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AND THE ELECTRIC UTILITY INDUSTRY

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ABSTRACT

A sulfur emission tax has been discussed as the most likely candidate for implementation from the general class of proposals characterized as pollution taxation. This paper reports the results of an empirical analysis which utilizes an econometric model of demand and fuel substitution and an engineering model of production. The conclusions which follow from the analysis are that emissions and damage would be significantly reduced, there would be little effect on electricity demand growth and nuclear power growth, and that the Sulfur Emission Tax assumes greater value if the Clean Air Act is not implemented. Net benefits are positive in all cases, and the highest calculated net benefit to the Nation is $32 billion.

The impact upon income groups is mixed. The reported inelastic income elasticities imply a regressive effect from tax-induced rate increases. However, other research has shown sulfur pollution to be concentrated among low income urban areas. This indicates that reduction of sulfur emissions would benefit low income groups disproportionately and hence be progressive in this aspect.

The study is qualified empirical support for a proposition which has long been preferred on theoretical grounds.

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Introduction

A Sulfur Emission Tax and the Electric Utility Industry

The question of internalizing external effects into market decision processes has received growing attention in recent years. The label may be effluent charges, pollution prices (or taxes), or emission taxes; approximately the same meaning is intended. A charge corresponding to the marginal damage of the pollutant should be imposed upon the economic enterprise responsible for the discharge. In this way, according to welfare theory, nonmarket costs will become internalized into market decisions, and social and market optima will more closely approximate each other. While the theoretical and general issues have been explored rather extensively,[1] few empirical policy oriented analyses are attempted. This paper reports the results of an investigation of a sulfur emission tax in the context of the electric utility industry in New York. With limitations, the conclusions are somewhat applicable on a national basis.

I. Problems in Economic Theory and Analysis

The proposals for a sulfur emission tax are probably the most widely known specific policy in the general class of pollutant charge proposals, having been advocated by the President, Senator William Proxmire, the Sierra Club, and the Council of Economic Advisors. Nevertheless, as noted above, few empirical studies exist.[2] I believe there is an explanation for this seeming paradox. The explanation lies in the existence of two types of problems , one of which is intra-disciplinary and the second inter-disciplinary. Regarding the first type of problem, this sort of empirical study necessarily relies upon the foundation of knowledge. If the foundation is weak, the structure is suspect. Within economics, the analysis must depend upon assumptions about the nature of the demand for electricity, the choice of fuel type, and the correct measure of public benefit.

Probably the most widely known econometric study of electricity demand is the pioneering study by Franklin Fisher and Carl Kaysen in 1959 for the General Electric Corporation. They concluded long run residential demand is essentially insensitive to electricity prices, but industrial demand is possibly price elastic. This point of view has guided national policy since.[3] However, recent studies by Paul MacAvoy, John Wilson (1971), and Robert Halvorsen have found more pronounced long run price effects with representative long run elasticities between -1.14 and -1.33.

In our work as reported by Timothy Mount et. al. we have examined various functional forms through ordinary least squares and instrumental variable analysis of pooled cross section and time series data (1947-1970). The results reinforce the MacAvoy-Wilson-Halvorsen findings. Taking a simple constant elasticity form useful in subsequent discussion,

$$(1)\quad Q_{i,t} = A_i Q_{i,t-1}^{\lambda} N_{i,t}^{B_1} Y_{i,t}^{B_2} P_{i,t}^{B_3} G_{i,t-1}^{B_4} L_{i,t-1}^{B_5}.$$

$Q_{i,t}$ is electricity demand in state i, year t; A is a regional constant; λ is the lag coefficient; N is population; Y is per capita personal income; P is average electricity price; G is average gas price; and L is the national appliance price index.[4] This form is recognizable as the familiar geometric lag structure reflecting an adjustment through time to changes in the explanatory variables. The subscript for consumer class (residential, commercial, industrial) is omitted in Eq. 1, but separate parameters by class are shown in Table 1.

From these results (as well as the findings of Halvorsen, MacAvoy, and Wilson) it is reasonable to suppose that sulfur tax costs will interact with demand growth, and that a version of Eq. 1 and the data in Table 1 provide a useful demand model to be described below.[5]

A second problem in economic analysis is the existence of competition between fuels as the energy source for electricity generation. The basic methodology employed by utility personnel is reasonably clear as discussed by Paul Jeynes and others. It is less obvious how these choices can be summarized at a state level. In 1969 MacAvoy reported this result:

$$(2)\quad \log(Q_n/Q) = -4.38 + 0.42 \log S - 0.86 \log(PNF/PFF) - 1.03 \log(PNK/PFK).$$

Q_n is new nuclear capacity; Q is new capacity of all forms (coal, hydro, oil, gas, nuclear); S is plant size; PNF and PFF are nuclear and fossil fuel price indices; and PNK and PFK are nuclear and fossil fuel capital costs per unit capacity.[6] In this equation, a one percent increase in both fuel and capital costs for fossil plants would cause a 1.89 percent increase in nuclear market share. MacAvoy's study thus provides some basis for predicting the effect of a sulfur emission tax on nuclear power plant growth; more below.

A third problem is the correct measurement of the welfare loss caused by retarded growth in electricity demand. Figure 1 shows how residential consumers' surplus might be affected by a sulfur emission tax. $P_t(Q_t)$ represents a demand function in a state in year t, and (following Eq. 1), $P^*_t(Q^*_t)$ defines a demand function which has shifted because of the higher rates caused by a sulfur tax. In comparison to the non-tax situation

Table 1--Electricity Demand Coefficients and Elasticities

Variable	Consumer Class		
	Residential[a]	Commercial	Industrial
Population coefficient	.11	.12	.12
t statistic	17.0	10.6	8.5
long run elasticity	.94	.98	1.09
Income coefficient	.03	.10	.08
t statistic	4.2	5.3	3.3
long run elasticity	.30	.80	.72
Electricity price coefficient	-.14	-.20	-.20
t statistic	12.5	9.6	8.1
long run elasticity	-1.21	-1.60	-1.79
Gas price coefficient	.02	.01	[b]
t statistic	6.7	1.0	[b]
long run elasticity	.13	.05	.00
Lag coefficient	.89	.87	.89
t statistic	136.5	75.7	79.9
R^2	.999	.999	.978

SOURCE: Mount _et._ _al._

[a] The residential appliance price coefficient is -.04 with a t statistic of 2.4 and a long run elasticity of -.36. Inapplicable to other classes.

[b] Deleted because its sign was insignificantly incorrect in first analysis.

