ln Q^s + \beta_2 \ln w_g + \beta_3 \ln w_i$

$$+ \beta_4 \ln r - \beta_5 \ln E/SM$$

where the variables not already defined are

Q^s: quantity of air pollution abatement supplied ('000 tons/square mile),

P^{mc}: price at which abatement is supplied,

w_g: wage rate of government workers engaged in air pollution abatement activities ('000\$/month),

w_i: wage rate of private industry workers engaged in air pollution abatement activities ('000\$/month),

r: user cost of capital ('000\$).

9.03 Equilibrium Condition: $\ln P^d = \ln P^{mc}$.

In equilibrium, the price the CTVs are willing to pay must equal the marginal cost of supplying air pollution abatement.

Simultaneity

This model was estimated simultaneously to capture all the interdependencies between the median CTVs, the state governments and the in-state private industry emitters. The decisions for abatement in one year are made largely in the previous year, when state governments act, through their legislature, to fund air pollution abatement oversight and enforcement in the coming year. At the same time, industry is deciding on this year's investment in air pollution abatement capital goods and employment levels or whether and how much to fight EPA implementation regulations. It is during this time that each of the involved parties attempts to read the other in order to produce a level of abatement consistent with the desires of the median voter and capabilities of private industry. Industry tries to influence the public in general and the state legislatures in particular in order to minimize the enforcement of existing air pollution laws and regulations. Public interest pressure groups plead for additional abatement and the state legislatures try to balance competing air pollution abatement demands. Reflecting this in the model, the attitudes variable, the pollution stock variable and the level of investment were all lagged one year. The level of investment does not appear explicitly but is used to calculate the implicit price of air pollution abatement.

Data

The data consist of a pooled time-series cross-section sample of the fifty states of the United States for the years 1974-1978. For details, see Chapter VIII. All the monetary series (expenditures, wage rates, income) were deflated by appropriate deflators to put money data in terms of constant 1972 dollars.

One limitation of this model is that a data series cannot be formed for Z. Z is a mixed term, an expression of several variables, for some of which no data exist. Therefore, Z will have to be dropped from the demand equation. Kmenta (23, p. 392) shows that if the omitted explanatory variable is uncorrelated with the included explanatory variables, then the estimators of the coefficients (except the intercept) will be unbiased, although the variance of the estimators will be biased upwards, leading to overly conservative tests of significance. It is assumed here that Z is uncorrelated with the other independent variables in the demand equation. If this is, in fact, an unreasonable assumption, then the coefficient estimates will be biased.

Estimation Techniques

The model was estimated using two-stage least squares (2SLS) to avoid simultaneity bias and inconsistency. As there has been unavoidable misspecification of the demand equation by dropping the variable Z, systems techniques such as three stage least squares (3SLS) are, for the most part, less useful. That is because these systems estimation techniques are sensitive to the specification of the model. According to Pindyck and Rubinfeld (33, p. 287): "A serious specification error in one equation can affect the parameter estimates in all equations of the model."

Pooling time-series and cross-section data present additional econometric problems. Ordinary least squares (OLS) estimates restrict the model by assuming constant slope and intercepts over time and cross-section observations. The decision to pool the data is based on the belief that the structural coefficients do not change over time, but the assumption of constant intercepts is not necessary. One method to avoid the assumption of constant intercepts over time and cross-section units would be to use dummy variables: N-1 cross-section dummies (49) and T-1 time-series dummies (4), for a total of 53 dummies. This approach was taken to some degree in the marginal cost equation. Time dummies and regional dummies were included in some of the estimations. The time dummies were never significant and are not reported. Regional dummies proved to be a useful addition in explaining the regional distribution of the costs of air pollution abatement. The demand equation was not estimated with either time or cross-section dummies as it was felt that the nature of demand makes it inherently stable over time and cross-section, thus the constancy of the intercept assumption seemed less restrictive. An extension of the dummy variable technique (covariance model) is the error components model. The error components model breaks up the error term into three component parts: cross-section, time-series and combined. The error components model treats the intercept terms as random variables (one time-series one cross-section) rather than as a group of coefficients. To apply OLS to a pooled sample is to assume, in terms of the error components model, that the intercepts do not vary randomly. The error components model is not directly applicable to the estimation of simultaneous equations. All of the above estimation methods provide unbiased and consistent coefficient estimates although with different efficiencies. In terms of efficiency, error components is more efficient than covariance while OLS is the least efficient of the three.

Other econometric problems associated with using a pooled time-series cross-section data sample are heteroscedasticity and serial correlation. Heteroscedasticity was not thought to be an important influence because many of the variables are on a per square mile basis thus reducing the likelihood of increasing error variance with increasing magnitude of the independent variable. Nevertheless, the sample was sorted by gross personal income (one of the variables not on a per square basis) and the Goldfeld-Quandt test for the presence of heteroscedasticity was performed. The null hypothesis of homoscedasticity was rejected but only after discovering that the Mean Squared Error (MSE) was higher for low income states than for high income states. This surprising result was taken as an indication of "over-correction" by the use of variables on a square mile basis. Several transformations of the data were attempted in order to correct for heteroscedasticity but none proved satisfactory. With heteroscedasticity remaining, the OLS (or 2SLS) estimates still will be unbiased and consistent although no longer efficient and the estimated variances of the estimated coefficients will be biased (Pindyck and Rubinfeld (33), page 96). Finally, using a pooled time-series cross-section data sample, there is the possibility of serial correlation. The use of Durbin-Watson's d-statistic is not appropriate to detect the presence of first-order autocorrelation in a pooled sample so it was not reported. The problem of serial correlation in this model is thought to be small given the time period chosen: 1974-1978. This included a severe recession then recovery, meaning that the errors would be unlikely to follow a simple autogressive process. No correction for serial correlation was made.

Results

The results from the estimation of the initial model are reported in Table 9.01. In general, the results are mixed. The demand equation performed particularly well with all coefficient signs as predicted by theory and all the coefficient estimates statistically significant at the 10 percent level. The marginal cost equation did not do as well. The sign on the user cost of capital is unexpected, but the coefficient is statistically insignificant. The coefficient estimate for the quantity term was also insignificant. It should be recalled that one of the effects of omitting a variable is to bias the variance of the coefficients' estimators upward, reducing the magnitude of the t-statistics and making the statistical significance of the coefficients appear weaker than they really are. The coefficients on the remaining terms in the marginal cost function all have the anticipated signs and are statistically significant.

