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The Cost of Air Pollution Abatement

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Econometric estimates of air pollution abatement costs for 100,000 U.S. factories provide conservative benchmarks for benefit-cost analysis of pollution control strategies in developing countries. They also suggest that U.S. command-and-control regulation has reduced air pollution at unnecessarily high cost.

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Summary findings

Using data from the U.S. Census Bureau, Hartman, Wheeler, and Singh have developed comprehensive estimates of pollution abatement costs by industry sector for several major air pollutants. Their results provide conservative benchmarks for benefit-cost analysis of pollution control strategies in developing countries. They also provide striking evidence of inefficiency in U.S. command-and-control regulation.

The cost estimates reflect the experience of about 100,000 U.S. manufacturing facilities under actual operating conditions. They are based on a complete accounting of costs — including capital, labor, energy, materials, and services. So, they should be more useful for benefit-cost analysis than idealized engineering estimates. But they also reflect strict pollution control regulation and input prices which are probably somewhat higher, on average, than those in developing countries. They should be interpreted as conservative estimates for environmental planning in developing countries. Regulatory options that are judged to have high net benefits using these numbers would probably look even better if local abatement cost data were available.

The estimates in this paper can provide useful information for pollution charges. They can also help make targeted regulation more cost-effective. With scarce resources for monitoring and enforcement, new regulatory institutions in developing countries will want to focus initially on industry sectors that are the main sources of locally-dangerous pollutants. After those sectors are identified, targeted regulation should be informed by sectoral differences in abatement cost. The estimates suggest, for example, that cost-effective control of suspended particulate emissions will focus on wood pulping rather than steelmaking when both are major sources of suspended particulates. The reason: average particulate abatement costs are four times higher in steelmaking.

This paper — a product of the Environment, Infrastructure, and Agriculture Division, Policy Research Department — is part of a larger effort in the department to support more cost-effective environmental regulation in developing countries. The study was funded by the Bank's Research Support Budget under the research project "Econometric Analysis of Pollution Abatement Costs" (RPO 677-81). Copies of this paper are available free from the World Bank, 1818 H Street NW, Washington, DC 20433. Please contact Elizabeth Schaper, room N10-037, extension 33457 (30 pages). December 1994.

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THE COST OF AIR POLLUTION ABATEMENT

by

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Abstract

Using data from the U.S. Census Bureau, we have developed comprehensive abatement cost estimates by industry sector for several major air pollutants. Our results provide conservative estimates for benefit/cost analysis of pollution control strategies in developing countries. They also reveal very high intersectoral variances in marginal and average abatement costs: maximum/minimum ratios are frequently near ten, and occasionally near one hundred. They suggest that command-and-control regulation in the U.S. has reduced air pollution at unnecessarily high cost.

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Executive Summary

This project began, and ends, on a practical note. Using a massive U.S. database, we have developed comprehensive abatement cost estimates by industry sector for several major air pollutants. Our results are summarized in Table 1 (p. E-5), which can be employed for benefit-cost analysis of air pollution regulation in client countries. For our colleagues in Operations and elsewhere who need only "the bottom line," we have designed the Executive Summary and Table 1 as a detachable, five-page working document.

Our paper provides a full explanation of the methodology and results. Comprehensive abatement cost estimates were our primary goal, but our results also provide striking evidence of inefficiency in U.S. command-and-control (CAC) regulation.[1] We therefore hope that they will serve two ends simultaneously: A caution against overreliance on CAC approaches, and a practical aid to adoption of more efficient market-based regulatory instruments.

The econometric research reported in this paper was undertaken in collaboration with the Center for Economic Studies, U.S. Bureau of the Census. At the Center, we had access to the U.S. Department of Commerce's annual 20,000-plant random survey of pollution abatement costs and expenditures (PACE). All told, the estimates reported in this paper reflect the experience of approximately 100,000 U.S. manufacturing facilities. In depth and coverage, they are by a considerable margin the most complete estimates available.

The paper offers U.S. estimates as a reference guide for benefit-cost analysis in developing countries. Their credibility depends on the answers to three basic questions:

(1) If the primary interest of our work lies in assistance to new regulatory institutions in developing countries, why use a U.S. database at all?

Until recently, most developing countries have had little formal regulation of air pollution. Data on pollution abatement costs is only generated by abatement, so we cannot reasonably expect to assemble a large, comprehensive and reliable database

[1] This approach to pollution control relies on enforcement of fixed effluent standards or mandated installation of abatement technology, with little or no regard for intersectoral differences in abatement costs.

on abatement costs by pollutant from developing countries. Second, the U.S. has the largest and most diverse manufacturing sector of any OECD economy. For a variety of historical, geographical and political reasons, its manufacturing sector is characterized by enormous variation in equipment vintages, processes, operational efficiency, and degrees of pollution control. U.S.-based estimates are therefore broadly representative at the sectoral level. Third, the PACE survey seems to be the largest and most complete of its kind. Fourth, the U.S. estimates are built up from a complete accounting of costs, including capital, labor, energy, materials and services. The are not, therefore, idealized engineering estimates but numbers for thousands of plants under actual operating conditions.

(2) Can we reasonably apply U.S.-based estimates to developing countries without modification?

Our estimates are based on high mandated levels of pollution control in the U.S. They also reflect U.S. input costs. While some inputs to abatement are traded at roughly constant prices in international markets, the non-traded inputs will generally be more costly in higher-income economies.[2] U.S. abatement costs should therefore be higher than those in developing countries unless protection or scarcity of engineering skills have very strong countervailing effects. Taking the regulatory and cost factors into account, we think that the U.S.-based numbers provide conservative upper-bound estimates of pollution control costs in developing countries. Regulatory options which are estimated to have high net benefits using these numbers would probably look even better if local abatement cost data were available.

(3) Why, if direct survey evidence was available, did we use econometric analysis?

Air pollution abatement is an activity of the firm, characterized by multiple inputs and multiple outputs. The latter are abatement volumes for all pollutants controlled by the firm. Separate abatement activities have joint and common costs, like other productive activities. Although firms have their accounting conventions, the truth is that imputation of these costs to separate activities is an exercise in inference from observed experience. In such a case, there is no substitute for econometric cost function estimation from large samples.

Table 1 reports average abatement costs in $US (1993) per ton for 37 sectors defined by the International Standard Industrial Classification (ISIC). All manufacturing activities are subsumed in these 37 estimates. Seven air pollutant

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[2] For a useful discussion and statistical analysis of this relationship, see Dollar (1992).

categories are included: Suspended particulate matter; sulfur oxides; nitrogen oxides and carbon monoxide; hydrocarbons; lead; hazardous (toxic) emissions; and other emissions. The abatement costs in Table 1 can be used in two ways:

1) Efficient Command-and-Control Regulation: Application of direct CAC regulation will be much more efficient if it is informed by information on relative abatement costs. For reasons explained in the paper, the estimates in Table 1 should be read as the costs associated with attainment of a relatively uniform (and strict) concentration standard for air emissions across sectors. Intersectoral variation in plant-level costs reflects significant differences in the average scale of abatement, number of emissions sources, pre-treatment concentration levels in the waste stream, and myriad technical factors. To attain near-uniform emissions standards, plants in different sectors have to incur very different average costs of abatement.

With scarce resources for monitoring and enforcement, many new regulatory institutions will want to focus on industry sectors which are the largest emitters of locally-dangerous pollutants. Once the relevant sectors are identified, targeting should be informed by the relative cost of abatement. Consider, for example, the case of particulate emissions from pulping and steelmaking facilities. If both are heavy local polluters, then the cost estimates in Table 1 would imply focusing on pulping facilities because their abatement costs are only 25% of those in steelmaking.