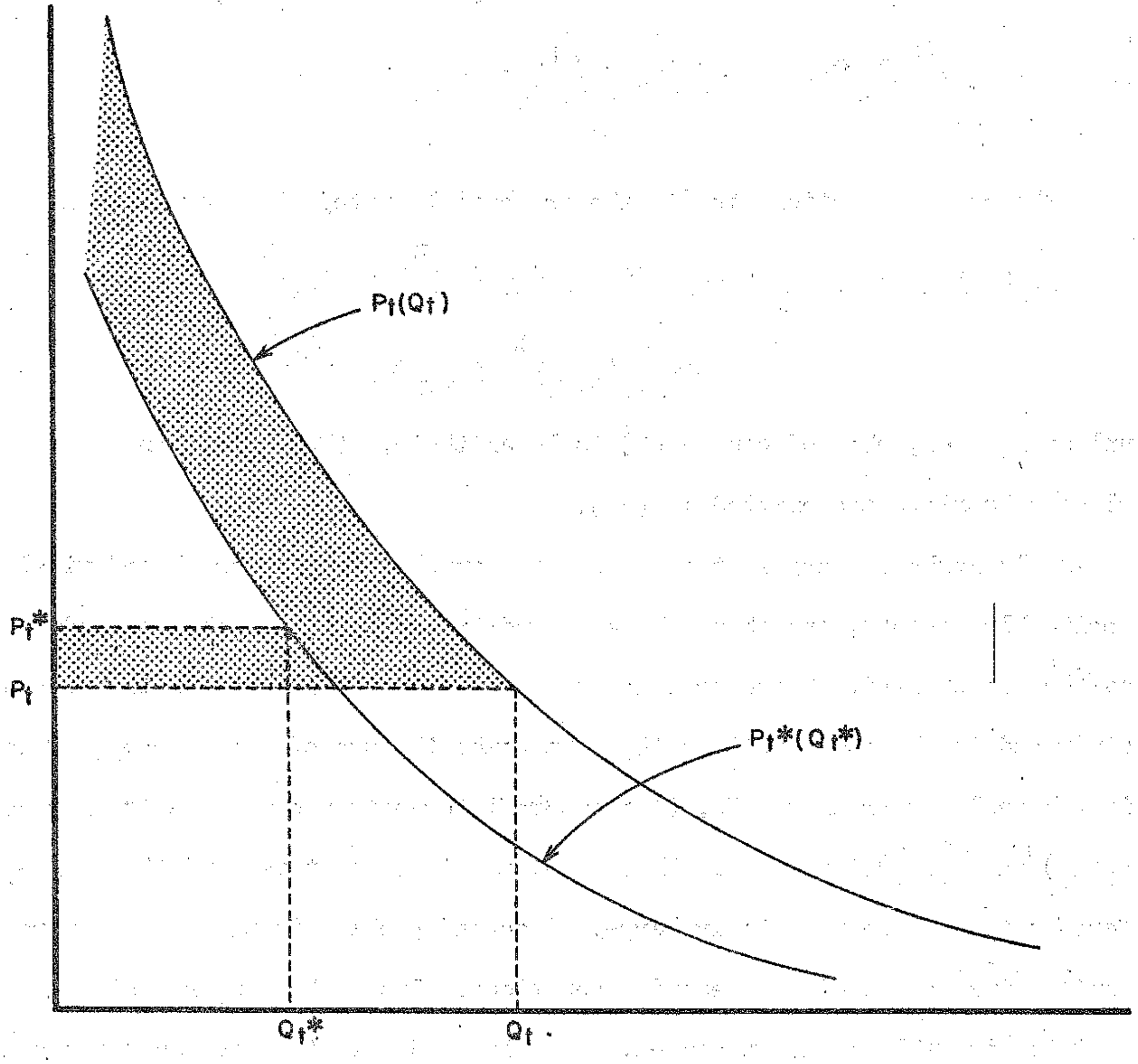

FIGURE I. DEMAND FUNCTIONS WITH AND WITHOUT A SULFUR TAX AND ASSOCIATED CONSUMERS SURPLUSES

P_t, Q_t, the higher rate P_t^* not only is associated with a shifted demand function, but of course calls forth lowered demand Q_t^*. The loss in consumers' surplus is presumably represented by the shaded area, or

$$(3)\quad \Delta CS = \int_0^{Q_t^*} P_t^*(Q_t^*)dQ_t - P_t^*Q_t^* - [\int_0^{Q_t} P_t(Q_t)dQ_t - P_tQ_t].$$

With the demand functions in (1) the appropriate integral to evaluate is

$$(4)\quad \int P_t(Q_t)dQ_t = B_3/(B_3 + 1)[Q_t/(Q_{t-1}^{\lambda} A(N_t/N_0)^{B_1} (Y_t/Y_0)^{B_2} (G_{t-1}/G_{0-1})^{B_4} (L_{t-1}/L_{0-1})^{B_5}]^{-(B_3 + 1)/B_3}$$

unless $B_3 = -1$, when of course (4) is logarithmic. (Both state and consumer class subscripts are omitted in (4)).

Arnold Harberger argues that consumers' surplus is a powerful and widely applicable concept, and should be employed in such applied welfare studies as the one at hand. There are, however, obstacles to its use in the present study and in the end I believe they proscribe the use of the concept. First is the analytic problem. Eq. (1) nowhere intersects the price axis, nor do $P_t(Q_t)$ and $P_t^*(Q_t^*)$ intersect. Therefore, the integral terms and their difference in (3) are infinitely large. A second problem is the clear general equilibrium nature of the demand assumptions. Since the long run elasticities in Table 1 all exceed -1, a tax-induced rate increase must cause an absolute decline in expenditures on electricity and consequently higher levels of consumption of other items. There is no method to calculate the increased consumers' surplus from increased consumption of other commodities caused by a sulfur emission tax. Analogously, to employ consumers' surplus accurately the demand functions for electric intensive products (plastics, aluminum, chemicals, synthetic fabrics, etc.) of industry and the demand functions for services of commercial enterprises should be evaluated to determine these welfare losses from a sulfur emission tax. Such an effort is beyond the scope of this paper.

A third problem is the argument of Myrick Freeman and David Seckler that consumers' surplus may bias public decisions in the favor of upper income groups. As Harberger notes, this may be equally true of economic data in general in that it presumes an existing income distribution. We can make some observations about a sulfur emission tax and income distribution (see below, section V), but they are not relevant to the use of the consumers' surplus concept.

In summary, the study assumes electricity demand is influenced in a predictable way by exogenous factors as in Table 1, that the MacAvoy study is a useful basis for determining the impact of the tax on fuel market shares, and that the consumers' surplus concept is not practical here.

II. Interdisciplinary Problems: Sulfur Emission Damage and Controls

The second type of problem confronting empirical studies of sulfur emission taxes is the existence of basic gaps in interdisciplinary knowledge. It must be acknowledged at the outset that there is no clear picture of the damage caused by sulfur emissions. However, the physical basis seems clear. Sulfur is contained in coal and oil, and insignificantly in natural gas. When the fuel is burned, the sulfur is oxidized into sulfur dioxide or sulfur trioxide. In the atmosphere some of these chemicals interact with moisture to form either sulfuric acid (H_2SO_4) or sulfurous acid (H_2SO_3). Other sulfur oxides may become associated with particulates. The acids, the particulate sulfates, and the sulfur oxide gasses from the atmosphere fall into contact with human beings, vegetation, property, and various materials. Although the fallout may have some occasional positive effect (such as a fungicide), it is generally deleterious. In this manner the bronchial passages and air sacs in the lung are functionally impaired. Respiratory diseases such as chronic bronchitis, emphysema, asthma, and lung cancer may be caused or worsened by the inhalation of these sulfur emission products.

There is significant disagreement about physical relationships beyond this level of generality. Richard Wilson, for example, argues that deaths are an exact linear function of sulfur oxide concentration, and that there is no safe threshold. This is shown in Fig. 2. On the other hand, R.A. Horne proposed a variable relationship hypothesis wherein low level concentrations near B are beneficial for most pollutants. Positive value changes to injurious effects at C and then death at D as concentrations increase. Further difficulties arise from the problems of separating effects of chronic vs. acute exposure, distinguishing the impact upon persons with pre-existing respiratory diseases, and determining the interactive effects of particulates. Other sources are available for a better discussion of these problems, particularly Henry Wohlers, Cyril Comar and John Thompson, and Larry Barrett and Thomas Waddell.

Barrett and Waddell in their widely cited study estimated national air pollution damage at $16 billion in 1968 with the major categories being $8.3 billion sulfur damage ($2.8 billion to residences, $2.2 billion to materials, $3.3 to health) and $5.9 billion particulate damage (particularly $2.4 billion to residences, $2.8 to health). Monetary damage to vegetation and natural ecosystems was thought to be minimal, as were the effects of carbon monoxide, hydrocarbons, and nitrogen oxides. As a national average, the 33.2 tons of emitted sulfur oxide define damage of $250 per ton of sulfur oxide. Assuming that almost all sulfur oxide is sulfur dioxide this is $500 per ton of sulfur in 1968 dollars, or $600 in 1972 dollars.7/