Table 9.01. Estimation results

Technique	Demand Equation: Q = f(Price, Y, ATT_a, E/SM)				
	P (-)[a]	Y (+)	ATT_a (+)	E/SM (+)	R^2
2SLS	-0.271 (-3.66)[b]	0.478 (6.53)	0.272 (2.96)	0.684 (12.52)	0.85

Variable Definitions:

P: per unit cost of abatement

Y: gross personal income

ATT_a: ideological view of air quality, pro-environment > anti-environment

E/SM: stock of air pollution, emissions per square mile

[a]Signs as predicted by theory.

[b]T-statistics.

[c]Sign is contrary to that predicted by theory.

*Insignificant at the 0.10 level.

Marginal Cost Equation: $P = g(Q, w_g, w_i, r, E/SM)$

Q	w_g	w_i	r	E/SM	R^2
(+)	(+)	(+)	(+)	(-)	
0.191 (0.94)*	0.927 (1.83)	4.007 (8.06)	-0.125[c] (-1.01)*	-0.511 (-2.371)	0.35

Variable Definitions:

Q: quantity of air pollution abatement

w_g: wage rate for government employees

w_i: wage rate for private industry employees engaged in air pollution abatement

r: user cost of capital

Discussion

Demand equation

Demand equation coefficient estimates   The price elasticity of demand is the coefficient estimate of -0.271. This would say that the demand for air pollution abatement is rather price insensitive, that air pollution abatement is more in the nature of a price inelastic necessity rather than a price elastic luxury good. There are at least two reasons for this price inelasticity. One may be a permanent change in tastes and preferences such that very dirty air is no longer tolerated and that voters have come to expect and demand the abatement necessary to provide a sufficient level of air quality. In a sense, spending on air pollution abatement is not a discretionary expenditure subject to shifting preferences, but rather an inherent part of modern life.

A second reason that the demand for air pollution abatement may be price inelastic is the magnitude and circumstances of the expenditures involved. The increased tax burden on the median voter due to air pollution monitoring and enforcement by state agencies and the price increases on emitter goods is bound to be small. In 1975, California (state and private industry) spent roughly $14.60 per person for air pollution abatement, while New York spent $5.69, Iowa spent $13.44 and Mississippi spent $26.09. With 10 or 20 percent increase in the implicit price, it is not going to have that big of an impact, especially if air pollution abatement is an ongoing program. Even though cross-section studies are often thought of as giving long run results, the air pollution abatement institutions and programs during this time period, with the possible exception of California, are immature, and therefore there would still be some resistance to change not found in a true long-run demand situation.

The second variable is gross personal income which is estimated with a coefficient of 0.478. This coefficient estimate is the income elasticity of demand: a 10 percent increase in gross state income would increase the demand for abatement by nearly five percent. One would expect air pollution abatement to be somewhat income elastic, that is, the demand for abatement would increase by the same percentage (or greater) as does income. Income here is gross personal income not per capita personal income. It can be shown[1], however, that the coefficient on the gross income variable should be the same as on the per capita income, if per capita income and population were substituted for gross income. Harrison and Rubinfeld (20), and Nelson (31) find income elasticities (based on household, not per capita, income) of approximately 1.0. This is a logical result in their models; higher priced property sites generally have better air quality, as incomes rise individuals move up to better, more expensive dwellings, where the air is cleaner. In the present study, as incomes rise, individuals demand more abatement for society in general, abatement being a normal good, but the increase in state-wide abatement may not have as dramatic an effect upon them as would switching neighborhoods. All neighborhoods may be somewhat

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[1]See Appendix C.

cleaner (in terms of air quality) if state-wide abatement increases but the relative cleanliness among neighborhoods may not change much. Therefore, those individuals with rising incomes and a positive preference for air quality will both move to a cleaner neighborhood and support more air pollution abatement. But the impact of increased state wide abatement on these individuals would be far less than switching neighborhoods; therefore, their demand for state wide abatement will be less income elastic.

The third variable is the attitudes variable, with a coefficient of 0.272. This attitude elasticity of demand says that a 10 percent positive shift in people's preferences for environmental quality will increase abatement almost three percent. Given the slow rate of change of people's preferences, this result would say that environmental sensitivity campaigns would have to cause dramatic shifts in attitudes before large increases in abatement would occur. But then in some states there is room for considerable percentage change. New Mexico, for instance, has in several years an attitude index score of 20 out of a possible 100, compared with Massachusetts's rating of 77.

The final variable on the demand side is the stock of air pollution with a coefficient estimate of 0.684. This is more elastic than the other estimates as one might expect. A 10 percent increase in the stock of pollution would increase demand for abatement by nearly 7 percent, as the state's environment would probably be able to naturally assimilate some portion of the emissions. The size of the coefficient indicates that people are aware of their environment and this awareness plays a significant role in their decisions about air pollution abatement.

Demand model parameter estimates The demand model in Chapter VII predicted that the coefficients for price and income would be of the same magnitude but opposite in sign. As shown above, the coefficient estimates in question are -0.271 (price) and 0.478 (income). The actual coefficients are expressions involving parameters of the utility function. In this case, they are equal to $-1/\mu$ (price) and $1/\mu$ (income). The null hypothesis H_0: $\alpha_1 (= -\frac{1}{\mu}) + \alpha_2 (= \frac{1}{\mu}) = 0$ is rejected even at the 2% level. Because the estimates do not conform to the theoretical prediction, one cannot safely calculate values for μ. But in both instances, the coefficient estimates call for values of μ in excess of unity. Recall that μ is the net exports parameter, and $\mu > 1$ means that on average the states are net importers of pollution. This is the expected result. This would mean that there are fewer exporting air pollution than importing, discounting international air pollution movements. This seems to fit the nature of this country with perhaps a dozen industrial states doing the net exporting to the remainder. If true, there would be a need for stronger federal intervention to reduce the flow of air pollution between states.

Other results called for by the theoretical demand model include a value of unity (μ/μ) for the stock of air pollution coefficient (actual value: 0.68). The estimated value is close to one but statistically different from one. Another result is the activism parameter α, calculated as part of the coefficient on the attitudes variable:

$\alpha/\mu = 0.27$. Although the value of μ is not known with certainty, its value was inferred to be greater than one but not so large as to make $\alpha \geq 1$. If so, this would imply low activism levels on the part of the median CTVs, a not unexpected result given the general apathy of the middle 1970s.

Marginal Cost Equation

Marginal cost equation coefficient estimates The first variable in the marginal cost equation is quantity of abatement. The coefficient is not statistically significant; thus one cannot analyze its magnitude without peril. But assuming that quantity does belong in the marginal cost equation it would seem to be safe to make some comments as if the actual magnitude of the estimate is in the inelastic range. If the price of abatement was inelastic with respect to quantity, with a 10 percent increase in quantity abated increasing abatement price 2-4 percent, then the following would be pertinent. States could increase their abatement requirements to get cleaner air without imposing heavy costs on either taxpayers or consumers. This is because the marginal cost curve would be fairly "flat", especially if the elasticity was around 0.2. If true, this would be important evidence to rebut some of the more excessive claims about the impending costs associated with additional abatement.