2) Cost-Effective Regulatory Strategies: If complete sectoral data on emissions are available, then a more sophisticated approach is warranted. We illustrate with a simple example. Suppose the area in question has five sectors which are significant emitters of suspended particulates. We order the sectoral emissions and cost data by ascending average abatement cost, as follows:

ISIC	Sector	Particulate Emissions (tons)	Cumulative Emissions (%)	Sectoral Average Abatement Cost ($US/ton)
3690	Non-Metal Products	400	40	20
3411	Pulp, Paper	100	50	43
3230	Agricultural Chemicals	250	75	127
3710	Iron, Steel	200	95	182
3520	Other Chemicals	50	100	212
	Total	1000		

These numbers provide a guide for economically sensible strategy, whether it is command-and-control or market-based in nature. When sorted by ascending unit cost, the numbers trace out a rough, aggregate social marginal cost curve: cumulative abatement can be approximately related to the unit cost of abatement. Suppose, for example, that we want to set quantitative targets for emissions reduction. The cheapest abatement will be in Non-Metal products (principally cement), where 400 tons of particulate can be abated for about $20/ton. Next cheapest is Pulp and Paper, where 100 more tons can be eliminated at $43/ton. Abatement from these two sectors will eliminate 50% of total emissions. We can therefore state, with rough accuracy, that the marginal social cost at 50% abatement of particulates is $43/ton. At 75% abatement, this rises sharply to $127/ton; at 95% abatement to $182/ton. Thus, a move from 40% to 95% abatement entails a ninefold increase in the marginal cost of abatement. Such large step increases should be enough to make policy makers think hard about the optimal degree of abatement in particular circumstances.

We can also reverse the logic of the example and use it as a guide for setting emissions charges. Our numbers tell us that an emissions charge of $30/ton should give us approximately 40% abatement, since it will be generally cost-effective for polluters in Non-Metal Products to reduce emissions substantially (at $20/ton) rather than pay the charge. Doubling the charge (to $60) should buy another 10% abatement. To effect 95% abatement the charge would have to be tripled again, to something over $182/ton.

We hope that these simple examples will suffice to illustrate the potential utility of our cost estimates. Complete information is included below, in Table 1.

TABLE 1

AVERAGE ABATEMENT COST BY SECTOR, 1979-1985 ($1993/ton)

ISIC		Particulates	Sulfur Oxides	NO2, CO2	Hydrocarbons	Lead	Haz. Emissions	Other
3110	Food	86	521	229	162	46612	55	55
3130	Beverages	156	271	11918	11918	76	76	76
3140	Tobacco	268	167	167	12030	128	128	167
3210	Textiles	396	396	1379	1379	1191	1191	1191
3211	Spinning	272	535	1431	188	781	188	188
3220	Apparel	445	61	61	61	61	61	61
3230	Leather	132	377	8430	633	132	324	427
3240	Footwear	540	207	993	1558	22141	1197	901
3310	Wood	47	38	38	38	38	38	38
3320	Furniture	43	25	25	25	24	13335	25
3410	Paper Products	87	364	472	472	87	87	87
3411	Pulp, Paper	43	155	20	20	35	35	35
3420	Printing	424	117	309	307	117	5604	117
3511	Industrial Chemicals	46	75	304	213	1300	311	206
3512	Agricultural Chemicals	127	519	889	341	532	1069	320
3513	Resins	82	562	207	123	435	63	264
3520	Chemical Products	212	681	48	157	29	29	204
3522	Drugs	269	1045	451	173	300	300	300
3530	Refineries	328	165	59	121	2750	2750	2750
3540	Petroleum, Coal	59	1942	77	77	42	42	42
3550	Rubber	219	1107	343	343	1010	1010	1010
3560	Plastics	219	2415	235	235	1132	1132	1132
3610	Pottery	185	106	3792	3792	4709	4709	4709
3620	Glass	186	550	339	339	186	186	186
3690	Non-Metal Products, n.e.c.	20	213	1647	1658	11	11	11
3710	Iron, Steel	182	528	115	1203	779	253	18
3720	Non-Ferrous Metals	340	152	49	622	1284	1153	177
3810	Metal Products	343	1563	461	399	161	161	427
3820	Other Machinery	254	855	515	515	138	138	138
3825	Office, Computing Machinery	245	245	864	937	248	17458	245
3830	Other Electrical Machinery	373	483	1559	215	365	166	166
3832	Radio, TV	394	1854	904	1096	738	1491	1138
3840	Transport Equipment	635	1266	468	1006	468	2331	468
3841	Shipbuilding	125	832	2229	2229	84	84	84
3843	Motor Vehicles	350	1523	1155	2441	21483	159	159
3850	Professional Goods	1208	3046	872	1376	995	1634	995
3900	Other Industries	38	26	110	110	26	26	26

The cost estimates in the Appendix Table 4.2 are in $1979. These have been inflated to $1993 for this executive summary, using an annual compound rate of inflation of 4.6%. The latter was computed using fixed-weight price indices for pollution abatement and control for 1979 and 1989 and was obtained from "Pollution Abatement and Control Expenditures, 1972-90", Survey of Current Business, June 1992.

1. Introduction

In this paper, we develop estimates of air pollution abatement costs for U.S. manufacturing sectors at the four-digit level of International Standard Industrial Classification (ISIC). We utilize a very large plant-level database for the period 1979-1985, a high point in industry response to the abatement requirements of the U.S. Clean Air Act. Our estimates measure both marginal and average total abatement costs for seven categories of air pollutants.[3] As far as we know, they provide the only consistent summary of abatement costs across all manufacturing sectors. As such, they offer new information to policy makers who are concerned with evaluating the benefits and costs of pollution control. The cost estimates also provide evidence on the relative economic efficiency of command-and-control regulation, as practiced in the U.S. The greater the variation in sectoral abatement costs for a given pollutant, the greater the inefficiency of the abatement efforts for society at large.

In developing our estimates, we have used a model of joint pollutant abatement cost which is discussed in Section 2. Section 3 describes the data, which have been created by merging plant-level information from two sources: The U.S. Department of Commerce's annual 20,000-plant random survey of pollution

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[3] These are particulates, sulfur oxides, nitrogen oxides and carbon monoxide, hydrocarbons, lead, hazardous air pollutants and a residual "Other" category.

abatement costs and expenditures (PACE), and the U.S. Census Bureau's Annual Survey of Manufactures.[4] The PACE data for 1979-85 include reported pollutant abatement and cost, while the Census provides detailed sectoral identifiers. In Section 4, we present our econometric results and the implied estimates of pollution abatement costs. Section 5 summarizes the paper.

2. The Abatement Cost Function

Until recently, the scarcity of appropriate plant-level data has prevented detailed empirical studies of average and marginal abatement costs by pollutant.[5] Policy analyses have frequently developed abatement cost estimates from engineering models. However, failure to rely on behavioral data has led to considerable estimation errors in some cases.[6] This paper attempts to advance the state of the art by analyzing plant-level data on end-of-pipe abatement and related costs.

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[4] While random sampling reduces the scope for assembling a panel of firms from PACE, it does assure very broad representation over time. The estimates reported in this paper incorporate some information from approximately 100,000 facilities.

[5] For a recent exception see Mundle, et. al. (1994).

[6] A useful illustration is provided by the trading price for SO_2 emissions permits under the U.S. Clean Air Act (Hamilton, 1994). Using engineering models, the U.S. Government forecast a price around $600/ton before the trading system was instituted. In fact, permits are currently trading around $150/ton.

2.1 Abatement Technology and Economics

End-of-pipe abatement volume is the difference between influent and effluent, where influent is the waste water or gas from production before treatment and effluent is the residual emitted after treatment. The presence of some pollutant in the waste stream registers as a concentration, typically measured in $\mu g/l^3$ for air emissions. From an engineering perspective, 'abatement' means installing and operating processes which reduce influent concentrations from one or more sources to target effluent concentrations. Box 1 (p. 5) includes illustrative descriptions for three pollution-intensive industry sectors, while Table 2.1 (p. 6) provides complementary average abatement volume and cost estimates from the Appendix tables.