There is substantial disagreement about the accuracy of this sort of

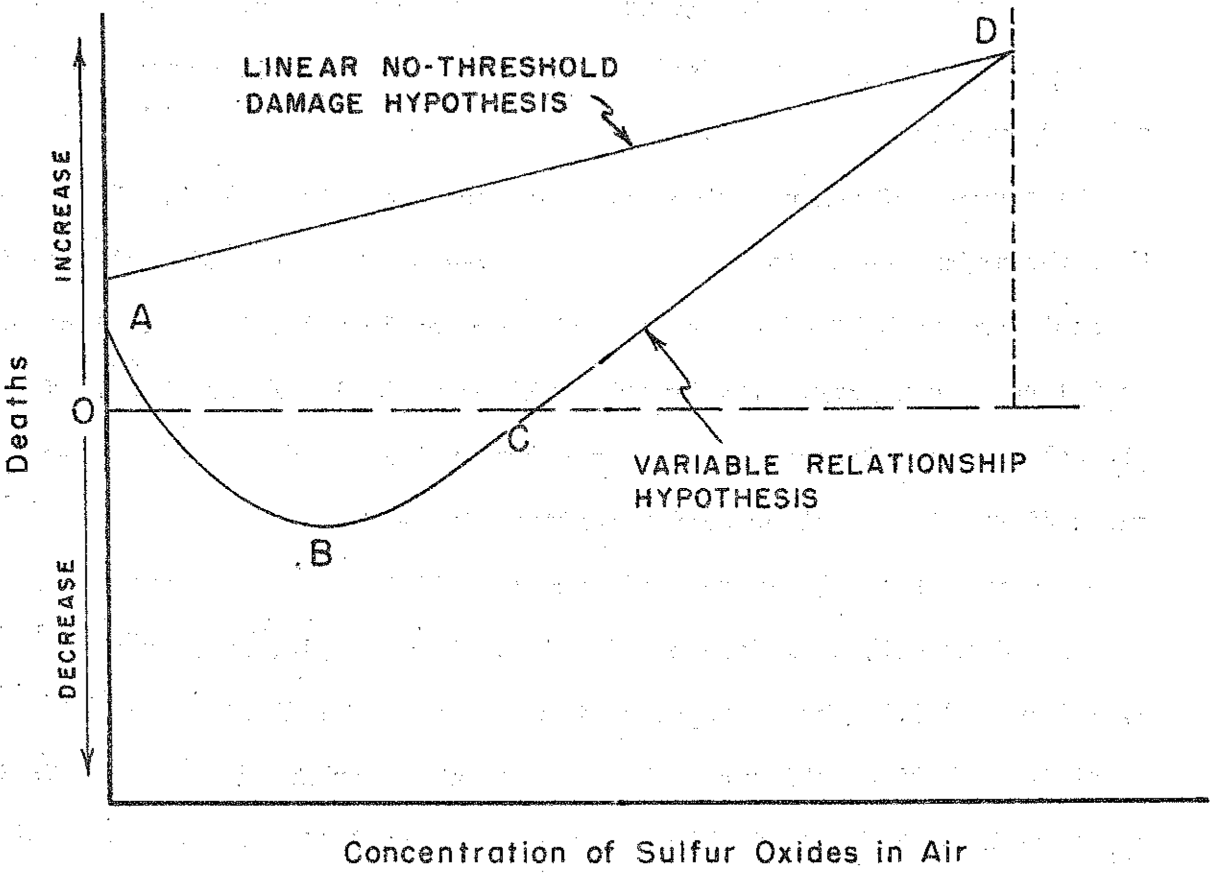

FIGURE 2. ALTERNATIVE HYPOTHESES OF MORTALITY-CONCENTRATION RELATIONSHIP FOR NATURAL SUBSTANCES

accounting. Comar and Thompson, for example, believe that sulfur oxides do not represent a significant health hazard at prevailing concentrations unless particulates are also present (pp. 44-45). It is beyond the scope of this paper to attempt further summary of the states of the arts in biology, physical sciences, and public health economics as they bear upon the question of sulfur emission damage. It is sufficient to note that damage is probably significant, and its extent and the processes by which it occurs remain unsettled questions.

The sources of sulfur oxide emissions are shown in Table 2. It is clear that the major source is fossil fuel steam-electric generating plants; they account for one half of the total and have nearly twice the emissions of the next largest category. Tax impact would be most significant here. The empirical analysis focuses upon the electric utility industry with some subsequent discussion of other sulfur emitting industries.

Until very recently it was believed that high smokestacks were a simple and efficient method of damage reduction. For example, in January of 1971 J. Holden and T.R. Mongan reported that the use of tall stacks resulted in electric utilities making only 14 percent of the sulfur dioxide population exposure in Cook County in 1968, although the utilities caused 78 percent of the emissions. Most of the utility emissions, in their view, take the form of "a relatively uniform 'background' pollution over a wide area determined by topography and the prevailing atmospheric conditions" (p. 382). However, tall stacks seemed a less desirable answer when Likens and Noye Johnson et. al. reported that precipitation in the Northeast now contains sulfuric acid from fossil fuel combustion. Given prevailing weather patterns, it is tempting to conclude that the tall stacks in Cook County favored by Golden and Mongan provided the sulfuric acid in the rainfall measured by Likens.

Table 2--Sources of Sulfur Emissions, 1967

Source	Nationwide Emissions, Million Tons of Sulfur Oxides
Solid waste disposal	0.17
Steam-electric power plants	15.40
Petroleum refineries	2.31
Copper smelting[a]	2.58
Lead smelting[a]	0.19
Zinc melting[a]	0.45
Sulfuric acid production	0.60
Other industrial processes	0.15
Residential, commercial, and industrial heating plants	8.48
Total	30.33

SOURCE: The Economics of Clean Air

[a] Primary metallurgical processes.

Current emphasis in emission control developments is placed upon either sulfur removal or fuel substitution. As a substitute for high-sulfur coal or oil, consideration is given to natural gas, low-sulfur coal or oil, and nuclear power. The removal processes can be characterized according to whether (1) sulfur is removed from the stack gas only, or from the fuel prior to or during combustion, (2) extracted sulfur is in waste form or capable of further processing into a saleable product, or (3) the process is designed to be added to old plants, integrated into the construction of new plants, or both. A review of current engineering literature indicates that by 1976 processes with 90% removal efficiency are expected to cost between .95 and 1.9 mills per KWH of electricity (or between \$2 and \$4 per ton of coal).[8/] These estimates of control costs may be compared to 1971 U.S. averages of electricity price of 17.8 mills per KWH and coal for utilities costing \$8 per ton.[9/] Thus, sulfur removal might raise coal use costs between 25% and 50% and total electricity costs in coal plants from 5% to 10%.

While the interaction effects between sulfur oxides and particulates in biological damage were observed above, a similar synergism exists in sulfur removal processes. In air pollution control, the simultaneous removal of certain percentages of particulates and sulfur oxide may be less costly than separate removal systems; sulfur oxide is sometimes injected into stacks to increase the efficiency of electrostatic precipitation of particulates. These synergisms in damage and control are not yet clearly defined, and the investigations here will proceed to examine sulfur emissions alone.

III. Proposed Emission Taxes

The various proposals for a sulfur emission tax can be compared according to their provisions for time phasing, geographic differentials, and average rates. The Administration's current proposal calls for initiation of a tax in 1976 with three levels of tax rates corresponding to three current ambient air quality standards.[10/] These regions are defined by the criteria of the existing Clean Air Act. A "clean" region with respect to sulfur oxide content is at present a region with less than an annual average .02 parts of sulfur oxides per million parts of air (ppm). This standard (termed the "secondary" standard) is intended to protect residences, materials, and natural ecosystems. A "dirty" region has air with an average annual sulfur content exceeding .03 ppm, the primary standard. (This is intended to protect public health.) A third type of region (grey?) has average annual air quality in between the two standards (i.e., between .02 and .03 ppm). The Administration's proposal suggests a tax rate of 15 cents per pound of emitted sulfur in dirty regions, 10 cents per pound in grey regions, and nothing in clean regions.

The relationship of the Clean Air Act and the Administration's sulfur emission tax proposal is further confused by recent reports that the Environmental Protection Agency (1973) is considering changing one or both definitions to an acute exposure basis.

A second proposal by Sen. William Proxmire would have a single rate applicable throughout the country and would have been phased to grow at 5 cents per pound emitted over a four year period (i.e., 5 cents in 1972, 10 cents in 1973, 15 cents in 1974, and 20 cents in 1975 and thereafter).

Each proposal would offer different incentives. The Administration proposal imposed increasing marginal costs on emitters in a region as emissions rise, while the Proxmire version has a constant marginal cost to emitters. This would seem to be related to assumptions about the nature of the damage curve as discussed above. The Administration proposal would offer incentive for emitting industries to locate in clean regions and an extra incentive for a region to achieve clean status (i.e., the tax rate falls from 10 cents per pound to nothing), while the Proxmire proposal would not. Either proposal seems to offer some kind of exemption to the Clean Air Act. The Act requires all regions to be out of the dirty category and into the grey or clean categories by 1976, but proposing a tax on emissions in regions not meeting the primary standards seems to lessen the strength of the requirement to meet this standard.

There are arguments on each side of the phasing question. As a practical matter it is unlikely that a tax would be imposed before 1976. It also appears likely that control costs will be at least 20 cents per pound of sulfur removed and probably higher. Therefore, the Administration's proposal in its present form would not contain a financial incentive for sulfur removal.

In the subsequent analysis we shall consider three tax rates: (1) $200 per ton sulfur emitted, the median rate in the Administration proposal; (2) $400 per ton, the ultimate level of the Proxmire proposal; and (3) $600 per ton, the average damage in the Barrett-Waddell study.

IV. The Basic Model and Selected Hypotheses

We shall hypothesize these significant effects of a sulfur emission tax on the electric utility industry:

(1) Emissions and damage will be reduced

(2) Demand growth will decline

(3) Nuclear generation (a substitute for coal and oil) will be accelerated

(4) Social benefits will exceed social costs

(5) If the tax rate differs from the damage rate, social optimality will differ from market optimality

(6) If the Clean Air Act is not implemented by 1976, the tax will have greater social value

These assertions are not hypotheses in the strict sense of statistical inference, but more generally, in that they are tentative assumptions intended to draw out the empirical consequences of the analysis. As will become evident below, the analysis seems to generally disprove the second and third propositions, support the first, fourth, and sixth, and give weak acceptance to the fifth.

A major methodological problem in this study is the definition of the appropriate geographic area. The decision here has been to examine the State of New York. Primary reasons for this selection are (1) the previous engineering-economic study by Olaf Hausgaard; (2) the states are basic decision making units with respect to air quality standards and electric utilities; (3) problems of aggregating the New York City area with Upstate New York provide qualitative insights into larger aggregation problems; (4) plans for air quality implementation and for electric utilities are relatively well defined and available. A disadvantage of this approach is the difficulty in generalizing results to the Nation.