The elasticity of the marginal cost of abatement curve with respect to price has important policy implications. Alt and Miranowski (1) show that in a world with less than perfect information the social cost of error from applying different policies to regulate pollution emissions depends upon the elasticity of the marginal cost/supply curve of abatement. According to Alt and Miranowski (p. 48ff)

> If the abatement supply curve is inelastic, a price incentive scheme implies less potential social cost of error. If the abatement supply curve is elastic, setting the level of abatement by direct regulations or by auctioning a fixed quantity of pollution rights implies less potential cost of an error.

An inelastic (price with respect to quantity) marginal cost curve means that for a large change in quantity abated, there is a small change in price. This is normally considered an elastic situation, as price elasticities are defined in terms of quantity with respect to price. Therefore, an inelastic marginal cost curve for abatement is the same as Alt and Miranowski's elastic supply curve of abatement. With inelastic marginal cost/elastic supply, direct regulation or auction rights are the policy types that provide the lowest cost of social error. Direct regulation is the course presently taken in air pollution abatement; thus, the low marginal cost/high supply function elasticity estimates provided by this model confirm the choice of policy in general.

The second variable in the marginal cost equation is the wages of government abatement workers. The elasticity of the price of abatement with respect to government wages is near unity. The size of this elasticity is to be expected despite the fact that government expenditures on air pollution abatement are a small portion of the total spending for air pollution abatement: in Illinois in 1974, the state government spent 2.5%, in Texas in 1975 the state government spent 2.1% and in Mississippi in 1978, the state government spent 1.7% of the total instate expenditure for air pollution abatement. One of the reasons some states may pay their air pollution abatement employees more than other states do is that their skill mix is higher. Those states with higher skill mixes in their air pollution abatement monitoring and enforcement employees are generally those states that provide higher levels of all government services. Some of the states paying the top government wages are Iowa, Michigan, Oregon, California, Illinois, Pennsylvania and Alaska. High levels of air pollution monitoring and abatement enforcement on the part of government translates into higher abatement costs (both current expenditure and investment) for private industry in the state. Thus, moving from low government wage states to high government wage states implies going from low cost of air pollution abatement to states where the costs of abatement, because of the increased enforcement, are higher.

The third variable in the marginal cost equation is the wages of the private industry abatement employees. Here, the elasticity of the price of abatement with respect to wages is four. Private industry wages capture several characteristics. One is the industrial base of the state. A second is the industrial mix of the state and closely related to that is a third attribute, skill level of the private industry workers.

The lightly industrialized states have lower emissions of air pollutants, lower abatement of air pollutants and generally lower wages than the industrialized states. For example, in 1976 Rhode Island emitted 41,700 tons, abated 137,490 tons and had a monthly wage (constant

1972 dollars) of \$434. Texas in 1976, emitted 591,580 tons, abated 682,826 tons and had a monthly wage (constant 1972 dollars) of \$663. Obviously Texas and Rhode Island are quite different states in terms of industrial base and industrial mix. The larger, more industrialized states emit/abate more air pollution while employing more expensive labor. The private industry wage differential between states in the cross-section sample captures these differences in size of the industrial base and industrial mix.

Further, lightly industrialized, low wage states spend less on abatement plant and equipment. Rhode Island's private industry in 1976 invested \$622,000 in air pollution abatement and equipment. Private industry in Texas invested \$168M during the same year.

As a result of two factors, low labor costs (reflecting differences in industrial mix) and low investment requirements (due to differences in industrial base), Rhode Island was able to abate air pollution for \$28 a ton while Texas paid \$45 a ton.

The private industry wage reflects not only labor costs, but differences in the size of the industrial base and industrial mix as well as investment in air pollution abatement capital goods. Therefore, it is not surprising to get a very elastic marginal cost with respect to private industry wage.

The fourth variable in the marginal cost equation is that of user cost of capital. It performed poorly, with a sign contrary to expectations but statistically insignificant. The cause for this may be in the construction of this variable. See Chapter VIII for details. The problem may be in the selection of the prime rate as opportunity cost of capital, perhaps the long term corporate bond rate would be more appropriate. Secondly, the appreciation term or expected rate of inflation in air pollution abatement capital goods, is particularly difficult to model. Branson (7) cites the work of Joregenson and Bischoff as examples of studies that have modeled the expected price change of capital goods term using lag distributions of past price changes. Lag structures, while appropriate for time-series, are not so for a basically cross-section model such as this one. Thus, the use of current period air pollution abatement plant and equipment price changes may not be capturing the expectations of future price changes.

Another possible cause for the poor showing of the user cost of capital may be the log transformation (which is obviously nonlinear). Simple correlations between price of abatement and user cost of capital are positive but insignificant, while the log transformed user cost and price of abatement are correlated negatively and significantly. As mentioned in Appendix C, of all the variables investigated only user cost of capital and per capita income (which was not used) were affected to any large degree by the log transformation. While simple correlations are hardly proof, they do give some indications of possible problems.

The last variable in the marginal cost equation is the stock of air pollution. The elasticity of abatement price with respect to the existing stock of air pollution is -0.511. That is to be expected. One environment that is 10 percent worse than another will experience a 5 percent lower price in the process of abatement. In very dirty environments, the marginal abatement units are less expensive, easier to bring about. Conversely, in cleaner environments additional abatement is costly. Continuing the previous example, in 1976 Texas's stock of air pollution was 22 tons per square mile, Rhode Island's was 34 tons.

Marginal cost model parameter estimates The parameter estimates of the marginal cost equation are functions of the coefficient estimates. See Appendix B for details. Each parameter estimate is partially a function of the coefficient on the user cost of capital which was not statistically different from zero. The parameter estimates would be seriously biased to an unknown degree if calculated using zero values for the coefficient estimate of the user cost of capital. Therefore, the parameter estimates were not calculated.

Comparison With Other Studies

Elasticities

There are only two studies that estimate price and income elasticities of demand for air quality, Harrison and Rubinfeld (20) and Nelson (31). As the Harrison and Rubinfeld study has been approvingly cited by Freeman (14) and as both studies are on similar subjects, yielding similar results, the comparison will be confined to Harrison and Rubinfeld (hereafter known as H-R). This study uses the hedonic price technique as was discussed in Chapter III. They find an income elasticity of demand of 1.0 and a price elasticity of -1.2. Their measure of income is household income, and the implicit price is a willingness-to-pay for sites with cleaner air.