The engineering literature identifies four major factors which determine the cost of abatement: Pollutant type, diversity of emissions sources, scale of abatement, and pollutant concentration in the waste stream.[7] When air emissions from industrial processes are concentrated at a few points, most abatement can be accomplished using three basic systems:

- **Dry systems** use gravity, centrifugal force or fabric filters to trap pollutants. Gravity/centrifugal systems are low-cost, but appropriate only for removal of relatively heavy particulates. Filter systems trap fine particulates; costs vary widely according to waste stream characteristics and desired removal rates.

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[7] The discussion in this section (including Box 1) relies heavily on Sell (1992).

- **Wet scrubbers** use streams of water or other liquids to increase collection efficiency. Wet collectors can cool and wash waste streams and remove gases. High-efficiency systems have high operating costs. Scrubbers come in a great variety of sizes, configurations and efficiency levels, depending on the problem. Their slurry can be a serious source of water pollution if it is discharged because hazardous pollutants may be highly concentrated. Thus, additional treatment may be needed to complement the cleaning of air pollutants.

- **Electrostatic precipitators** use the principle of electrostatic attraction to trap pollutants by channeling the waste stream between two electrodes - a high-voltage discharge electrode and a grounded collecting electrode. Plate precipitators allow for the dry collection of very fine particles and are highly efficient. Pipe precipitators work better for liquid aerosols or fumes. In general precipitator systems have low maintenance costs, although dry systems are subject to explosion dangers if they are operated beyond rated capacity.

2.1.1 Pollutant-specific factors

Simpler, less energy-intensive collection systems are less efficient and generally suitable only for large, dense particulates. Fine particulates and other air pollutants require more sophisticated, costly collection devices. This difference can be seen, for example, in Table 2.1, where average abatement costs for sulphur oxide removal are at least three times higher than those for particulates.[8]

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[8] In some sectors, removal of fine particulates from diverse sources may increase abatement costs substantially. As Table 1 indicates, sulphur oxide abatement costs by sector are generally, but not always, higher than particulate abatement costs.

BOX 1: PRODUCTION PROCESSES AND EMISSIONS CONTROL IN THREE POLLUTION-INTENSIVE SECTORS

In this box we describe the basic processes and emissions control problems in three sectors: Iron and Steel, Pulp and Paper and Cement. All three sectors are extremely energy-intensive, and large installations frequently maintain their own power-generation facilities. When the latter burn fossil fuels, they have common control problems which focus on particulate and sulphur oxide removal. Sectoral abatement costs therefore reflect a mix of common costs from power plant emissions control and costs which reflect differences in sectoral production processes.

IRON AND STEEL

Pig Iron Production

The production of pig iron involves coking and blast furnace operation. During coking, there are many possible emissions sources. SO2 and particulates are emitted into the atmosphere during charging (filling the oven), from door and lid leaks, and from quenching the coke with wastewater. Coke oven gas is often burned for fuel elsewhere in the plant and can also produce these emissions.

Diverse emissions sources require diverse solutions: Oven lid and door maintenance; putting baffles in the quenching towers; using clean, not waste, water for the quenching process; stack gas cleaning of the SO2; using negative oven pressures during the charging; and hooding many of the steps to capture releases. In general, coke oven emissions are very difficult to control.

Blast furnace operation produces primarily SO2 and CO. Sulphur in the coke oxidizes to form SO2, which escapes from the top of the furnace.

Steelmaking

Air pollution problems in this process come mostly from fume generation by the furnaces and from pouring operations. Open hearth and basic oxygen units use electrostatic precipitators or venturi scrubbers to remove particulates; newer electric furnaces use dry collection in bag houses (fabric filtering installations).

PULP AND PAPER

Specific environmental effects depend on the process used. Kraft (or sulfate) pulping processes are dominant in the industry and produce most of the pollution. Kraft pulping uses chemicals, heat and pressure to dissolve the wood material. Sulphur-containing gases are released during this process; after concentration of waste 'liquor' into solid residuals, burning of the latter for organic residue removal also releases sulphurous waste gases. Most plants use wet scrubbers to remove sulphur gases and particulates from the waste stream.

CEMENT

The major environmental problem for this sector is handling the waste kiln dust, particularly from plants employing wet processes. Dust removal is generally done with electrostatic precipitators.

Table 2.1

Average Abatement Volume and Cost for PACE Facilities

Average Abatement Volume (Tons)

Sector	ISIC	Total Suspended Particulates	Sulphur Oxides
Cement	3690	34,773	613
Pulp and Paper	3411	28,029	1,672
Iron and Steel	3710	12,336	1,108

Average Cost of Abatement ($US 1993/Ton)

Sector	ISIC	Total Suspended Particulates	Sulphur Oxides
Cement	3690	20	213
Pulp and Paper	3411	43	155
Iron and Steel	3710	182	528

Source: Tables 1, 3.2 (Abatement volumes in Table 2.1 are means from non-missing cells in Appendix Table 3.2)

2.1.2 Diversity of emissions sources

A major problem for control costs arises when significant emissions sources are dispersed and highly varied. For example, Box 1 describes the diversity of iron and steel emissions as compared with those of pulp, paper and cement. The consequences are suggested in Table 2.1: Average abatement costs for iron and steel are much higher than those for the other sectors.

2.1.3 Scale of abatement

Scale economies may apply to some abatement processes, yielding declines in marginal and average cost as treatment volume increases. The impact of this factor seems clearly apparent for Total Suspended Particulates in Table 2.1: Average abatement cost drops sharply as abatement volume increases.

2.2 Joint Production of Abatement

Abatement is frequently a joint process, since both scrubbing and electrostatic precipitation systems can be used to reduce influent concentrations for several pollutants at the same time. For example, as noted in Box 1, stack scrubbers can be used to remove both TSP and SO_2 from air emissions. Even where separate equipment is called for, there may be common use of skilled and unskilled labor, materials and energy.

Generally then, abatement can be characterized as a multiple-output process whose costs are affected by diminishing returns, pollutant-specific technology requirements, scale economies, and diseconomies associated with diversity of emissions sources.

2.3 Model Specification

Our regression model is specified in equation (1) below.

We assume that the abatement cost function is separable from the firm's production cost function, reflecting purely end-of-pipe activity.[9] In light of the preceding discussion, we estimate separate regressions by sector, using sectoral identification as our control for the influence of many unobservable factors: Influent concentration, differential reduction of influent, abatement scale, source diversity, and more detailed engineering considerations. The quadratic specification of the cost function allows for testing possible pollutant-specific scale economies.

$$(1) \quad C_{ij} = \beta_{0j} + \Sigma_i \beta_{jk} A_{ijk} + \Sigma_i \beta_{jjk} A^2_{ijk} + \epsilon_{ij}$$

where C_{ij} = Total cost of abatement for end-of-pipe air pollution control by plant i in sector j
A_{ijk} = Quantity of air pollutant k abated by plant i
ϵ_{ij} = A random disturbance term

There are various techniques for allocating the fixed cost component (β_0) in (1) across pollutants to yield average cost estimates. We opt for the simplest in this paper, averaging the joint and common cost across the sum (in tons) of all pollutants

[9] The PACE survey attempts to maintain this distinction, and we think that our assumption is a reasonable approximation. However, it will not hold true in all cases. For example, the description of iron and steel production in Box 1 notes the importance of costly adjustments such as negative oven pressure for the reduction of emissions. In such cases, there is clearly some interaction between processing and abatement costs.

abated.[10] Sectoral marginal and average costs are therefore computed as follows:

(2a) $MC_{jk} = \beta_{jk} + 2\beta_{jjk}A_{ijk}$

(2b) $AFC_{jk} = \beta_{0j}/\Sigma_k A_{ijk}$ (A_{ijk}= plant-level mean abatement of k)

(2c) $AC_{jk} = MC_{jk} + AFC_{jk} = \beta_{jk} + 2\beta_{jjk}A_{ijk} + \beta_{0j}/\Sigma_{0k}A_{ijk}$

We estimate Equation (1) for two sets of pollutant categories, depending on data availability. During the period 1979-1982, PACE aggregated air pollutants into four categories: 1) particulates; 2) sulfur oxides; 3) nitrogen oxides, carbon monoxide and hydrocarbons; and 4) other pollutants, including lead and toxic emissions. During 1983-1985, pollutants were surveyed in seven categories: 1) particulates; 2) sulfur oxides; 3) nitrogen oxides and carbon monoxide; 4) hydrocarbons; 5) lead; 6) hazardous emissions; 7) other.