Selected comparative data for New York and the rest of the Nation are shown in Table 3. New York would seem to be reasonably representative on the basis of the proportion of sulfur emissions from electric utilities and the proportion of generation by coal and oil plants. As does most of the country, New York plans to meet primary air quality standards by the use of low sulfur fuels--an important point we will discuss further.

Further discussion of the basic model will make continued reference to Table 4 which shows results in one of the 40 cases studied. Definitions employed there should become clear by the end of this section.

Table 3--New York and US Population, Generation and Sulfur Emissions, 1970

Item	New York	US
Population, millions	18.3	203.8
Electricity generation, billion KWH		
Total	95.4	1,531.6
% by coal	27.7%	46.1%
% by oil	32.5%	11.9%
% by coal and oil	60.2%	58.0%
Sulfur oxide emissions, million tons		
Total	1.339	33.9
% from power plants	48.8%	50.8%[a]
Emissions per capita, pounds	146	333

SOURCES: Statistical Abstract, Environmental Quality, the Economics of Clean Air, and New York State Department of Environmental Conservation, Edison Electric Institute.

[a] 1967

Table 4--Sulfur Tax Analysis with Medium Control Costs, High Tax Rate, Low Nuclear Market Share, and Without Clean Air Act Implementation

			--------Demand, Billion KWH--------				---------Generation, Billion KWH---------					
Year	($) Per Capita Person. Income (1)	Pop. 1,000 (2)	Res. (3)	Com. (4)	Ind. (5)	Total, Inc. Other (6)	Total (7)	Gas (8)	Hydro (9)	Intern. Combust. (10)	Nuclear Power (11)	Year
1970	5171	18191	25.2	24.9	27.3	87.4	95.5	8.8	24.8	0.2	4.3	1970
1971	5314	18447	27.1	26.4	28.2	92.3	100.8	8.8	24.9	0.2	6.9	1971
1972	5461	18708	28.9	27.9	29.0	97.0	105.9	8.8	25.0	0.2	9.4	1972
1973	5611	18971	30.8	29.3	29.9	101.6	110.9	8.8	25.1	0.2	11.8	1973
1974	5766	19239	32.5	30.7	30.7	106.1	115.8	8.8	25.2	0.3	14.2	1974
1975	5925	19510	34.2	32.0	31.5	110.5	120.6	8.8	25.3	0.3	16.6	1975
1976	6089	19785	35.9	33.3	32.4	114.8	125.4	8.8	25.4	0.3	19.3	1976
1977	6257	20064	37.1	34.1	32.7	117.4	128.2	8.8	25.5	0.3	21.8	1977
1978	6430	20347	38.3	35.0	33.2	120.3	131.4	8.8	25.5	0.3	24.9	1978
1979	6607	20634	39.6	36.0	33.7	123.4	134.8	8.8	25.6	0.3	28.5	1979
1980	66789	20918	40.8	37.0	34.4	126.8	138.5	8.8	25.7	0.3	32.7	1980
1981	6952	21194	42.1	38.1	35.0	130.2	142.2	8.8	25.7	0.3	37.8	1981
1982	7118	21474	43.3	39.1	35.7	133.5	145.8	8.8	25.8	0.4	42.9	1982
1983	7288	21757	44.5	40.2	36.4	136.9	149.5	8.8	25.9	0.4	47.9	1983
1984	7462	22044	45.6	41.3	37.2	140.2	153.1	8.8	26.0	0.4	52.8	1984
1985	7640	22335	46.8	42.3	37.9	143.5	156.7	8.8	26.0	0.4	57.7	1985
1986	7823	22630	47.9	43.4	38.6	146.8	160.3	8.8	26.1	0.4	62.5	1986
1987	8010	22929	48.9	44.5	39.4	150.1	163.9	8.8	26.2	0.4	67.3	1987
1988	8201	23232	50.0	45.6	40.2	153.4	167.5	8.8	26.2	0.4	72.1	1988
1989	8397	23538	51.0	46.6	41.0	156.7	171.1	8.8	26.3	0.4	76.8	1989
1990	8598	23849	52.1	47.7	41.8	160.0	174.7	8.8	26.4	0.4	81.5	1990

Table 4 CONTINUED

	Generation, Billion KWH			Tax, Control Costs, Million Dollars			Average Costs and Prices, cents/KWH					
Year	Coal (12)	Oil (13)	Emis. 10,000 Tons Sulfur (14)	Tax (15)	Control Cost (16)	Control Cost + Tax (17)	Av. Cost, No. Tax (18)	Res. Av. Price (19)	Com. Av. Price (20)	Ind. Av. Price (21)	Damage Million Dollars (22)	Year
1970	26.5	30.9	35.3	0.0	0.0	0.0	2.13	3.09	2.82	1.21	211.5	1970
1971	26.5	33.5	36.5	0.0	0.0	0.0	2.14	3.12	2.84	1.22	219.1	1971
1972	26.5	36.0	37.8	0.0	0.0	0.0	2.16	3.14	2.86	1.23	226.5	1972
1973	26.5	38.4	39.0	0.0	0.0	0.0	2.18	3.17	2.89	1.24	233.7	1973
1974	26.5	40.8	40.1	0.0	0.0	0.0	2.20	3.19	2.91	1.25	240.8	1974
1975	26.5	43.2	41.3	0.0	0.0	0.0	2.22	3.22	2.94	1.26	247.7	1975
1976	26.5	45.0	32.8	196.9	25.5	222.3	2.24	3.25	2.96	1.27	196.9	1976
1977	26.3	45.5	23.5	140.9	51.2	192.1	2.25	3.53	3.22	1.38	140.9	1977
1978	26.1	45.8	14.1	84.5	76.8	161.3	2.27	3.52	3.21	1.38	84.5	1978
1979	25.9	45.7	4.7	28.0	102.0	130.0	2.29	3.51	3.20	1.37	28.0	1979
1980	25.7	45.4	4.6	27.8	101.2	129.0	2.31	3.50	3.19	1.37	27.8	1980
1981	24.6	44.9	4.5	27.1	99.0	126.1	2.33	3.52	3.21	1.38	27.1	1981
1982	23.5	44.5	4.4	26.4	96.9	123.3	2.35	3.54	3.23	1.38	26.4	1982
1983	22.5	44.0	4.3	25.8	94.8	120.6	2.37	3.56	3.25	1.39	25.8	1983
1984	21.5	43.6	4.2	25.1	92.8	118.0	2.39	3.59	3.27	1.40	25.1	1984
1985	20.6	43.2	4.1	24.5	90.9	115.4	2.41	3.61	3.29	1.41	24.5	1985
1986	19.7	42.7	4.0	24.0	89.0	113.0	2.43	3.63	3.31	1.42	24.0	1986
1987	18.9	42.3	3.9	23.4	87.2	110.6	2.45	3.66	3.34	1.43	23.4	1987
1988	18.1	41.9	3.8	22.8	85.4	108.3	2.47	3.68	3.36	1.44	22.8	1988
1989	17.3	41.5	3.7	22.3	83.7	106.0	2.49	3.71	3.38	1.45	22.3	1989
1990	16.5	41.1	3.6	21.8	82.1	103.9	2.51	3.74	3.41	1.46	21.8	1990

A. Growth in Demand and Generation

Utilization of Eq. (1) demand functions required independent projections of the explanatory variables. It is convenient to use recent Bureau of Economic Analysis predictions by Robert Graham *et. al.* for population and income growth in New York. They show population growing from 18.2 million in 1970 to 23.8 million in 1990, and per capita income growth of $5200 to $8600 (1972 dollars) in the same period. (See columns 1 and 2 of Table 4.)

Remaining explanatory variables in (1) are electricity and gas rates. The basic assumption here is that the sulfur emission tax induced increases in taxes and control costs are passed along to consumers in the next year. This follows from the rate of return pricing policies used by the Public Service Commission in New York and most other states. The responsiveness of the regulatory agencies in incorporating average cost changes into rate structures is suggested by the stability of the aggregate rate of return to investment by private utilities. Notwithstanding minor definitional changes, it has been either 7.3 or 7.4 percent of investment from 1965 through 1971.[11] Costs in the model consist of two components: an increasing average cost exogenously defined and internally defined tax-related costs. The National Power Survey (p. I-19-10) calculates average power costs will increase 19.9% from 1968 to 1990. This is used on a simple linear growth basis for exogenous average cost increases (col. 18). Residential, commercial, and industrial electricity prices (cols. 19-21) increase at the same rate, and they further increase by the internally calculated fraction of tax plus control costs to total generating costs in the preceding year. Gas prices are assumed to increase 50% over the period,[12] and household appliance prices are maintained at their 1971 level.

Columns 3-7 show the variable demand and total generation estimates for the particular cost-price assumptions of this case. Other sales are 11.5% of total sales and transmission losses are 8.4% of total generation.

Predictions of growth in generation by type of process involve many uncertainties about environmental protection, fuel availability, and cost. Herein we shall merely note some educated guesses and offer our own.