The income and price elasticities of demand estimated from the study at hand are 0.48 and -0.27 respectively. The differences between the two studies are significant enough to account for the disparity.

H-R uses a measure of air pollution (e.g., NO_x per cubic meter) as the quantity variable whereas the present study uses abatement of pollution. H-R uses individual households as observations whereas the present study focuses on states as the unit of observation with all the necessary aggregation that it implies. H-R is concerned with the air pollution just at the home residence, not at work, not out in the community, and not at recreation sites. The present study presents the median voter's aggregate demand for all those areas. Although the demand for air pollution abatement may be elastic with respect to price and income in any or all of the different sites, there are fewer trade-offs after aggregation at the state level, resulting in a more inelastic curve. H-R is concerned with pollution from all sources, whereas the present study excludes mobile sources of air pollution. The framework of the two studies is different as well with the consumer able to freely choose between houses with good and bad air quality (along with their many other characteristics) in the H-R study. In the present study, to have a choice would mean a willingness to move out of state which most ordinary people won't do just for air quality. That unwillingness to move to different states with higher or lower implicit price of abatement builds an additional inelastic element into the model. In sum, then, one would not expect identical estimates from both studies.

Distribution impacts of air pollution policy

Gianessi et al. (17) have argued that there are profound distributional impacts (who gets the benefits vs. who pays the cost) of air pollution policy. Specifically they find the benefits to be highly concentrated while the costs are widely dispersed. In the Gianessi study, benefits and damages (health, property and productivity) were assumed to be synonymous, meaning that those areas with the dirtiest air would get the greatest benefit. This also assumes, in the context of the present study, that abatement will equal emissions. Further, Gianessi rejects the public good aspect of air pollution/air pollution abatement in favor of a more private good approach (e.g., air quality as a costly attribute of housing).

Baumol and Oates (3) argue that environmental programs, when viewed as public goods, will be worth more to the rich than poor because one, environmental goods are normal goods and two, the level of environmental quality, if provided through a median voter framework will be higher than that desired by the poor. In a Teibout world, they find different results. General improvements in environmental quality will benefit both rich and poor ("a rising tide lifts all boats") while minimum standards (such as demanded by the Clean Air Act) may have its primary impacts on poorer, dirtier neighborhoods. These conclusions are qualified (p. 203):

> First, although such programs may bring greater improvement measured in physical terms to areas of poorer residents, it cannot be stated unequivocally that the nature of these increases in environmental quality will be greater to the poor than to the rich. Depending on the geographical pattern of the improvements, the income elasticity of demand for environmental

> quality, and current income differentials, the value in money terms of a lesser increase in, say, air quality may still be greater in rich, than in poor, areas. [emphasis in original]

With the public good/median voter demand/marginal cost model used in the present study, the quality of the air in the state is determined by the level of abatement in the state (ignoring transboundary effects for the time being). The most likely amount of abatement undertaken will reflect the environment and tastes of the median voter.

There are two ways that nonnormal distributions of income could affect the median voter's demand for abatement. One is through the income tax burden of paying for governmental monitoring and enforcement, the other is the consumption tax burden, placed on consumers by producers to fund the cost of private industry air pollution abatement.

If, as likely, the distribution of income is positively skewed ("to the right"), then the average income will be above the median income. In this case, the median voter/income recipient will pay for government air pollution abatement activities at a bargain price if, as assumed in the present study, the funds for governmental monitoring and enforcement are raised through a proportional income tax. Therefore, with the median voter dominating, the greater the positive skewness to the income distribution, *ceteris paribus*, the greater will be the funding of government enforcement of air pollution standards, resulting in more abatement.

The second way that income distribution would affect the median voter/income recipient would be indirectly through air pollution abated-caused price increases in emitter goods. If the bundle of emitter goods bearing the consumption tax was consumed equally by all income classes but constituted a larger portion of the income of those in the lower income classes, then the funding of private industry air pollution abatement could be seen as regressive. If the same amounts of emitter goods are not purchased by every income class, then the distribution of income serves to distribute the costs of air pollution abatement. Consider, for example, a situation where 60% of income recipients get only 30% of total income. If the emitter industries in the state produce only bars of soap (with a consumption tax of a penny a bar) and every individual, rich or poor, uses 100 bars a year, then obviously, those receiving 30% of the income will pay 60% of the private industry air pollution abatement costs. If, on the other hand, the emitter industries produce only luxury motorcars, then those receiving 70% of the total income will be the only group able to purchase the goods and pay the consumption tax for air pollution abatement. In this latter case, those receiving 70% of the income pay 100% of the private industry air pollution abatement costs.

Therefore, the median voter/income recipient's demand for air pollution abatement is affected by direct income distribution effects (proportional income tax for state government monitoring and enforcement) and indirect income distribution effects through consumption of emitter goods. The net effect is an empirical question.

To test the strength and direction of these income distribution effects, a term reflecting the skewness of the income distribution is calculated for every state. This measure of skewness is appropriately named the coefficient of skewness and is the third moment about the mean. See either Merrill and Fox (29, p. 31ff) or Mood et al. (30, p. 75ff) for details. The coefficient of skewness was calculated from a distribution of family income for 1975 given in the State and Metropolitan Area Data Book (45). Once calculated, the coefficient of skewness was assumed to be the same in all years of the study, 1974-1978. This assumption seeems reasonable in view that state income distributions probably change quite slowly over time. The model was reestimated including the coefficient of skewness as a variable (in log form to be consistent with the rest of the model) in the demand equation to try to capture the income distribution effects. The new results are shown in Table 9.02.

The results in Table 9.02 show that inclusion of the coefficient of skewness alters none of the previous coefficient signs and perturbs the magnitudes and significances of previous coefficients only to a small degree. Some exceptions proved to be (1) the coefficient on price in the demand equation which became even more inelastic (-0.173 vs. -0.271), a result due to the isolation of the price term from the effects of income distribution, and (2) the magnitude and significance of the coefficient on the quantity term in the marginal cost equation. The coefficient estimate on the quantity grew (0.324 vs. 0.191) and the t-statistic improved (1.65 vs. 0.94) for marginal significance at the 10% level. This shows that the addition of the coefficient of skewness improves the predicted values of endogenous variables generated during the first stage of 2SLS. Although the R^2's for the first stage are not significantly higher, the inclusion of the coefficient of skewness may be, in the words

Table 9.02. Estimation results including coefficient of skewness

	Demand Equation: Q = f(Price, Y, ATT_a, E/SM, SKEW)					
Technique	P (-)[a]	Y (+)	ATT_a (+)	E/SM (+)	SKEW	R^2
2SLS	-0.173 (-2.42)[b]	0.441 (6.09)	0.385 (4.18)	0.702 (12.92)	1.562 (4.76)	0.85

Variable Definitions:
- P: per unit cost of abatement
- Y: gross personal income
- ATT_a: ideological view of air quality, pro-environment > anti-environment
- E/SM: stock of air pollution, emissions per square mile
- SKEW: coefficient of skewness

[a]Signs as predicted by theory.