We also test whether we can pool the data over 1979-1985. This pooling involves aggregating the seven categories to the four categories for the 1983-1985 period. We test whether we can pool the pollutants in both linear and quadratic forms of equation (1). For sectors in which we cannot reject pooling by pollutant category over 1983-1985, we gain efficiency by estimating the equation for the four categories over the whole

[10] An alternative method would be to allocate joint and common costs among pollutants abated in proportion to their variable costs. This approach is called "axiomatic cost analysis." See for example Mirman, Samet and Tauman (1983).

period 1979-1985.

Because our focus is on internationally-comparable estimates, we have recoded all U.S. plants to ISIC (International Standard Industrial Classification) categories using a concordance made available by the U.S. Census Bureau. Our data set provides observations on C_{ij} and A_{ijk} for a large sample of plants within each ISIC. We express all costs in U.S. 1979 dollars; volumes are in tons.[11] We estimate the regression equations using OLS, because command-and-control regulation has forced U.S. plants toward similar effluent concentrations with little regard for relative abatement costs. Several WLS corrections have been tested and rejected.

3. Econometric Issues -- Data and Estimation

Since the 1970's, the United States Department of Commerce has implemented an annual survey of pollution abatement costs and expenditures (PACE).[12] The survey summarizes annual capital and operating costs of abatement for a random sample of approximately

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[11] Note that the regressions reported in Tables 4.1 and 4.2 were run on data adjusted to constant $US 1979. These results are inflated to $US 1993 for presentation in the Executive Summary (Table 1).

[12] The annual survey continues, but its scope and relevance were seriously compromised in 1986 by the elimination of questions on abatement volumes. We are therefore unable to exploit more recent PACE data for the work reported in this paper.

20,000 establishments identified at the four-digit SIC level.[13] The PACE data also record annual abatement volumes for many air, water and solid waste pollutants. In this paper, we focus on the air pollutants.[14]

We have used common identifier numbers to merge the PACE data with the Longitudinal Research Database (LRD) of the US Bureau of the Census.[15] The LRD pools annual data at the establishment level from the U.S. Census of Manufactures and the Annual Survey of Manufactures. It includes detailed information on location; ownership; inputs (labor, energy, materials, plant and equipment); and production of goods and services at a highly disaggregated level. For this study, we have used the LRD only for sectoral identification of the PACE facilities.

We have translated the U.S. coding of our sample establishments (4-digit SIC) into 37 four-digit ISIC categories. The latter are listed in Appendix Table 3.1. For each sector and pollutant category, Appendix Table 3.2 displays mean tons abated during the periods 1979-1982 and 1983-1985. These estimates

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13 Specifically, the annual operating expenses include the cost of capital services in the form of depreciation; labor costs; materials, supplies, fuel and electricity; and contracted services, equipment, leasing and other. The survey also quantifies annual capital expenditures for abatement equipment.

14 Regression-based estimates for the major regulated water pollutants are also available from the authors on request.

15 See McGuckin and Pascoe (1988).

reflect abatement by the representative establishment in each ISIC. Volumes for the chemical and resource processing industries (ISIC 3411 - 3690) are particularly noteworthy for most air pollutants. The more disaggregated information for 1983-1985 makes it clear that lead and some hazardous air pollutants have small average volumes at the plant level.

4. Results

Because the complete results for all 37 ISIC industries are quite lengthy, we do not discuss them in detail here. Full results are available from the authors on request. In this section, we present estimates of marginal and average total abatement costs for cases where statistically significant regression coefficients have been obtained. These cost estimates are provided in Appendix Tables 4.1 and 4.2. Separate cost estimates are presented for 1979-1982, 1983-1985 and (where pooling cannot be rejected) 1979-1985. Cost estimates are always presented for all seven pollutants (denoted P_1 - P_7). In the four-pollutant cases, cost estimates for the aggregate categories are assumed constant across the constituent pollutants.[16] Tables 4.1 and 4.2 also identify whether the linear or non-linear

[16] For example, the estimated costs for the third category of pollutant will apply to both P_3 and P_4, while the estimated costs for the fourth category will apply to P_5, P_6 and P_7.

version of the cost function is reported.[17]

Several conclusions can be drawn from Table 4.1. First, many sectors have nonlinear abatement cost functions. Some marginal costs rise with abatement (due to the technological difficulty of increasing abatement rates), while others fall (due, presumably, to the scale effect once some threshold level of abatement is achieved).

Second, we accept the pooling hypothesis (and associated pooled cost estimates) for approximately 30% of the industries (3130, 3210, 3310, 3410, 3411, 3540, 3610, 3620, 3820, 3841 and 3900 -- see Table 3.1).[18]

Third, marginal abatement costs vary considerably by pollutant and sector. Notice, for example, that marginal costs for ISIC 3610 range from $69.04 for particulates to $2484.90 for lead, hazardous air pollutants and other pollutants. These costs are substantially less for ISICs 3410 and 3411.

Fourth, the separate estimates for 1979-1982 and 1983-1985 reveal a very broad pattern of variation. For some sectors and

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[17] The choice of linear or non-linear version is determined by the relative statistical performance of each. In a few cases, the version that was selected on overall statistical merit (that is, across all pollutants simultaneously) did not produce a usable cost estimate for a given pollutant. In such cases, we report the pollutant-specific cost estimate from the relevant "next-best" regression.

[18] Where pooling cannot be rejected, these estimates are the most efficient.

some pollutants, marginal abatement costs decline over time (e.g., particulates in 3211 and 3520 and sulphur oxides in 3512). For other sectors and pollutants, marginal costs rise with time, perhaps reflecting scale effects or (more likely) changes in subsectoral composition of plants surveyed (e.g., 3511: nitrogen oxides plus carbon monoxide; hydrocarbons). In both cases, the changes are probably due to some combination of technical change, scale effects and alteration in subsectoral composition.

Many estimates are not statistically distinct.[19] In some cases, estimates seem affected by small sample sizes or joint abatement costs which are far larger than abatement quantities for particular pollutants. For example, the marginal cost estimates for lead and hazardous air pollutants are quite large for some sectors (e.g., 3110, 3320, 3843, and 3900).

Fifth, we should note that separate regressions for individual years (1979 through 1985) did not yield generally robust results and are not reported.

Finally, we report the results of a fixed effects regression of marginal abatement costs for <u>all</u> establishments whose sole pollutant was particulates. Pooling of these establishments increases degrees of freedom and estimation efficiency considerably. Our fixed effects model allows for slope and

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[19] We do not test statistically whether the cost estimates differ across the two periods.

intercept dummies for establishments in each ISIC. For this simpler abatement function, our results suggest that the marginal cost of abatement is fairly constant at approximately $5.54/ton for many sectors. Some sectors do reveal distinct abatement problems with much higher marginal costs (e.g., ISIC 3140 = $61.17; ISIC 3530 = $98.75; and ISIC 3843 = $81.24). The estimates of average total abatement cost in Table 4.2 extend these interpretations, but remain consistent with them.

5. Summary and Conclusions

In this paper, we have estimated the costs of abating major air pollutants. Our results reveal very high variances in abatement costs for individual pollutants by sector: maximum/minimum ratios are frequently near ten, and occasionally near one hundred. They also show large differences in the means and variances of costs across pollutants.

For environmental policymakers, these results suggest an important lesson: Command-and-control (CAC) regulation in the U.S. seems to have reduced pollution at a very high cost. Optimal regulation would attain the desired reduction in pollution while equalizing the marginal cost of abatement across sectors. Where they are feasible, market-based instruments such as emissions charges and tradable permits are optimal in this sense. In principle, regulators who were properly informed about abatement costs could approach this optimum using CAC-type methods. In practice, we can see that nothing like this has occurred. For the same pollutant, intersectoral abatement costs can differ by more than a factor of 100.