The National Power Survey predicted actual declines in the Northeast in generation for coal and oil throughout the coming two decades. They believed nuclear power to be the only major growth process, with modest increases expected for gas turbines, pumped storage, and internal combustion for peaking power. Generation from natural gas and conventional hydropower were thought to be nearly constant.

Hausgaard, focusing on New York, predicted that nuclear plants would account for 50% of new capacity in this decade. Oil generation increases rapidly in the late 1970's. Coal generation declines slowly to a plateau in the late 1970's. Natural gas generation remains constant. Gas and diesel turbine capacity trebles but remains the smallest source.

The assumptions used here generally follow Hausgaard's. Natural gas (column 8) stays at its 1970 level of 8.8 BKWH (billion kilowatt hours). Hydrogeneration (both conventional and pumped storage) accounts for 2% of generation growth, and is shown in column 9. Internal combustion generation (column 10) provides .3% of new generation. Coal, oil, and nuclear generation are defined as providing "base load growth"--the remaining 97.7% of new generation not made through essentially peak load processes. Through 1976 generation by these processes is unaffected by the cost of a sulfur emission tax. Coal generation (column 12) is unchanged, and oil (column 13) and nuclear power (column 11) each account for one half of base load growth. Beginning in 1977 (the first year after imposition of a tax), each of these three processes changes its generation because of two factors. First is an autonomous component reflecting other economic conditions, and second is a tax-induced effect. Autonomous nuclear growth increases from 60% of base load growth in 1976 to 100% in 1980. From 1980 to 1990, autonomous nuclear growth is all of the base load growth and a replacement of 3 1/3% of the preceding year's coal generation. These relationships and similar ones for oil and coal are shown in the Appendix.

The sulfur emission tax-induced nuclear growth depends upon the treatment of the MacAvoy findings reported in the preceding section. If we define a market share elasticity as the ratio of a percentage increase in nuclear market share to a percentage increase in coal and oil generating costs with constant nuclear generating costs, the MacAvoy estimate is 1.89. However, MacAvoy's study was apparently undertaken in 1966-68, a period when nonmarket costs were less important than at present. That is, I believe that choice of generating process was based almost completely upon cost considerations at that time, but at present and in the foreseeable future environmental protection and fuel availability will be significant nonmonetary considerations in process selection. Selecting between 0%, 1%, and 2% as the nuclear market share elasticity, I conclude that if MacAvoy's 1.89% estimate was accurate at that time, 1% is equally likely now. Both values are examined in separate sets of cases. Thus, we arrive at an important assumption about the sulfur emission tax-induced substitution of nuclear power for coal and oil generation:

$$(5) \quad TNMS_t = MSEN * [(TCC_{t-1}/GCO_{t-1}) / (.5 * ACWT_{t-1})].$$

TNMS is the tax induced nuclear market share increase as a fraction, and MSEN is the market share elasticity for nuclear power taken at either 1.89 or 1.00. The term in brackets is the sulfur emission tax-induced costs for coal and oil as a proportion of total generating costs; TCC is tax plus control cost in million dollars and GCO is generation by coal and oil in billion KWH. ACWT is average cost without the tax (defined above) in mills/KWH; since the National Power Survey (p. I-19-10) estimates generating costs at one half of total costs in the Northeast in the next two decades, one half ACWT is the appropriate generating cost estimate. Thus, (5) shows that tax induced nuclear growth results from an increased market share of nuclear power in new generation, and this increased market share is caused by the increased tax and control costs for coal and oil generation relative to average generating cost without the tax.

B. <u>The Clean Air Act, Emissions, Taxes, and Control Costs</u>

Sulfur emissions will depend upon the amounts of coal and oil burned, the sulfur content of those fuels, and the proportion of sulfur which is emitted. Following Hausgaard, coal use is .4214 tons per 1000 KWH and oil use is .2725 tons per 1000 KWH. Future sulfur content will depend upon municipal, State and Federal regulations. The impact of a sulfur emission tax must be considered in this uncertain context. Hausgaard's base case calculated emissions in the context of a 1% statewide sulfur content average, presumably a mixture of low sulfur New York City fuels and high sulfur upstate fuels. Support for this figure is given by the Economics of Clean Air (p. A-2) in noting new emission standards are equivalent to the use of 1% sulfur coal and 1.4% sulfur oil. Taking into account the stricter New York City standards and the relative concentration there of oil generation, one set of analyses will assume that by 1976 the average sulfur content of both coal and oil is 1%.

However, we must take note of the strong probability of the Clean Air Act not being implemented by 1976. The Environmental Protection Agency stated

(1972, p. 10843) ". . .there is strong evidence that the complete implementation of the State plans as submitted may not be obtainable in the time prescribed." They believed low sulfur fuel was insufficient in quantity, and that the area most affected would be New York, the Midwest, and the South Central region. Recent reports (noted above) indicate possible modification of the standards. Therefore, another set of analyses is conducted with the assumption that the Clean Air Act is not implemented by 1976, and the average statewide sulfur content is 2%.

If the fuel is untreated, about 90% of the sulfur is passed into the atmosphere. The control costs discussed above are based upon 90% removal. If control is implemented in one fourth of the coal and oil plants in each year from 1976 to 1979, the proportion of sulfur emitted is 90% until 1976; 70%, 50%, and 30% in 1976, '77, and '78; and 10% thereafter. If control is not implemented, emissions remain at 90% throughout the period. Emissions appear in column 14.

C. Social Benefits and Market Decisions

Illustrative damages in the absence of a tax depend upon Clean Air Act effectiveness. Table 5 shows this case for quinquennial periods. Implementation of the Clean Air Act standards reduces damage by exactly 50% because of the sulfur content definitions: 1% with implementation and 2% without.

If the tax is imposed and further control undertaken, damage reduction follows emission reduction as in column 22 of Table 4 and in Figure 3.

Social benefit is narrowly defined in each case with a tax. The only claimed benefit is from direct damage reduction relative to the no-tax base case in Table 5. Major indirect benefits might include reduced strip mining, lessened oil spillage, decreased death and injury in coal mining and petro-

Table 5--Possible Sulfur Emission Damage in New York Without a Tax

(Million Dollars)

	Clean Air Act Implemented	
	Yes	No
Year		
1970	105.8	211.5
1975	121.1	242.2
1980	127.1	254.1
1985	117.8	235.5
1990	109.9	219.8