[b]t-statistics.

[c]Sign is contrary to that predicted by theory.

*Insignificant at the 0.10 level.

Marginal Cost Equation: $P = g(Q, w_g, w_i, r, E/SM)$					
Q	w_g	w_i	r	E/SM	R^2
(+)	(+)	(+)	(+)	(-)	
0.325	0.893	4.070	-0.154[c]	-0.649	0.33
(1.65)	(1.68)	(7.81)	(-0.98)*	(-3.08)	

Variable Definitions:

Q: quantity of air pollution abatement

w_g: wage rate for government employees

w_i: wage rate for private industry employees engaged in air pollution abatement

r: user cost of capital

of Gujarati (19, p. 378), ". . . to [better] purify the stochastic explanatory variable [price, in the marginal cost equation] of the influence of the disturbance term [in the demand equation]," thus giving better estimation results.

The coefficient estimate on the skewness variable proved to be positive, elastic (1.56) and with a significant t-statistic (4.76). The magnitude of the elasticity means that a 10 percent increase in the skewness of the income distribution increases the demand for air pollution abatement by almost 16 percent. The median voter/income recipient apparently feels that a positively skewed income distribution is much to his advantage: higher income classes pay more of the proportional income tax for government activities and income groups other than the median voter/income recipient's own pay a larger percentage of the consumption tax on emitter goods. The size of the abatement elasticity with respect to income distribution skewness suggests that the assumption that the median voter has the median income may be questionable. If voters in general have higher average incomes than the population in general, then the median voter would have an income higher than the median income recipient. If true, this would make the median voter more likely to demand more abatement, given that the bundle of emitter goods produced is such that the consumption tax will fall on the lower income classes, as demonstrated in a earlier example. The median voter will be better off, despite the higher income classes having to pay a larger amount for the government side of air pollution abatement, because the cost of government air pollution abatement activities is small compared to the air pollution abatement expenditures undertaken by private industry which are financed through emitter goods price increases. In 1975, for instance, Pennsylvania state government spent $3.7M on air pollution abatement activities while private industry in Pennsylvania spent about $225M. Therefore, if the median voter has an income closer to the average income, then a skewed income distribution would be much to his advantage. The strong showing of the coefficient of skewness makes this a distinct possibility and an avenue for further research.

The present study finds income distribution to be a significant factor in the demand for air pollution abatement largely because there can be shifting of the costs of abatement from those who are decisive in determining the quantity of abatement demanded (the median voter) to others, most likely lower income classes, who may have very different demands for air pollution abatement.

There is also the question of regional effects on the distribution of costs. To separate out the effects of regional factors on the cost of air pollution abatement, a series of regional dummies were included in the marginal cost equation. The results are reported in Table 9.03, with the region not having a dummy being the central states: Iowa, Nebraska, Minnesota, the Dakotas, Kansas and Missouri. Positive and significant coefficients for the Southeast, Southwest and West (marginally) indicate upward shifts in the intercept term in their respective marginal cost functions as compared with the central states baseline marginal cost function. Level of industrialization, industrial mix and geography largely account for these regions having higher marginal costs than the

Table 9.03. Estimation results including coefficient of skewness and regional dummies using 2SLS

Demand Equation: $Q = f(PRICE, Y, ATT_a, E/SM, SKEW)$

P	Y	ATT_a	E/SM	SKEW	R^2
(-)	(+)	(+)	(+)		
-0.271 (-5.32)	0.515 (8.62)	0.314 (3.88)	0.647 (14.37)	1.569 (5.06)	0.87

Marginal Cost Equation: $P = g(Q, w_g, w_i\ r, E/SM\ NE, SE, SW, WE, ME, H/A)$

Q	w_g	w_i	r	E/SM	NE	SE	SW	WE	ME	H/A	R^2
0.39 (2.35)	1.40 (2.89)	2.99 (6.47)	-0.09 (-0.69)	-0.59 (-3.45)	-1.45 (-5.65)	0.60 (2.53)	1.20 (4.17)	0.35 (1.44)	0.04 (0.15)	0.18 (0.44)	0.57

Dummy Variable Definitions:

NE: CT, DE, ME, MD, MA, NH, NJ, NY, RI, VT

SE: AR, LA, AL, MS, TN, KY, WV, FL, GA, SC, NC, VA

SW: AZ, NM, TX, OK

WE: MT, WY, CO, UT, ID, WA, OR, NV, CA

ME: OH, IN, PA, MI, IL, WI

H/A: HI, AK

central states. The Mideast results are something of a puzzle with the positive but insignificant coefficient, although the geography of the Mideast and central states is similar. New England, not surprisingly, has a negative coefficient, reflecting both its geographical situation (Altantic coast states, west-to-east flow of air) and its small industrial base.

The demand equation is only marginally affected as might be expected although the coefficient on price increased in absolute magnitude. The results, from including the dummy variables in the marginal cost equation, suggest that regional factors are important in the distribution of costs of air pollution abatement.

Benefits of air pollution abatement

The major benefits from air pollution abatement and the resulting clean air are (1) health benefits, (2) productivity benefits, and (3) property benefits. The health and property effects are generally considered to be very much more important than the productivity effects (Gerking and Schulze (16)). Thus only health and property will be considered here. Both of these sets of benefits have been estimated using the hedonic price technique. Taking health effects first, the primary (and controversial) data consist of the health risk (mortality rates) in being exposed to different levels of air pollution. Then, from safety studies, a willingness-to-pay for a statistical death avoided is selected. Using the health risk and the willingness-to-pay measure, the benefits of lower pollution levels can be calculated. Crocker et al.

(10) calculated (p. 71) the urban benefits from reduced mortality: value of safety for 60% air pollution control (reduce particulate and SO_2 concentration by 60%). They found the average individual safety benefit to be between $34-$106 per year. Using a completely different method, Crocker et al. also (p. 149)

> . . . calculated, under some extremely crude assumptions and on the basis of only a single sample, [emphasis theirs] that the representative individual would be willing to pay an undiscounted lump sum of $25,000 to be in the clean rather than the dirty environment.