While command-and-control regulation has certainly not been optimal for the U.S., it has undeniably been useful for this exercise. By forcing roughly uniform emissions standards on sectors with very different pollution control problems, it has permitted us to estimate intersectoral differences in costs. These are so large that environmental policy-makers would be unwise to ignore them. Table 1 provides our current best estimates of average abatement costs by sector and pollutant.[20] When combined with information on the main sectoral sources of air pollution in a particular region, Table 1 can be used as a guide to setting priorities for pollution control. Since regulatory resources are scarce, it undoubtedly makes sense to focus initial efforts on those sectors characterized by relatively large contributions to total emissions and relatively low average costs of abatement.

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[20] These estimates come from Table 4.2 and are inflated to \$1993, as discussed in the Executive Summary.

Table 3.1

Industry Sectors

(International Standard Industrial Classification)

ISIC	SECTOR
3110	Food Products
3130	Beverages
3140	Tobacco
3210	Other Textile Products
3211	Spinning, Weaving
3220	Wearing Apparel
3230	Leather & Products
3240	Footwear
3310	Wood Products
3320	Furniture, Fixtures
3410	Other Paper Products
3411	Pulp, Paper
3420	Printing, Publishing
3510	Other Industrial Chemicals
3511	Basic Industrial Chemicals
3512	Agricultural Chemicals
3513	Synthetic Resins
3520	Other Chemical Products
3522	Drugs and Medicines
3530	Petroleum Refineries
3540	Petroleum & Coal Products
3550	Rubber Products
3560	Plastic Products
3610	Pottery, China, etc.
3620	Glass & Products
3690	Non-Metal Products n.e.c.
3710	Iron and Steel
3720	Non-Ferrous Metals
3810	Metal Products
3820	Other Machinery n.e.c.
3825	Office & Computing Machinery
3830	Other Electrical Machinery
3832	Radio, Television, etc.
3840	Transport Equipment
3841	Shipbuilding, Repair
3843	Motor Vehicles
3850	Professional goods
3900	Other Industries

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TABLE 3.2

MEAN TONS ABATED

ISIC	3110	3130	3140	3210	3211	3220	3230	3240	3310
	Food	Beverages	Tobacco	Textile	Spinning	Apparel	Leather	Footwear	Wood
P1 - Particulates									
Four Pollutants 1979-1982	1474.9	2770.8	1348.9	93.3	574.7		134.7	18.1	2345.5
Four Pollutants 1983-1985		1170.0		163.3					2333.5
Seven Pollutants 1983-1985	1429.3	1170.0	1968.0	163.3	658.6		252.4	13.4	2333.5
P2 - Sulfur Oxides									
Four Pollutants 1979-1982	56.2	144.7	41.2	3.3	9.1		14.3	0.1	6.5
Four Pollutants 1983-1985		107.0		1.8					2.5
Seven Pollutants 1983-1985	40.6	107.0	34.8	1.8	28.2		1.4		2.5
P3 - NO2 and CO									
Four Pollutants 1979-1982	165.7	1.8	15.6	112.9	37.7		11.8	0.7	23.2
Four Pollutants 1983-1985		9.4		142.1					56.0
Seven Pollutants 1983-1985	6.5	7.4	4.5	4.1	6.3		2.4	2.2	13.3
P4 - Hydrocarbons									
Four Pollutants 1979-1982	13.7	25.0	15.0	20.9	13.3		0.4	0.2	14.1
Four Pollutants 1983-1985		0.3		18.1					71.6
Seven Pollutants 1983-1985	12.5	2.0	7.0	138.0	24.1		47.6	2.3	42.8
P5 - Lead									
Four Pollutants 1979-1982									
Four Pollutants 1983-1985									
Seven Pollutants 1983-1985	0.1				3.7		0.01	0.008	0.002
P6 - Hazardous Emissions									
Four Pollutants 1979-1982									
Four Pollutants 1983-1985									
Seven Pollutants 1983-1985	0.4			15.4	2.5		5	0.2	0.8
P7 - Other									
Four Pollutants 1979-1982									
Four Pollutants 1983-1985									
Seven Pollutants 1983-1985	13.7	0.3	0.4	0.7	13.7		5.01	2.1	70.8

TABLE 3.2

MEAN TONS ABATED

ISIC	*3320*	*3410*	*3411*	*3420*	*3511*	*3512*	*3513*	*3520*	*3522*	*3530*
	Furniture	*Paper*	*Pulp*	*Print.*	*Ind. Chem.*	*Ag. Chem.*	*Resins*	*Chem. Prod.*	*Drugs*	*Petro.*
P1 - Particulates										
Four Pollutants 1979-1982	2756.5	1382.8	26565.4	39.0	7353.6	1296.8	4820.0	463.2	977.6	1906.1
Four Pollutants 1983-1985		37.3	28760.5	197.7					447.1	
Seven Pollutants 1983-1985	2047.8	37.3	28760.5	197.7	242784.4	1350.5	4783.7	738.2	447.1	1851.4
P2 - Sulfur Oxides										
Four Pollutants 1979-1982	3.3	75.6	1837.3	0.2	1879.8	311.8	118.8	40.0	265.8	26687.8
Four Pollutants 1983-1985		24.9	1589.6	0.2					81.8	
Seven Pollutants 1983-1985	2.5	24.9	1589.6	0.2	69102.0	654.4	82.0	24.6	81.8	33267.2
P3 - NO2 and CO										
Four Pollutants 1979-1982	31.6	268.4	305.1	696.4	3205.8	1237.0	2233.9	1792.5	318.2	49095.3
Four Pollutants 1983-1985		6.5	379.6	1518.0					526.6	
Seven Pollutants 1983-1985	77.8	0.1	318.7	397.2	1583.2	270.0	217.7	11257.5	12.4	38138.4
P4 - Hydrocarbons										
Four Pollutants 1979-1982	22.3	17.0	1002.5	2.4	876.6	383.2	165.1	48.3	68.9	1182.8
Four Pollutants 1983-1985		3.7	1044.7	19.1					184.6	
Seven Pollutants 1983-1985	5.2	6.4	60.8	1120.8	1656.0	824.5	1911.3	1003.4	514.2	10044.6
P5 - Lead										
Four Pollutants 1979-1982										
Four Pollutants 1983-1985										
Seven Pollutants 1983-1985			0.1		17.7		6.5	0.8	0.3	73.6
P6 - Hazardous Emissions										
Four Pollutants 1979-1982										
Four Pollutants 1983-1985										
Seven Pollutants 1983-1985	0.2	0.03	27.3	0.2	216.1	22.8	605.3	9.7	1.8	142.6
P7 - Other										
Four Pollutants 1979-1982										
Four Pollutants 1983-1985										
Seven Pollutants 1983-1985	11.5	3.7	1017.3	18.9	1011.1	1285.3	63.4	1142.9	182.5	79.6