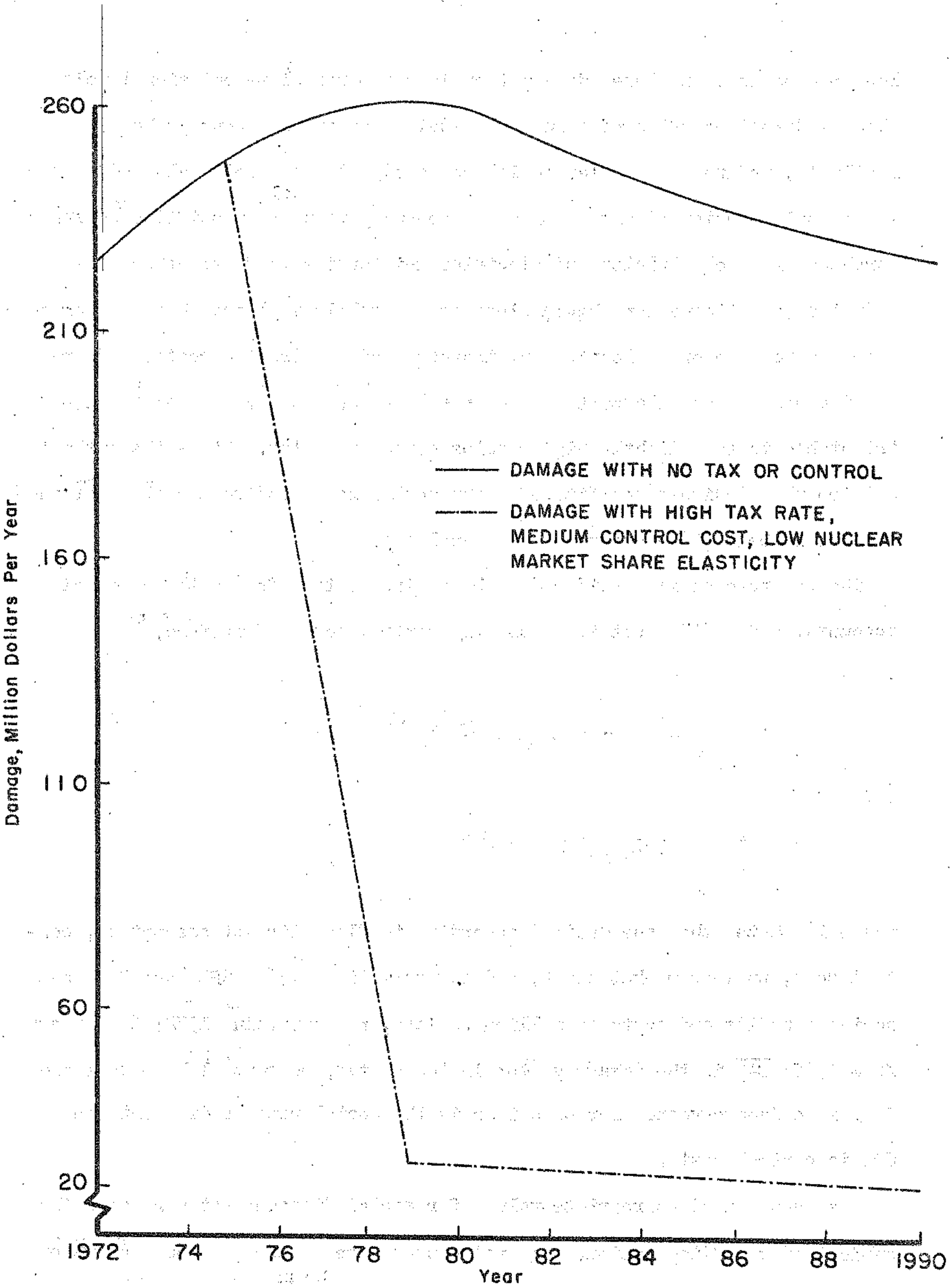

FIGURE 3. SULFUR EMISSION DAMAGE WITHOUT CLEAN AIR ACT IMPLEMENTATION WITH AND WITHOUT TAX

leum processing, and lower damage from lesser particulate emission levels. These indirect benefits of a sulfur emission tax are not counted here. Similarly, indirect and other social costs of a tax are not evaluated here. These would consist of any net loss in consumer value from shifting consumer purchases from electricity and electricity-intensive goods to other commodities (see discussion above), increased psychological and physical damage from greater use of nuclear power, increased administrative costs, and any net increase in unemployment or nonutilization of productive capacity attributable to the slightly higher rates caused by a tax. It is the author's opinion that indirect benefits of a tax would exceed indirect costs, but the subject is beyond the extent of this analysis.

The tax revenue is considered to be an income transfer in these social accounts, and social cost is simply the control cost. Therefore,

$$
\begin{aligned}
&SBEN_i = \sum_{t=6}^{20} (\overline{DAM}_t - DAM_{i,t}) \,/\, (1 + r)^{t-2} \\
(6)\quad & \\
&SCOS_i = \sum_{t=6}^{20} CON_{i,t} \,/\, (1 + r)^{t-2}
\end{aligned}
$$

where i denotes the case defined according to Clean Air Act assumption, control cost, nuclear market share, and tax rate ($i = 1,36$); SBEN and SCOS are social benefits and costs in million dollars, present value 1972; t is years from 1970; $\overline{DAM}$ is the damage vector in the no tax, no control base case and DAM_i is a damage vector for case i; r is the social rate of discount; and CON is control costs.

The question of appropriate values for social discount rates remains the subject of much disputation. The value used here is 10%, representative of conclusions reached in recent studies in this area.[13/]

The market decision to implement or not to provide control is independent of net social benefits. Control will be implemented if taxes plus control costs with removal are less than taxes without removal. The problem of choosing a minimum tax rate which will stimulate control can be generally defined in this manner:

(7a) $T: FCN > FCC\,(1 + E)$

(7b) $FCN = \min FCN_j$

(7c) $FCC = \min FCC_{i,j}$

(7d) $FCN_j = (PF_j + T * (1 - RET_j) * SC_j)F_j$

(7e) $FCC_{i,j} = (PF_j + CON_{i,j} + T * (1 - EFF_{i,j}) * SC_j)F_j$

where T is the tax rate which will make non-control more costly than control, \$ per ton of sulfur emission; FCN and FCC are minimum fuel cost without and with control, mills/KWH; E is proportional difference between FCN and FCC; j is fuel type arrayed by form (coal, oil, gas), sulfur content, heat content, etc.; i is type of control process; PF is price of fuel, \$/ton; RET is proportion of sulfur retained in fuel and not emitted without control; SC is sulfur content of fuel by weight; F is fuel use, tons/1000 KWH; CON is control cost per unit fuel, \$/ton; and EFF is sulfur removal efficiency.

These relationships can be modified for the present problem in this way:

(8) $T_{i,j} = CON_i \,/\, ((EFF - RET) * SC_j * F_j)$

Applying (8) to the present data results in Table 6. We shall note this table again in the conclusions. In the model it is assumed that developing control equipment for coal alone would be infeasible, so it is required that total control costs (and tax on remaining emissions) be less than the tax without control before control is instituted. Control cost is defined both as social cost and market cost to the utilities. However, on the benefit side, social benefits are equivalent to damage reduction while market

Table 6--Tax Rate Making Tax Cost Without Control Equal To

Tax Plus Control Cost

($ Per Ton Sulfur Emission)

Clean Air Act Implemented	Yes		No	
Fuel	Oil	Coal	Oil	Coal
Control cost (mills/KWH)				
Low (0.950)	$435.8	$281.8	$217.9	$140.9
Medium (1.425)	653.6	422.7	326.8	211.3
High (1.900)	871.5	563.6	435.8	281.8

NOTE: Fuel use is .4214 tons coal per 1000 KWH and .2725 tons oil per 1000 KWH (1.677 BL/1000 KWH at 325 lb/BL).

benefits are equal to reduced tax liability. As we shall see, whenever the tax rate differs from the damage rate the social optimum may depart from the market optimum.

V. Results and Generalizations to National Policy

In the 26 of the 36 tax cases examined, the market decision is to install the additional control equipment and remove the sulfur. In these 26 cases emissions and damage rise through 1975 and decline thereafter, as in columns 14 and 22 in Table 4. If we assume each of the tax rates, control cost levels, sulfur tax levels, and nuclear market share assumptions are equally likely, then our first hypothesis given above is accepted: emissions and damage will be significantly reduced by a sulfur tax. The possible damage reduction is shown in Figure 3.

Demand growth seemed essentially unaffected by the tax. The high demand in 1990 occurs in the no tax case, 166.8 billion KWH. The low demand naturally occurs in the case with maximum tax-induced cost: 158.5 billion KWH with the high tax rate, high control cost, and low nuclear market share elasticity in the absence of Clean Air Act implementation. This is a small difference--5%--and the second hypothesis is probably false. It appears likely that a sulfur emission tax would not significantly affect demand growth. There are three reasons why there is no important demand reduction from the tax. First, regardless of a tax, the proportion of total generation by coal and oil is expected to decline (see Table 7). Second, although assumed control costs are a significant fraction of fuel costs, the tax plus control cost adds only about .65 mills (or 2.4%) to the 25 mills total average cost per kilowatt hour in 1990 (see cols. 6 and 17, Table 4).[14] Third, although electricity prices seem to be the most important factor influencing demand, the lag in demand response further re-

Table 7--Maximum and Minimum Nuclear Generation Levels in 1990

(Billion Kilowatt Hours and Percents)

			Generation		
		Total	Nuclear	Oil	Coal
I.	No tax or control	182.2	79.8(43.8%)	47.7(26.2%)	18.9(10.4%)
II.	High tax, high control cost, no Clean Air Act, high NMSE[a]	173.8	90.9(52.3%)	33.7(19.4%)	13.5(7.8%)
III.	1970 Levels	95.5	4.3(4.5%)	30.9(32.4%)	26.5(27.7%)

[a] Nuclear market share elasticity.

duces the effect on demand (see Table 1 above).

The third hypothesis asserted that nuclear power generation growth would be substantially increased by a tax. Table 7 and Figure 4 display the cases with maximum and minimum generation levels for nuclear power, oil, coal, and total generation for each nuclear share assumption and for 1970. There is little difference within each demand model. Suppose this generation growth is expressed in terms of 1000 MWe units. In the maximum case (high tax, high control cost, no Clean Air Act, high nuclear share), 12 new units (or their equivalent) are needed in New York by 1990.[15] In the minimum case 11 new units are needed without a tax, a difference of only one equivalent unit. The hypothesis is rejected. Hausgaard anticipated this result (p.33).