Property studies (e.g., Brookshire et al., (9)) calculate rent gradients as a function of pollution levels. Pollution is entered in log form into an otherwise linear hedonic equation, thus making the price (the coefficient on air quality) a function of the level of air quality. After estimation, different quantities (levels of air quality) can be substituted into the hedonic rent gradient equations, and the rent differentials calculated. But as Brookshire et al. note (p. 172):

> Due to the estimated functional form of the rent gradient, the calculated rent differential is dependent upon the value of all other variables [House characteristics and neighborhood characteristics].

Brookshire et al. calculate sale price differentials for particular neighborhoods in southern California. These sale price differentials are calculated on the basis of a 30% decrease in air pollution. The sale price differentials are annualized and divided by 12 to give the monthly rent differentials. This makes comparison of benefits among studies (health, property, and the present study) quite difficult. Brookshire et al. found that (p. 173)

> Monthly rent differentials ranged from \$15.44 to \$45.92 for an improvement from fair to poor air quality [about a 30% improvement] and \$33.17 to \$128.46 for an improvement from fair to good air quality [another 30% improvement].

The present study estimates the demand curve for air pollution abatement as well as the marginal cost curve of providing abatement. The implicit price-quantity combinations derived from the expenditure data are assumed to represent a point of implicit market equilibrium hence the use of simultaneous equations' techniques. Therefore, consider Figure 9.01 which represents just such a point of equilibrium: $P^* Q^*$. Now suppose a tough new federal standard was introduced requiring the doubling of the level of abatement - would the CTVs be better off? The increase might be from Q^* to Q^r. But that level of abatement Q^r comes at a per unit cost of P^r, and the CTVs would only want Q^m. In the presence of federal government regulation, the short side of the market can't win, and the CTVs are forced to pay $P^rQ^r - P^*Q^*$ for the additional abatement, and suffer a loss of consumer surplus equal to the shaded area. Clearly, as a result of the new regulations, the CTVs are worse off despite having cleaner air.

The benefits studies to date make the implicit assumption of disequilibrium in the market for clean air. Consider Figure 9.02.

For both types of previous hedonic benefit studies (health, property), it is assumed that the level of abatement is less than desired. In this case, people would pay more for cleaner air or the situation where the abatement provided is Q_a at price P_a. There is a gain in consumer surplus to be made (the shaded area) if abatement is increased to Q^*. The maximum amount people would bid is $P^*Q^* - P_aQ_a$.

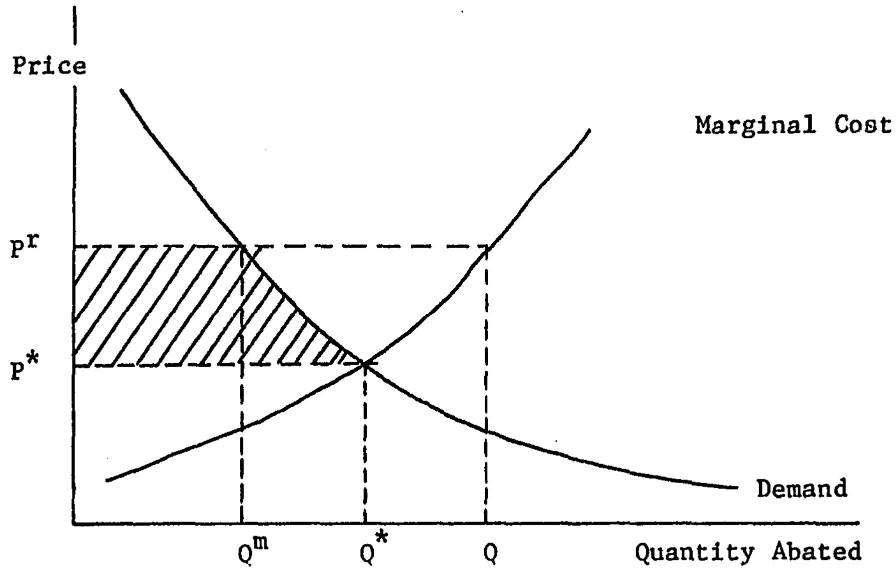

Figure 9.01 Initial equilibrium in implicit air pollution abatement market

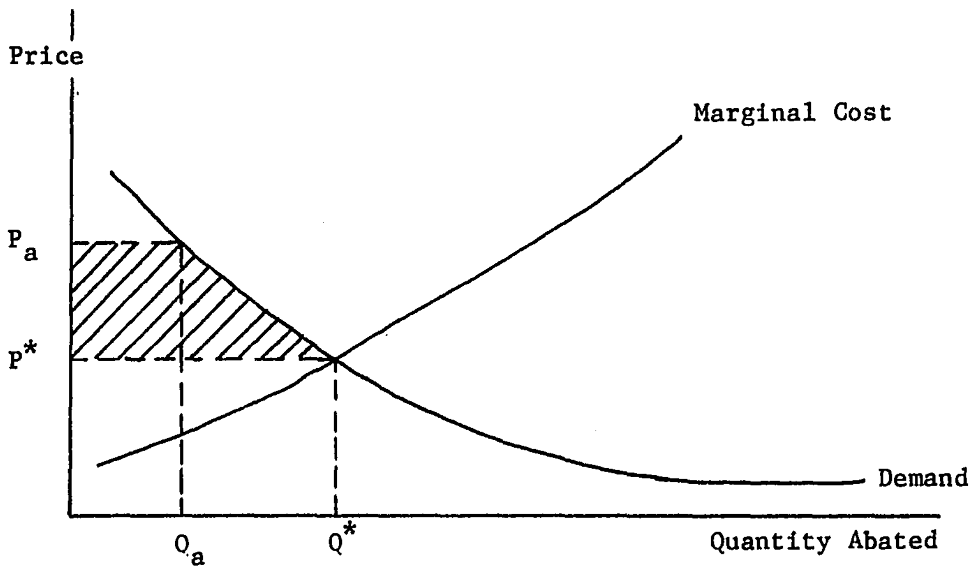

Figure 9.02 Initial disequilibrium in the market for air pollution abatement

Another difficulty in comparing benefit estimates from the health and property studies to implied benefits in the present study concerns the nature of benefits of air quality vs. demand for air pollution abatement.

Consider the following example. One could calculate the national health and productivity benefits from a reduced number of headaches per year. If aspirin were the only headache medicine, would the demand for aspirin yield information on the benefits of increased worker productivity, fewer sick days, fewer domestic disputes, lower suicide rates? Or would the demand curve for aspirin measure instead the benefits of lower priced aspirin? If someone purchases a 100 tablet bottle of aspirin for a dollar, does that mean the benefits of being free of a headache are two cents? It seems clear that to calculate the benefits of clean air one would need additional information beyond that provided by the demand curve for abatement.