TABLE 3.2

MEAN TONS ABATED

ISIC	*3540*	*3550*	*3560*	*3610*	*3620*	*3690*	*3710*	*3720*	*3810*
	Coal	*Rubber*	*Plastic*	*Pottery*	*Glass*	*N-Metal*	*Iron*	*N-Ferrous Metal*	*Metal*
P1 - Particulates									
Four Pollutants 1979-1982	3777.0	525.2	290.0	408.0	508.2	34936.0	15205.6	4530.3	225.0
Four Pollutants 1983-1985	2623.8	581.5		508.4	685.9	34690.6			
Seven Pollutants 1983-1985	2623.8	581.5		508.4	685.9	34690.6	9466.1	2895.0	201.5
P2 - Sulfur Oxides									
Four Pollutants 1979-1982	42.7	63.5	2.8	0.1	29.2	257.0	796.2	5527.9	7.0
Four Pollutants 1983-1985	33.6	37.1		0.03	15.4	791.6			
Seven Pollutants 1983-1985	33.6	37.1		0.03	15.4	791.6	1418.7	4468.0	10.5
P3 - NO2 and CO									
Four Pollutants 1979-1982	1919.9	89.0	132.2	6.3	27.8	81.5	3299.3	154.5	123.0
Four Pollutants 1983-1985	1527.4	70.2		12.4	61.7	223.2			
Seven Pollutants 1983-1985	540.1	21.5		2.1	59.1	161.7	2040.5	16.4	19.4
P4 - Hydrocarbons									
Four Pollutants 1979-1982	3.3	40.7	35.3	0.2	7.3	353.8	800.6	724.5	21.5
Four Pollutants 1983-1985	0.3	3.6		4.8	10	102.5			
Seven Pollutants 1983-1985	987.3	48.7		10.3	2.6	61.5	64.5	55.2	122.5
P6 - Lead									
Four Pollutants 1979-1982									
Four Pollutants 1983-1985									
Seven Pollutants 1983-1985	0.01			0.02	0.6	0.1	13.3	93.1	1.1
P6 - Hazardous Emissions									
Four Pollutants 1979-1982									
Four Pollutants 1983-1985									
Seven Pollutants 1983-1985	0.2	0.02			0.3	27.7	120.6	124.4	3.4
P7 - Other									
Four Pollutants 1979-1982									
Four Pollutants 1983-1985									
Seven Pollutants 1983-1985	0.2	3.6		4.8	9.2	74.8	184.2	776.9	6.5

TABLE 3.2

MEAN TONS ABATED

ISIC	*3820*	*3825*	*3830*	*3832*	*3840*	*3841*	*3843*	*3850*	*3900*
	Machinery	*Computing*	*Electrical*	*Radio*	*Transport*	*Ships*	*Vehicles*	*P. Goods*	*Other*
P1 - Particulates									
Four Pollutants 1979-1982	404.0	109.9	583.2	186.2	159.9	420.9	1022.1	23.8	245.4
Four Pollutants 1983-1985	203.5					204.0			1080.5
Seven Pollutants 1983-1985	203.5	72.3	399.6	101.5	178.8	204.0	547.4	28.7	1080.5
P2 - Sulfur Oxides									
Four Pollutants 1979-1982	62.6	5.2	31.0	8.0	55.0	185.4	120.2	1.2	0.2
Four Pollutants 1983-1985	48.7					141.7			0.3
Seven Pollutants 1983-1985	48.7	4.5	46.8	5.0	20.1	141.7	142.0	0.8	0.3
P3 - NO2 and CO									
Four Pollutants 1979-1982	37.0	211.3	168.8	148.7	27.6	28.1	139.9	17.4	7.8
Four Pollutants 1983-1985	26.0					28.8			444.7
Seven Pollutants 1983-1985	7.8	0.6	6.5	51.6	16.6	22.8	11.3	7.4	1.2
P4 - Hydrocarbons									
Four Pollutants 1979-1982	30.1	4.7	84.8	16.0	7.3	13.4	407.2	2.8	10.1
Four Pollutants 1983-1985	7.1					1.9			1376.4
Seven Pollutants 1983-1985	18.2	269.7	62.4	114.3	17.3	6.0	110.2	11.3	443.5
P5 - Lead									
Four Pollutants 1979-1982									
Four Pollutants 1983-1985									
Seven Pollutants 1983-1985	0.5		87.2	0.2	0.004	0.008	1.3	0.1	0.119
P6 - Hazardous Emissions									
Four Pollutants 1979-1982									
Four Pollutants 1983-1985									
Seven Pollutants 1983-1985	0.8	2.1	0.8	14.6	1.4	1.2	8.3	4.4	89.9
P7 - Other									
Four Pollutants 1979-1982									
Four Pollutants 1983-1985									
Seven Pollutants 1983-1985	5.8	1.8	12.5	13.6	7.9	0.6	11.4	6.9	1286.4

TABLE 4.1

MARGINAL ABATEMENT COSTS ($1979)

ISIC	*3110*	*3130*	*3140*	*3210*	*3211*	*3220*	*3230*	*3240*	*3310*
	Food	*Beverages*	*Tobacco*	*Textile*	*Spinning*	*Apparel*	*Leather*	*Footwear*	*Wood*
Marginal Cost (79-82)	NL		L	NL	NL	L	L	L	L
P1 - Particulates	14.77		107.90	405.62	49.38	204.95	261.67	72.11	5.47
P2 - Sulfur Oxides	381.28			4777.57	370.80		311.11		
P3 - NO2 and CO	2.99			187.24	92.52		311.11	555.38	
P4 - Hydrocarbons	2.99			187.24	92.52			555.38	
P5 - Lead				490.00		20.28			
P6 - Hazardous Emissions				490.00		20.28			
P7 - Other				490.00		20.28			
Marginal Cost (83-85)			L	NL	L		NL	L	NL
P1 - Particulates	17.82				39.69				14.38
P2 - Sulfur Oxides	116.54								
P3 - NO2 and CO	182.77			698.99	1327.18		8550.88		
P4 - Hydrocarbons	111.01		12669.50	712.09	453.33		223.47	603.73	
P5 - Lead	49,723.02				633.16			23,142.34	
P6 - Hazardous Emissions	747.32						191.06	773.40	
P7 - Other							300.10	457.51	
Marginal Cost (79-85)		NL		NL					L
P1 - Particulates		42.42							4.78
P2 - Sulfur Oxides		103.91							
P3 - NO2 and CO		6323.80		524.76					
P4 - Hydrocarbons		6323.80		524.76					
P5 - Lead				424.44					
P6 - Hazardous Emissions				424.44					
P7 - Other				424.44					
Marginal Cost (79-85)									
*P1 - Particulates**	5.54	5.54	61.17	5.54	35.62	223.58	5.54	5.54	5.45

**(Particulates only)*

*** L - Linear, NL - Non-Linear*

TABLE 4.1

MARGINAL ABATEMENT COSTS ($1979)

ISIC	3320	3410	3411	3420	3511	3512	3513	3520	3522	3530
	Furniture	Paper	Pulp	Printing	Ind. Chem.	Ag. Chem.	Resins	Chem. Prod.	Drugs	Petro.
Marginal Cost (79-82)	NL	NL	NL	L	NL	NL	NL	NL	NL	NL
P1 - Particulates	6.30	26.58	16.74	327.23	7.83	45.24	17.34	166.69	115.20	336.43
P2 - Sulfur Oxides		178.48	67.79		42.36	295.28	232.46		386.29	64.72
P3 - NO2 and CO		214.70		113.21	72.22	158.56	40.26	19.99	72.96	16.99
P4 - Hydrocarbons		214.70		113.21	72.22	158.56	40.26	19.99	72.96	16.99
P5 - Lead		43.36	31.69		170.63	212.12			217.78	2923.71
P6 - Hazardous Emissions		43.36	31.69		170.63	212.12			217.78	2923.71
P7 - Other		43.36	31.69		170.63	212.12			217.78	2923.71
Marginal Cost (83-85)	NL	L	NL	L	NL	NL	NL	NL	L	L
P1 - Particulates	12.69		13.41		13.42		19.77	29.09	69.63	
P2 - Sulfur Oxides	1620.60	178.14	76.29	92.11	10.12	168.22	317.20	696.35	627.51	97.80
P3 - NO2 and CO		417.86		89.52	225.30	700.05	130.18		306.33	32.91
P4 - Hydrocarbons		417.86			127.40	114.79	40.19	117.34	6.95	98.07
P5 - Lead			8.57	5859.95	1169.70		413.83			
P6 - Hazardous Emissions	14,215.16		8.57		133.45	839.09	7.52			
P7 - Other			8.57		20.56	38.44	231.23	167.04		
Marginal Cost (79-85)		NL	NL							
P1 - Particulates		28.85	12.78							
P2 - Sulfur Oxides		176.83	72.12							
P3 - NO2 and CO		234.39								
P4 - Hydrocarbons		234.39								
P5 - Lead		28.79	8.08							
P6 - Hazardous Emissions		28.79	8.08							
P7 - Other		28.79	8.08							
Marginal Cost (79-85)										
P1 - Particulates*	5.45	5.54	5.54	5.54	1.65	5.54	5.54	5.54	5.54	98.75