The fourth hypothesis stated that the social benefits of a tax would exceed its social cost. Table 8 displays gross social benefits and costs. In Table 9 all cases have positive net benefits. Their present value ranges from a low of $11 million to a high of $776 million. In the cases where the tax rate is high enough for the market decision to favor control, net benefits range from $70 to $776 million and benefit-cost ratios from 1.2 to 3.6. In the cases in which the market decision is to pay the tax on full emissions rather than institute control, net benefits range from $11 to $92 million. In these latter cases there is no social cost since control is not effected and benefit-cost ratios are undefined. Benefit arises from demand reduction and from the slight tax-induced shift from coal and oil to nuclear power. While the decisions made within the model are independent of the assumed damage rate, the benefit-cost ratios are directly proportional to the damage rate. Thus, if actual damage is $400 per ton sulfur rather than $600, all ratios would be reduced by one third and one case

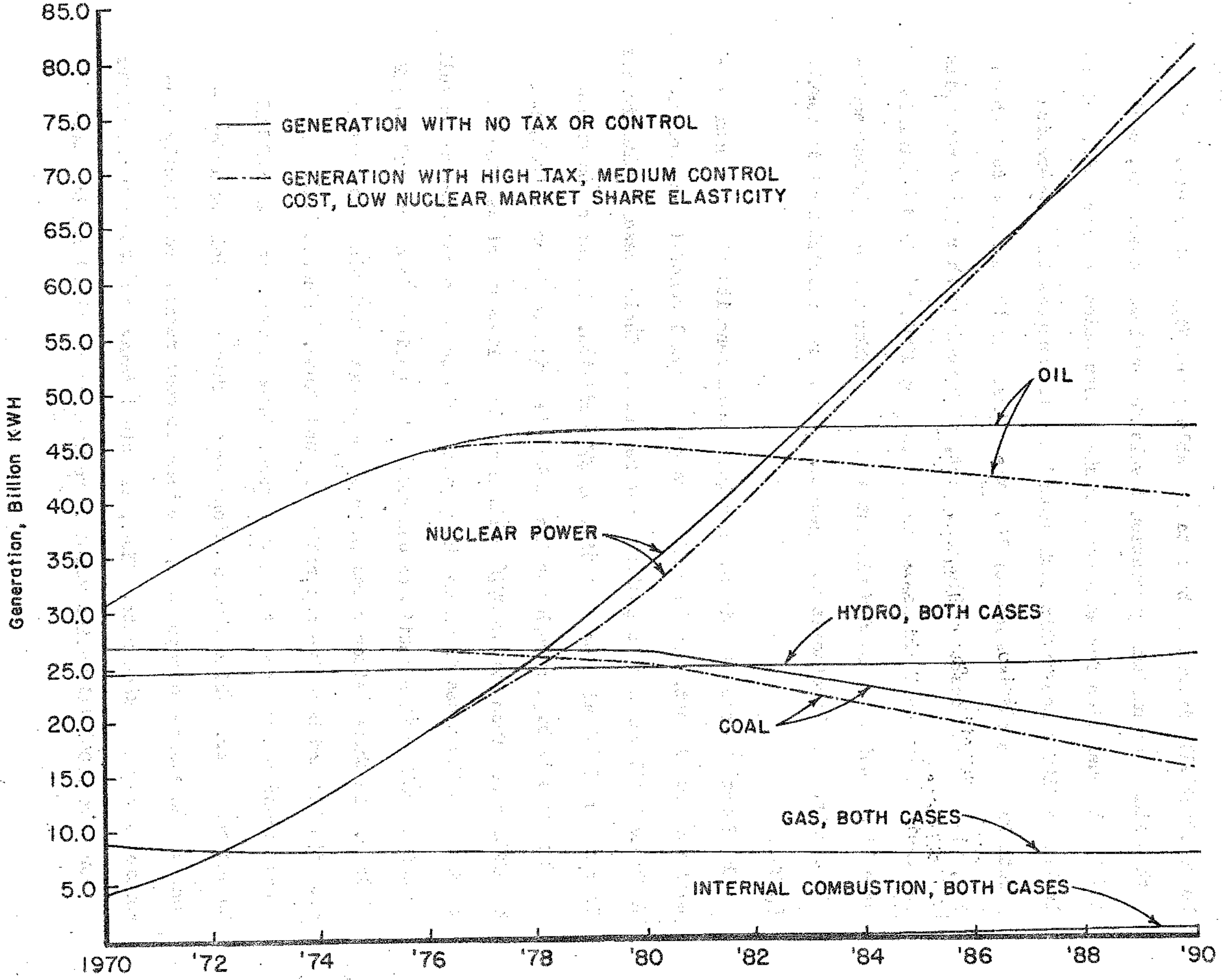

FIGURE 4. EFFECT OF TAX ON GENERATION LEVELS WITHOUT CLEAN AIR ACT IMPLEMENTATION.

Table 8--Social Benefits and Costs from Sulfur Emission Tax on Electric Utilities in New York

(Million Dollars Present Value in 1972; Costs in Parentheses)

Control Cost	Low		Medium		High	
Nuclear Share Elasticity	1%	1.89%	1%	1.89%	1%	1.89%
I. Clean Air Act Implemented						
Tax						
Low	11.3	20.3	11.3	20.3	11.3	20.3
	(0)	(0)	(0)	(0)	(0)	(0)
Medium	530.4	532.4	21.6	38.5	21.6	38.5
	(312.3)	(303.7)	(0)	(0)	(0)	(0)
High	530.8	533.2	531.5	534.4	30.9	54.9
	(310.6)	(301.0)	(461.2)	(442.8)	(0)	(0)
II. Clean Air Act Not Implemented						
Tax						
Low	1060.8	1064.8	43.3	77.0	43.3	77.0
	(312.3)	(303.7)	(0)	(0)	(0)	(0)
Medium	1062.6	1067.7	1063.9	1070.1	1065.1	1072.3
	(309.1)	(298.4)	(458.9)	(439.1)	(606.2)	(575.0)
High	1064.1	1070.2	1065.4	1072.5	1066.5	1074.6
	(306.2)	(293.8)	(454.8)	(432.5)	(600.9)	(566.6)

Table 9--Net Benefits and Benefit-Cost Ratios
From Sulfur Emission Tax on Electric Utilities in New York
(Million Dollars Present Value in 1972; Ratios in Parentheses)

Control Cost	Low		Medium		High	
Nuclear Share Elasticity	1%	1.89%	1%	1.89%	1%	1.89%
	I. Clean Air Act Implemented					
Tax						
Low	11.3	20.3	11.3	20.3	11.3	20.3
	(*)	(*)	(*)	(*)	(*)	(*)
Medium	218.0	228.6	21.6	38.5	21.6	38.5
	(1.7)	(1.8)	(*)	(*)	(*)	(*)
High	220.2	232.2	70.3	91.6	30.9	54.9
	(1.7)	(1.8)	(1.2)	(1.2)	(*)	(*)
	II. Clean Air Act Not Implemented					
Tax						
Low	748.4	761.0	43.3	77.0	43.3	77.0
	(3.4)	(3.5)	(*)	(*)	(*)	(*)
Medium	753.5	769.3	605.0	631.0	458.9	497.3
	(3.4)	(3.6)	(2.3)	(2.4)	(1.8)	(1.9)
High	758.0	776.4	610.6	640.0	465.6	507.9
	(3.5)	(3.6)	(2.3)	(2.5)	(1.8)	(1.9)

*Since control is not implemented in these cases, there is no control cost. Benefit is the reduced damage attributable to slight total generation decrease and nuclear substitution. Benefit-cost ratios are undefined.

would have negative net benefits.[16] If actual damage is equal to or greater than the Barrett-Waddell estimate, and the indirect benefits of a tax are at least as great as the indirect costs as discussed above, the conclusion here is that the social benefits of a tax would exceed its social costs.

The fifth hypothesis suggests that if the tax rate differs from the damage rate, social optimality will differ in an important way from market decisions. Table 9 indicates that this is only partially correct. Within any triad of assumptions about the Clean Air Act, nuclear market share elasticity, and control cost, the maximum net benefits are always with the case with the highest tax rate which equals the damage rate. If the tax rate is so low that control is not effected social net benefits depart significantly from the maximum possible. However, once the tax rate exceeds the necessary level to promote implementation, there is little further increase in net benefits.[17]

Finally, the presumption that a sulfur emission tax has higher social value if the Clean Air Act has not been implemented seems confirmed by Table 9.

To what extent can these conclusions be generalized to other industries and to the nation? The economic choices facing the electric utility industry in New York are representative of utility economics throughout the country with respect to a sulfur emission tax, and utilities account for 50% of sulfur emissions (see Table 1). Sulfur is emitted in copper, lead, and zinc primary smelting through the separation of the metal from sulfur in the ores. Similarly, sulfur is emitted in petroleum refining when sulfur is removed from oil, and sulfur emissions are a by-product of sulfuric acid production. Control costs in these industries may be the same or a little lower than for the electric utility industry.[18/] Control costs for steam-heat boilers and hot air furnaces may be much higher than for electric utilities. As a possible lower limit of national benefit, the analysis here is taken as representative of the electric utility industry; all net benefits in Table 9 would be multiplied by 23.6. As an upper limit, the analysis is representative of all sulfur emitting processes; all net benefits in Table 9 would be multiplied by 51.9.[19/]

In the case without implementation of the Clean Air Act, medium control costs, high tax rate, and low nuclear market share elasticity (see Tables 4 and 9), the possible upper limit national values are net benefits of $32 billion (present value 1972), social cost of control implementation of $24 billion, and social benefits of damage reduction of $55 billion. The lower limit values would be $14 billion net benefits, $11 billion social cost, and $25 billion social benefit.