The following benefits are calculated on the basis of an exogenous improvement in state air quality, what it would have cost to achieve that level of abatement. Because the improvement is exogenous, the abatement costs foregone can be viewed as a measure of "benefits."

From the marginal cost equation of the present study, an increase in abatement by 30% would increase price by 10%. Taking Iowa as an example using 1975 data, a 30% increase would boost abatement from 1,182,000 tons to 1,536,600 tons while price would increase from $25.14 per ton to $27.65 or an expenditure avoidance of $12.77M. Iowa would experience a per capita benefit from air pollution abatement of $4.44 per year per person or $9.52 a year per person for a 60% increase in abatement.

Similarly for California in 1975, a 30% increase in abatement would be worth $4.91 per capita per year while a 60% increase would be worth $10.51.

On the demand side, the potential benefits could be calculated by determining how far price would have to fall to produce a 30% and a 60% increase in the demand for abatement. Given the low elasticities involved (estimates are -0.173 and -0.271 for price elasticity of demand for abatement), the price of abatement would have to fall over 100%. In the case of zero price, the entire cost of present abatement would be the potential benefit. In the examples cited above, zero cost of abatement to state residents would produce $10.35 in benefits per year per person in Iowa, and a figure of $11.42 for California.

Summary of Findings

The present study uses median voter dominance to model the demand for air pollution abatement and cost minimization behavior on the part of state governments and private industry to derive the marginal cost curve for abatement. Although it uses the median voter model, the present study does not test it against competing theories; thus, the present study does not provide additional evidence as to the adequacy of the median voter model, other than to say that it seems to work well in this context. The question of whether governments provide services (such as air pollution abatement) at least cost (as is partially assumed in the present model) remains an arguable point in the literature. No additional light is shed on that question in the present study.

On the demand side, all of the variables that influence the quantity of abatement demanded, except the coefficient of skewness, were found to be moderately to highly inelastic. The reasons why this is so in each case vary, but the overall effect is that the quantity of air pollution being abated in each state resists change. Put another way, the factors that influence the demand for air pollution abatement do so weakly. The magnitude of change required in the independent variables before significant change can be made in quantity abated is quite large. This should not be an unexpected result given that much of the impetus for air pollution abatement comes from the federal government. The states are somewhat limited in the range of abatement they can accommodate: abatement requirements far beyond the federal standards would discourage new industries from coming in and would act as an incentive for industries presently located in the state to relocate to less demanding areas. Abatement enforcement that is too slack on the other hand may invite federal intervention or lawsuits from environmentally minded state residents. Therefore, states and private industries do react to the forces of demand but the effect is muted.

The present study does provide some new demand-for-air-pollution-abatement information to decision makers in private industry, state and federal government. First, many of the factors are those over which the decision makers have little control: gross state income, cost of abatement, skewness of the income distribution. Even so, as shown, with the exception of skewness, these factors are inelastic in their influence. The factors that decision makers can effect are attitudes and stock of air pollution. Attitudes about the environment are malleable to some degree as shown by the overall effectivenss of anti-litter campaigns. Although the attitudes elasticity is low (0.39), many areas are characterized by very weak preferences for environmental quality, hence there is room for large percentage increases in their attitudes. As for the stock of air pollution, it is useless as a control variable: if one wished to increase the demand for air pollution abatement it would be perverse to further dirty the environment to achieve that. The rule of thumb for decision makers thus far from the demand side is pretty much "steady as she goes."

Another result from the demand side is the elastic (1.56) coefficient of skewness measuring the skewness of the income distribution. This should give pause to those who order up air pollution abatement willingly on the presumption that costs and benefits are equitably shared by rich and poor alike. The result from the present study is that the greater the income distribution skewness (the larger the percentage of income in a smaller number of hands), the higher the demand for abatement. This would infer that those who are decisive in determining the level of air pollution abatement get an increasingly better deal in terms of paying for abatement as the income distribution becomes more skewed "to the right."

Overall then, the present study provides decision makers with a feeling for what factors influence the demand for abatement (and hence their controlability) and an indication that there are equity questions involved in the level of air pollution abatement provided.

The marginal cost side of the model is somewhat more traditional with the independent variables being factor prices plus the air pollution stock variable. Of great interest to decision makers is the elasticity of the marginal cost curve. As pointed out earlier, the magnitude of the elasticity has a definite bearing on which air pollution policy should be selected from a reduction in social cost of error point of view. Given the estimated low elasticity of marginal cost with respect to quantity, a policy of direct regulation or auction of a fixed quantity of pollution rights is preferred. Direct regulation is the present method of air pollution control. Therefore, the present study confirms the correctness of the general choice of air pollution abatement policy. The remaining marginal cost variable coefficients while insightful in other contexts, provide little information that can be acted upon by decision makers.

Comparison of studies estimating the benefits of air quality improvement to the present study is fraught with both conceptual and practical problems, the most significant of which are the determination benefits of air quality (which is undertaken in other studies) versus the demand for air pollution abatement (which is undertaken in the present study) and disequilibrium (other studies) versus equilibrium (present study) analysis.

The theoretical model moves median voter analysis into uncharted waters by attempting to incorporate costs and benefits that cross jurisdictional boundaries. Unfortunately, little hard empirical evidence was discovered that could shed light on the magnitude and direction of these cost/benefit flows. The theoretical model posits an estimable marginal cost function for a public good (air pollution abatement) and analyzes this marginal cost function simultaneously with the demand function. From a simultaneous equations point of view, the empirical results are encouraging and indicative of the benefits to be gained from abandoning the assumption of exogenous public good supply.

There are several avenues for further research. One would be to use more sophisticated econometric techniques in dealing with pooled time-series cross-section data. A good example, cited by Pindyck and Rubinfeld, is Heller (21). A second would be disaggregation of total air pollution into its component parts. Not only do different air pollutants most likely have different effects on individuals (and hence their demand for abatement), but the individual states air pollution load varies widely among states in its composition. A third extension would be to investigate the effects of including mobile source air pollution/ abatement into the model. Much of the urban air pollution seems to be directly related to automobile emissions. Since the 1970s was largely the decade of automobile emissions control, there would seem to be much that could be learned by such an extension. A fourth possibility would be to investigate in greater depth the regional effects on air pollution abatement, that is, for example, are different factors of different importance in New England and the West? A fifth, but no means final, extension would be to utilize disequilibrium analysis rather than assuming that the implicit price - quantity of abatement combinations in each state represent points of equilibrium.

APPENDIX A: IMPORTS AND EXPORTS OF AIR POLLUTION

Case 1: Imports = Exports ($\mu = 1$)

Consider a hypothetical state.

Let:

Q_a: actual abatement equal 100 tons.