(Particulates only)
***** L - Linear, NL - Non-Linear***

TABLE 4.1

MARGINAL ABATEMENT COSTS ($1979)

ISIC	*3540*	*3550*	*3560*	*3610*	*3620*	*3690*	*3710*	*3720*	*3810*
	Coal	*Rubber*	*Plastic*	*Pottery*	*Glass*	*N-Metal*	*Iron*	*N-Ferrous Metal*	*Metal*
Marginal Cost (79-82)	NL	NL	NL	NL	L	NL	NL	NL	NL
P1 - Particulates	10.89	52.44	84.01	166.01		4.51	77.10	173.27	101.46
P2 - Sulfur Oxides	1914.63	312.98	1256.79		205.14	138.36	539.79	64.55	949.68
P3 - NO2 and CO	8.79	169.15	92.44	2134.64	128.48	911.98	69.34		135.69
P4 - Hydrocarbons	8.79	169.15	92.44	2134.64	128.48	911.98	69.34		135.69
P5 - Lead		343.54	571.43					136.91	
P6 - Hazardous Emissions		343.54	571.43					136.91	
P7 - Other		343.54	571.43					136.91	
Marginal Cost (83-85)	NL	NL		NL	NL	NL	NL	NL	NL
P1 - Particulates	7.21	33.72				4.60	97.60	137.55	93.48
P2 - Sulfur Oxides	227.32	308.30				77.06	4.32	45.14	547.53
P3 - NO2 and CO	44.03			5907.00	220.22	835.36	33.34		184.63
P4 - Hydrocarbons	18.91			2662.79	196.34	847.33	1195.59	612.08	119.11
P5 - Lead					22,536.78		811.80	1182.05	
P6 - Hazardous Emissions							250.58	1029.47	
P7 - Other		1127.01		3667.96					284.14
Marginal Cost (79-85)	NL	NL		NL	L				
P1 - Particulates	9.25	25.18		69.04					
P2 - Sulfur Oxides	1014.70	498.96			194.69				
P3 - NO2 and CO	18.78	93.99		1994.90	81.61				
P4 - Hydrocarbons	18.78	93.99		1994.90	81.61				
P5 - Lead		447.48		2484.90					
P6 - Hazardous Emissions		447.48		2484.90					
P7 - Other		447.48		2484.90					
Marginal Cost (79-85)									
P1 - Particulates*	5.54	5.54	5.54	5.54	5.54	3.25	64.54	5.54	53.32

(Particulates only)
***** L - Linear, NL - Non-Linear***

TABLE 4.1

MARGINAL ABATEMENT COSTS ($1979)

	3820	3825	3830	3832	3840	3841	3843	3850	3900
	Machinery	Computing	Electrical	Radio	Transport	Ships	Vehicles	P. Goods	Other
Marginal Cost (79-82)	NL	NL	NL	NL	L	NL	NL	NL	NL
P1 - Particulates	52.15		110.01	39.04	50.96	126.89		264.90	5.77
P2 - Sulfur Oxides	425.83		408.46	1718.26	427.70	374.17	1354.92	2632.73	
P3 - NO2 and CO	294.98	661.33	81.64	513.09		1618.58	1080.98	65.57	134.69
P4 - Hydrocarbons	294.98	661.33	81.64	513.09		1618.58	1080.98	65.57	134.69
P5 - Lead			69.93	526.38			17.41	442.22	
P6 - Hazardous Emissions			69.93	526.38			17.41	442.22	
P7 - Other			69.93	526.38			17.41	442.22	
Marginal Cost (83-85)	NL	L	NL	NL	NL	NL	NL	NL	L
P1 - Particulates	89.93		181.63	117.81	127.41	334.01	221.47	359.63	13.32
P2 - Sulfur Oxides	288.53				424.62	632.50	118.80		
P3 - NO2 and CO	122.32		1476.22	190.17		520.62		193.09	
P4 - Hydrocarbons	198.34	78.24	40.49	395.21	574.13		1393.42	783.15	33.66
P5 - Lead			213.00				22738.60		3855.22
P6 - Hazardous Emissions		18384.10		803.70	1989.31			682.11	119.65
P7 - Other									
Marginal Cost (79-85)	NL					L			L
P1 - Particulates	62.,29					21.93			6.22
P2 - Sulfur Oxides	383.00					399.53			
P3 - NO2 and CO	201.42					1145.40			44.67
P4 - Hydrocarbons	201.42					1145.40			44.67
P5 - Lead									
P6 - Hazardous Emissions									
P7 - Other									
Marginal Cost (79-85)									
*P1 - Particulates**	36.80	5.54	76.00	5.54	49.25	5.54	81.24	5.54	5.54

**(Particulates only)*
*** L - Linear, NL - Non-Linear*

TABLE 4.2

TOTAL AVERAGE ABATEMENT COSTS ($1979)

ISIC	*3110*	*3130*	*3140*	*3210*	*3211*	*3220*	*3230*	*3240*	*3310*
	Food	*Beverages*	*Tobacco*	*Textile*	*Spinning*	*Apparel*	*Leather*	*Footwear*	*Wood*
Average Cost (79-82)									
	NL		L	NL	NL	L	L	L	L
P1 - Particulates	47.62		176.41	612.99	160.77	237.58	109.40	182.42	25.84
P2 - Sulfur Oxides	414.13		68.51	4984.94	482.19	32.63	371.07	110.31	20.37
P3 - NO2 and CO	35.84		68.51	394.61	111.39	32.63	420.51	665.69	20.37
P4 - Hydrocarbons	35.84		68.51	394.61	111.39	32.63	420.51	665.69	20.37
P5 - Lead	32.85		68.51	697.37	111.39	32.63	109.40	110.31	20.37
P6 - Hazardous Emissions	32.85		68.51	697.37	111.39	32.63	109.40	110.31	20.37
P7 - Other	32.85		68.51	697.37	111.39	32.63	109.40	110.31	20.37
Average Cost (83-85)									
	NL		L	NL	L		NL	L	L
P1 - Particulates	43.99		110.06	177.46	129.36		31.95	394.51	23.44
P2 - Sulfur Oxides	142.66		110.06	177.46	89.67		31.95		20.32
P3 - NO2 and CO	208.88		110.06	177.46	1416.86		8582.83	394.51	20.32
P4 - Hydrocarbons	137.12		12,779.56	889.55	89.67		255.42	998.51	20.32
P5 - Lead	49,749.13				722.82		31.95	23,536.86	20.32
P6 - Hazardous Emissions	26.11			177.46	89.67		237.10	1167.91	20.32
P7 - Other	26.11		110.06	177.46	89.67		346.14	852.02	20.32
Average Cost (79-85)									
		NL		NL					L
P1 - Particulates		83.08		211.59					24.87
P2 - Sulfur Oxides		144.57		211.59					20.09
P3 - NO2 and CO		6364.46		736.35					20.09
P4 - Hydrocarbons		6364.46		736.35					20.09
P5 - Lead		40.65		636.03					20.09
P6 - Hazardous Emissions		40.65		636.03					20.09
P7 - Other		40.65		636.03					20.09
Average Cost (79-85)									
P1 - Particulates*	5.55	5.79	61.84	7.08	35.76	226.54	7.59	20.22	5.56

****(Particulates only)***
***** L - Linear, NL - Non-Linear***

TABLE 4.2

TOTAL AVERAGE ABATEMENT COSTS ($1979)