As an ex post note, we may consider the likely consequences of electricity and gas prices much higher than those postulated here. Given the coefficients in Table 1, it is likely that the impact of electricity price increases will exceed that of gas prices, and demand growth would be reduced in all cases. Thus, the assumption of increased costs for all generation processes means the proportional impact of a sulfur tax and its induced control costs must be lower. It is probable that none of the six conclusions stated here would be substantively affected by an analysis with higher electricity and gas prices.

It is of some interest to speculate upon the differential impact upon income classes that might follow from a tax. According to the less-than-unity long run income elasticities in Table 1, electricity use rises with income but at a decreasing rate. Thus, the cost of a tax would be regressive in its common meaning: an upper income group would pay more for electricity in dollars and less as a percentage of income. On the benefit side, Freeman has shown that low income groups are disproportionately exposed to sulfate and particulate pollution. In a study of three metropolitan areas, the rank correlation of sulfation concentration and income class is nearly perfectly negative. It is probable that reduction of sulfur emissions brought about by a tax would benefit lower income groups.

In summary, the tentative conclusions which follow from this analysis are that a sulfur emission tax would cause significant reductions in emissions and damage, have little effect on electricity demand growth and nuclear power generation growth, result in greater social benefits than costs, and cause greater social benefits if the Clean Air Act is not implemented than with implementation. If the Clean Air Act standards should be met in New York by 1976 with emissions being equivalent to the use of 1% sulfur coal and oil, and if control costs should be in the medium to high range, the tax levels currently being discussed--$200 to $400 per ton emitted sulfur-- appear to be too low to motivate additional sulfur emission reduction. However, if those standards are not met, a tax might provide incentive to reach and go below the standards.

The introductory section noted obstacles in the path of empirical, policy oriented studies of environmental problems vis-a-vis the theoretical route. The value to this exercise would seem to be qualified empirical support for a proposition which has long been preferred on theoretical grounds. Perhaps, as Freeman et. al. noted (p. 170), the reason it has not been effectively tried is that it would work.

Appendix--Generation Changes in Coal, Oil And Nuclear Power, New York State

I. Nuclear Power

A. 1976-80

$$\Delta GN_t = ANG_t + TNG_t$$

$$ANG_t = .1 * J * .977 * \Delta G_t$$

$$TNG_t = ANG_t * TNMS_t$$

$$TNMS_t = NMSE * (TCC_{t-1} / GCO_{t-1}) / (.5 * ACWT_{t-1})$$

B. 1981-90

$$ANG_t = .977 * \Delta G_t + .033 * GC_{t-1}$$

II. Oil Generation

A. 1976-80

$$\Delta GO_t = AOG + TOG_t$$

$$AOG_t = .1 * (10 - J) * .977 * \Delta G_t$$

$$TOG_t = -TNG_t * (GO_{t-1} / GCO_{t-1})$$

B. 1981-90

$$AOG_t = 0$$

III. Coal Generation

A. 1976-80

$$\Delta GC_t = ACG_t + TCG_t$$

$$ACG_t = 0$$

$$TCG_t = -TNG_t * (GC_{t-1} / GCO_{t-1})$$

B. 1981-90

$$ACG_t = -.033 * GC_{t-1}$$

where ΔGN = nuclear generation growth, t = year, J = years from 1970, ANG = autonomous nuclear generation growth, TNG = tax induced nuclear generation growth, ΔG = growth in total generation, TNMS = tax induced nuclear market share increase, NMSE = nuclear market share elasticity, TCC = tax plus control cost, GCO = generation by coal and oil, ACWT = average cost without tax, GC = generation by coal, CO = generation by oil, AOG = autonomous oil generation growth, TOG = tax induced oil generation change, GC = generation by coal, ACG = autonomous change in coal generation, and TCG = tax induced coal generation change.

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Footnotes

1. William Baumol (1972), Allen Kneese, Jerome Stein, A. Myrick Freeman and Robert Haveman, Larry Ruff, Council of Economic Advisors (1971 and 1972), etc.
2. Another study of a sulfur emission tax has been undertaken by James Griffin.
3. See for example *The 1970 National Power Survey*, p. I-1-14.
4. Units of measurement are million kilowatt hours, thousands of persons, thousand dollars per capita deflated, mills per kilowatt hour deflated, dollars per thousand therms deflated, and the wholesale household appliance price index deflated.
5. It is known that ordinary least squares (OLS) applied to equations with lagged terms give biased estimates when the error terms are interdependent, as the lagged term is there correlated with the residuals. With pooled cross section and time series observations, no available statistic affords a convenient method of testing possible interdependency. One alternate approach is to obtain instrumental variable (IV) estimates for the data. If these estimates differ noticeably from OLS estimates, neither may be best although the IV estimates are presumably consistent. An obvious instrumental variable is $Q_{-1} = X_{-1}\theta$ with X being the matrix of explanatory variables lagged one year and θ the vector of OLS estimates. The results of this analysis (in comparison to Table 1) are smaller lag coefficients, but nearly identical long run elasticities. Readers interested in this subject and other current controversies in electricity demand may wish to read Mount *et. al.*
6. The data covered nine regions in three five-year periods. T statistics were 0.88, -2.72, -2.51 with fourteen observations having no nu-

clear shares.

7. Barrett-Waddell report 33.2 million tons SO_x in 1968. Using 49.8% as the proportion of sulfur in sulfur oxides, this is 16.55 million tons sulfur. The average damage per ton is \$501.2 (\$8,295 million ÷ 16.55 million tons sulfur). Adjusting this 1968 estimate by the implicit Gross National Product deflator defines a 1972 value of \$597.4 damage per ton sulfur emission. For comparative purposes, the Barrett-Waddell estimate of \$6.1 billion health costs in 1968 from sulfur and particulate air pollution may be contrasted with the Lave-Seskin calculation that a 50 percent reduction in these air pollutants would have saved \$2.1 billion in health costs in (apparently) 1963.

8. Recent discussions of engineering economics of sulfur removal include Ketchum, Spaite, Slack and Falkenberry, National Economic Research Associates, and <u>The Economic Impact of Pollution Control</u> (EIPC). Chemical engineers tend to report cost estimates in terms of fuel costs, while other engineers may prefer construction and operating costs. They can be compared on an economic basis through discounted costs per kilowatt hour. For example, Slack and Falkenberry reported in 1971 a low cost estimate of \$2 per ton of coal treated. This is one mill per pound. In 1971 the EEI Yearbook reports a national average of .918 lbs coal/KWH. The Slack-Falkenberry figure is thus equivalent to .946 mills/KWH in 1972 prices according to the GNP deflator. The low estimate in the 1972 EIPC study is \$30 per kilowatt capital cost and .35 mills per KWH operating cost. Assuming that the facility operates 80% of the year for 30 years, that interest cost is 8%, and other fixed annual costs are 6% of investment (see National Power Survey, p. I-19-6), the annual capital charge is \$4.2 per kilowatt, or .599 mills per KWH for each of 7012.8

KWH per KW per year. The combined capital and operating cost estimate is thus .949 mills per KWH. When compared in this manner on an economic basis the two types of estimates are seen to be quite similar.

9. See 1971 EEI Yearbook pp. 50, 54.

10. See Secretary Connally's transmittal letter and the Treasury Department background statement.

11. See Statistics of Privately Owned Electric Utilities, 1969 - 1971.

12. This may be compared to National Petroleum Council suggestions for wellhead gas price increases of 80 to 250 percent by 1985. Wilson (1973) would argue that this level of increase is essentially monopolistic. Actual average gas prices will probably depend upon political economics.

13. See Baumol (1968), U.S. Water Resources Council, and Joint Economic Committee.

14. In Table 4 the tax adds 1.8 mills/KWH to coal and oil costs in 1990 (cols. 12, 13, 17), but recall these sources constitute only one-third of total generation then.

15. A 1,000 MWe plant operated at 80% load factor would produce 7.013 billion KWH in a 365.25 day year.

16. From Tables 8 and 9, a damage estimate of $400 per ton sulfur emission would change the high tax, medium control cost cases with Clean Air Act implementation to negative net benefits. Net benefits would be -$107 million with low nuclear market share elasticity and -$87 million with the high elasticity.

17. More precisely, when the tax rate is less than or equal to the damage rate, net benefits are positive. When control cost exceeds the tax rate

net benefits are positive but small. When the tax rate exceeds control costs and these costs exceed the damage rate, control will be unnecessarily implemented and net benefits will be negative. Example: suppose the damage rate is $300 per ton sulfur emission. Gross benefits in Table 8 and BCR's in Table 9 are reduced by one-half, and there are ten cases with negative net benefits.

18. The discussion here is derived from The Economics of Clean Air, and, to a lesser extent, from The Economic Impact of Pollution Control.

19. For the lower limit ratio, divide national power plant sulfur emissions by New York power plant emissions. For the upper limit ratio, divide total national sulfur emissions by New York power plant emissions; see Table 2.