Q_a^i: abatement needed for instate emitter sources equal 100 tons.

Q_a^x: exported pollution, that otherwise would be abated, equal 20 tons.

Q_a^m: imported pollution that must be compensated for, equal 20 tons.

$$Q_a = Q_a^i - Q_a^x + Q_a^m$$

$$= 100 - 20 + 20$$

$$Q_a = 100 \text{ tons}$$

As 100 tons of abatement is needed for instate sources and 100 tons is actually abated

A.1 $$\psi = \frac{\text{100 tons of instate abatement needed}}{\text{100 tons of instate abatement}} = 1$$

From 5.02 $Q_a = (\psi Q_a)^\mu$, it is seen that μ must equal one.

Case 2: Exports > Imports ($\mu < 1$)

Let:

Q_a: 100 tons.

Q_a^i: 120 tons.

Q_a^x: 40 tons.

Q_a^m: 20 tons.

$$Q_a = Q_a^i - Q_a^x + Q_a^m$$

$$= 120 - 40 + 20$$

$$Q_a = 100 \text{ tons}$$

Notice that the requirement for instate industry air pollution abatement is achieved through the sum of instate abatement and net exports.

As 120 tons is needed and 100 tons is actually abated instate then

A.2 $$\psi = \frac{120}{100} = 1.2.$$

With $\psi = 1.2$, then $\mu = 0.96$ showing the state to be a net exporter.

Case 3: Imports > Exports ($\mu > 1$)

Let:

Q_a: 100 tons.

Q_a^i: 80 tons.

Q_a^x: 20 tons.

Q_a^m: 40 tons.

$$Q_a = Q_a^i - Q_a^x + Q_a^m$$

$$= 80 - 20 + 40$$

$$Q_a = 100 \text{ tons}$$

Notice that despite an instate abatement requirement of 80 tons, actual abatement instate is 100 tons due to the presence of net imports of 20 tons.

As 80 tons is needed and 100 tons is actually abated instate then

A.3 $$\psi = \frac{80}{100} = 0.8.$$

With $\psi = 0.8$, then $\mu = 1.05$, showing the state to be a net importer of air pollution.

APPENDIX B: SOLUTION OF STRUCTURAL PARAMETERS IN TERMS OF MODEL COEFFICIENTS

The coefficients in the marginal cost equation are combinations of the structural parameters of the marginal cost function:

B.01 $$\beta_1 = \frac{1 - (\sigma\rho + \pi + \phi)}{\sigma\rho + \pi + \phi},$$

B.02 $$\beta_2 = \frac{1 - (\sigma\rho + \pi + \phi)}{\sigma\rho},$$

B.03 $$\beta_3 = \frac{1 - (\sigma\rho + \pi + \phi)}{\pi},$$

B.04 $$\beta_4 = \frac{1 - (\sigma\rho + \pi + \phi)}{\phi},$$

Solving B.01 - B.04 gives the following

B.05 $$\frac{\beta_1}{\beta_2} = \frac{\sigma\rho}{\sigma\rho + \pi + \phi},$$

B.06 $$\frac{\beta_1}{\beta_3} = \frac{\sigma\rho}{\sigma\rho + \pi + \phi},$$

B.07 $$\frac{\beta_1}{\beta_4} = \frac{\phi}{\sigma\rho + \pi + \phi},$$

Solving B.06 and B.07 gives ϕ in terms of π, solving B.05 and B.06 gives $\sigma\rho$ in terms of π, substituting in B.03 gives

B.08 $$\pi = \frac{\beta_2\beta_4}{\beta_2\beta_3 + \beta_2\beta_4 + \beta_3\beta_4 + \beta_2\beta_3\beta_4}.$$

Solving B.05 and B.07 gives $\sigma\rho$ in terms of ϕ, solving B.06 and B.07 gives π in terms of ϕ, substituting in B.04 gives

B.09 $$\phi = \frac{\beta_2\beta_3}{\beta_2\beta_3 + \beta_2\beta_4 + \beta_3\beta_4 + \beta_2\beta_3\beta_4}.$$

The individual parameters σ and ρ cannot be disentangled from their product $\sigma\rho$. The product can be solved for using the results determined above ($\sigma\rho$ in terms of π and ϕ) and substituting them in B.05:

B.10 $$\sigma\rho = \frac{\beta_2\beta_3\beta_4}{\beta_2\beta_3 + \beta_2\beta_4 + \beta_3\beta_4 + \beta_2\beta_3\beta_4}.$$

APPENDIX C: COEFFICIENTS ON GROSS AND PER CAPITA INCOME

Consider part of the demand equation as it appears in Chapter IX:

C.1 $$\ln Q^d = \alpha_0 - \alpha_1 \ln P^d + \alpha_2 \ln Y + \ldots .$$

Given that income Y and per capital income Y/N are related by

C.2 $$Y = \left(\frac{Y}{N}\right) \cdot N,$$

C.2 can be substituted in C.1 to give

C.3 $$\ln Q^d = \alpha_0 - \alpha_1 \ln P^d + \alpha_2 \ln \left(\frac{Y}{N} \cdot N\right) + \ldots .$$

Expanding the income term yields

C.4 $$\ln Q^d = \alpha_0 - \alpha_1 \ln P^d + \alpha_2 \ln \frac{Y}{N} + \alpha_2 \ln N + \ldots .$$

Estimating C.4 yields (t-statistics):

C.5 $$\ln Q^d = \alpha_0 - \alpha_1 \ln P^d + \alpha_2 \ln \frac{Y}{N} + \alpha_2 \ln N + \ldots$$

0.35	-0.15	-0.12	0.44
(0.08)	(-2.13)	(-0.25)	(5.95)

Estimating C.3 yields

C.6 $$\ln Q^d = \alpha_0 - \alpha_1 \ln P^d + \alpha_2 \ln Y + \ldots$$

-4.61	-0.17	0.44
(-4.64)	(-2.42)	(6.09)

Two of the α_2's are the same while the third, the coefficient on per capita income, is statistically no different than zero. An analysis of the simple correlations involved shows the unlogged values of Q^d and Y/N are positively and significantly correlated ($\rho = 0.16$). With unlogged Q^d and logged Y/N the correlation is still postiive and significant ($\rho = 0.22$) but when both Q^d and Y/N are logged, the correlation is small, negative and insignificant ($\rho = 0.044$). Another variable to behave in a similar manner is the user cost of capital, which similarly switched signs after the log transformation. The remaining simple correlations between the dependent and independent variables were only marginally affected by the nonlinear transformation used in this model. This suggests that the phenomenon of negative but insignificant coefficient for the per capita income variable is caused in some measure by the log transformation.

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