ISIC	3320	3410	3411	3420	3511	3512	3513	3520	3522	3530
	Furniture	Paper	Pulp	Printing	Ind. Chem.	Ag. Chem.	Resins	Chem. Prod.	Drugs	Petro.
Average Cost (79-82)										
	NL	NL	NL	L	NL	NL	NL	NL	NL	NL
P1 - Particulates	19.02	44.09	25.41	411.08	34.46	117.39	47.13	192.90	149.16	347.91
P2 - Sulfur Oxides	12.72	195.99	76.46	83.84	68.99	367.43	262.25	26.21	420.25	76.20
P3 - NO2 and CO	12.72	232.21	8.67	197.05	98.85	230.71	70.05	46.20	106.92	28.47
P4 - Hydrocarbons	12.72	232.21	8.67	197.05	98.85	230.71	70.05	46.20	106.92	28.47
P5 - Lead	12.72	60.87	40.36	83.84	197.26	284.27	29.79	26.21	251.74	2935.19
P6 - Hazardous Emissions	12.72	60.87	40.36	83.84	197.26	284.27	29.79	26.21	251.74	2935.19
P7 - Other	12.72	60.87	40.36	83.84	197.26	284.27	29.79	26.21	251.74	2935.19
Average Cost (83-85)										
	NL	L	NL	L	NL	NL	NL	NL	L	L
P1 - Particulates	26.50	73.01	22.60	41.33	14.33	18.76	40.55	33.70	138.20	2.14
P2 - Sulfur Oxides	13.81	251.11	85.48	41.33	11.03	186.98	337.98	700.96	696.09	99.94
P3 - NO2 and CO	13.81	73.01	9.19	133.44	226.21	718.81	150.96	4.61	374.90	35.05
P4 - Hydrocarbons	13.81	490.81	9.19	130.85	128.31	133.55	60.94	121.95	77.52	100.22
P5 - Lead			17.76	41.33	1190.68		434.61	4.61	68.57	2.14
P6 - Hazardous Emissions	14,228.97	73.01	17.76	5901.28	134.36	857.85	37.16	4.61	68.57	2.14
P7 - Other	13.81	73.01	17.76	41.33	22.24	57.20	252.01	191.65	68.57	2.14
Average Cost (79-85)										
		NL	NL							
P1 - Particulates		46.37	23.20							
P2 - Sulfur Oxides		194.35	82.64							
P3 - NO2 and CO		251.91	10.52							
P4 - Hydrocarbons		251.91	10.52							
P5 - Lead		46.31	18.60							
P6 - Hazardous Emissions		46.31	18.60							
P7 - Other		46.31	18.60							
Average Cost (79-85)										
P1 - Particulates*	5.61	8.20	5.57	9.79	1.74	8.70	5.61	5.74	8.94	99.09

*(Particulates only)

** L - Linear, NL - Non-Linear

TABLE 4.2

TOTAL AVERAGE ABATEMENT COSTS ($1979)

ISIC	3540	3550	3560	3610	3620	3690	3710	3720
	Coal	Rubber	Plastic	Pottery	Glass	N-Metal	Iron	N-Ferrous Metal
Average Cost (79-82)								
	NL	NL	NL	NL	L	NL	NL	NL
P1 - Particulates	30.82	104.55	116.85	166.01	136.15	11.36	88.37	195.10
P2 - Sulfur Oxides	1934.56	365.09	1289.63		341.29	145.21	551.07	86.38
P3 - NO2 and CO	28.72	221.26	125.28	2134.64	264.63	918.83	80.62	21.83
P4 - Hydrocarbons	28.72	221.26	125.28	2134.64	264.63	918.83	80.62	21.83
P5 - Lead	19.93	395.65	604.27		136.15	6.85	11.28	158.74
P6 - Hazardous Emissions	19.93	395.65	604.27		136.15	6.85	11.28	158.74
P7 - Other	19.93	395.65	604.27		136.15	6.85	11.28	158.74
Average Cost (83-85)								
	NL	NL		NL	NL	NL	NL	NL
P1 - Particulates	33.82	126.91		36.04	73.97	9.52	106.03	167.85
P2 - Sulfur Oxides	253.93	401.49		36.04	73.97	81.98	12.75	75.44
P3 - NO2 and CO	70.64	93.19		5943.04	294.19	840.28	41.77	30.30
P4 - Hydrocarbons	45.52	93.19		2696.84	270.32	852.25	1204.02	642.38
P5 - Lead	26.61	93.19		36.04	22,610.75	4.92	820.23	1212.35
P6 - Hazardous Emissions	26.61	93.19			73.97	4.92	259.01	1072.44
P7 - Other	26.61	1246.42		3704	73.97	4.92	6.43	30.30
Average Cost (79-85)								
	NL	NL		NL	NL			
P1 - Particulates	31.76	117.12		98.88	99.21			
P2 - Sulfur Oxides	1037.21	590.90		56.38	293.90			
P3 - NO2 and CO	41.29	183.24		2024.74	180.82			
P4 - Hydrocarbons	41.29	183.24		2024.74	180.82			
P5 - Lead	22.51	539.42		2514.74	99.21			
P6 - Hazardous Emissions	22.51	539.42		2514.74	99.21			
P7 - Other	22.51	539.42		2514.74	99.21			
Average Cost (79-85)								
P1 - Particulates*	5.82	5.87	7.78	6.67	5.63	3.26	64.57	5.85

** (Particulates only)*

*** L - Linear, NL - Non-Linear*

TABLE 4.2

TOTAL AVERAGE ABATEMENT COSTS ($1979)

ISIC	*3810*	*3820*	*3825*	*3830*	*3832*	*3840*	*3841*	*3843*	*3850*	*3900*
	Metal	*Machinery*	*Computing*	*Electrical*	*Radio*	*Transport*	*Ships*	*Vehicles*	*P. Goods*	*Other*
Average Cost (79-82)										
	NL	NL	NL	NL	NL	L	NL	NL	NL	L
P1 - Particulates	184.94	112.92	132.23	155.45	136.63	349.35	166.57	79.19	606.53	74.19
P2 - Sulfur Oxides	1033.16	486.60	132.23	453.90	1815.85	726.09	413.85	1434.11	2974.36	68.43
P3 - NO2 and CO	219.17	355.75	793.56	127.08	610.68	298.39	1658.26	1160.17	407.20	203.12
P4 - Hydrocarbons	219.17	355.75	793.56	127.08	610.68	298.39	1658.26	1160.17	407.20	203.12
P5 - Lead	83.48	60.77	132.23	115.37	623.97	298.39	39.68	96.60	783.85	68.43
P6 - Hazardous Emissions	83.48	60.77	132.23	115.37	623.97	298.39	39.68	98.60	783.85	68.43
P7 - Other	83.48	60.77	132.23	115.37	623.97	298.39	39.68	96.60	783.85	68.43
Average Cost (83-85)										
	NL	NL	L	NL	NL	NL	NL	NL	NL	L
P1 - Particulates	181.67	183.20	129.10	243.42	284.02	329.03	412.34	294.69	683.61	21.59
P2 - Sulfur Oxides	635.72	361.80	129.10	61.79	164.51	626.24	674.36	192.02	278.98	8.27
P3 - NO2 and CO	272.82	218.26	129.10	1538.01	354.68	201.62	598.95	73.22	524.06	8.27
P4 - Hydrocarbons	207.30	291.61	207.34	102.28	559.72	775.75	78.33	1446.64	1062.13	41.93
P5 - Lead	66.19	93.27		274.79	164.51	201.62	78.33	22,847.82	278.98	3863.50
P6 - Hazardous Emissions	88.19	93.27	18,513.25	61.79	968.21	2190.93	78.33	73.22	961.09	126.34
P7 - Other	372.33	93.27	129.10	61.79	591.66	201.62	78.33	73.22	278.98	6.69
Average Cost (79-85)										
		NL					L			L
P1 - Particulates		135.82					66.80			20.16
P2 - Sulfur Oxides		456.53					444.41			13.94
P3 - NO2 and CO		274.95					1190.30			58.61
P4 - Hydrocarbons		274.95					1190.30			58.61
P5 - Lead		73.53					44.87			13.94
P6 - Hazardous Emissions		73.53					44.87			13.94
P7 - Other		73.53					44.87			13.94
Average Cost (79-85)										
P1 - Particulates*	53.42	36.91	234.06	76.17	8.99	49.75	7.36	81.53	10.23	6.24

** (Particulates only)*

*** L - Linear, NL - Non-Linear*

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