RESEARCH TRIANGLE INSTITUTE

Contract No. 68-01-0484
RTI Project No. 41U-862

October 1974

FINAL REPORT

ALLOCATIVE AND DISTRIBUTIVE EFFECTS OF ALTERNATIVE AIR QUALITY ATTAINMENT POLICIES

Prepared for

Implementation Research Division
Environmental Protection Agency

by

Tayler H. Bingham and Allen K. Miederna

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ACKNOWLEDGEMENTS

This project was conducted by the Research Triangle Institute, Research Triangle Park, North Carolina, pursuant to Contract No. 68-01-0484 with the Environmental Protection Agency. The statements, findings, conclusions, and recommendations presented in this report do not necessarily reflect the views of the Environmental Protection Agency.

Principal investigators for the project were Tayler H. Bingham, under whose direct supervision this project was conducted, and Allen K. Miedema, who was responsible for the model design and analysis described in this report. Several other individuals contributed to specific aspects of the described research. Principal among these and their contributions are:

Philip C. Cooley	Programming and model implementation
John C. Matthews	Control costs for fuel combusion sources
Joanne T. Rogoff	Data collection and management.

Marshall Rose, Environmental Protection Agency, was project officer. His interest, guidance, and critical reviews are very much appreciated.

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Chapter 1: SUMMARY

1.1 Objective

Private markets have failed to adequately ration the use of the atmosphere for residuals disposal. This was predictable because the atmosphere is a public good. As a consequence, government intervention is justified and was initiated in the form of national ambient air quality standards for several pollutants (including sulfur oxide, particulate matter, carbon monoxide, hydrocarbons, and photochemical oxidants). These air quality standards represent goals to be attained to protect the "public health" (primary standards) and "public welfare" (secondary standards).* Effective government action is being achieved through the authority delegated to the States for the implementation, maintenance, and enforcement of these ambient air quality standards.

A broad variety of policy instruments have potential for controlling pollutant discharges to rates consistent with the ambient air quality standards. These policy instruments range from the use of moral suasion, which requires voluntary compliance, to outright prohibition of pollutant discharges, which requires legal sanctions.† In practice, the States have not chosen either extreme but instead have relied upon a system of direct controls usually termed "emission standards." This approach embodies the use of government regulatory authority to dictate the residuals management behavior of emitters. An alternative to the use of direct control is the establishment of price incentives for inducing emitters to reduce their discharges of pollutants to the atmosphere.

Both direct controls and price incentives can be expected to have a unique set of impacts on emission rates and costs depending, among other things, on the specific policy instrument and its chosen parameter values;

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*See The Clean Air Act, December 1970 (42 U.S.C. 1857 et seq.).

†See Government Approaches to Air Pollution Control, Institute of Public Administration, Environmental Protection Agency, Washington, D.C., July 1971, and The Instruments for Environmental Policy, Wallace E. Oates and William J. Baumol, Conference on Economics of the Environment, National Bureau of Economic Research, November 1972.

the industrial composition of the region; and on the zeal of the enforcement authority. This study provides projections of the allocative and distributive* effects of emission standards, several types of emission charges, and a combination of standards and charges (called "hybrid programs") as applied to the major point sources of sulfur† emissions in two of the Nation's Air Quality Control Regions (AQCR).

1.2 Methodology and Limitations

Six policy instruments were selected for analysis:

1. emission standards (direct control),
2. emission charges (price incentive),
3. emission charges based on effects (price incentive),
4. emission charges with an emission exemption (price incentive),
5. emission charges with a subsidy (price incentive),
6. emission charges combined with current and relaxed emission standards (hybrid program).

Emitters, faced with either emission standards or charges, are assumed (holding output constant) to be cost minimizers. That is, with emission standards, emitters choose the least-cost abatement alternative such that emissions are less than, or equal to, the standard. Under a system of emission charges, emitters minimize the sum of abatement costs and charge payments. Costs in the emitter decision-function are measured on an after-corporate income tax basis using a present value approach and assuming rapid amortization of abatement equipment capital outlays. These after-tax costs are referred to as net private costs.

The capital and operating costs and abatement efficiencies of abatement alternatives have been included in a programmed, deterministic, simulation model that uses a comparative statics approach to estimating costs and emissions under each policy instrument for the major point sources of sulfur

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*As used here, allocative effects are those that relate to the aggregate level of the resource (i.e., abatement) costs, and emissions, whereas distributive effects are those that relate to the incidence of the private costs of a policy instrument.

†The term "sulfur" is used herein to mean any one of the several forms in which sulfur-bearing gases may be discharged to the atmosphere. All measurements in this study are in terms of the sulfur equivalent.

emissions in the St. Louis and Cleveland AQCR's. The sulfur emission sources included in the model are: steam-electric power plants; industrial, commercial, and institutional boilers; petroleum refineries; sulfuric acid plants; and primary nonferrous smelters. Abatement alternatives costed for the model include process modification, stack-gas desulfurization, and fuel switching.

Some caveats are in order regarding the following analysis. First, the redistributive impact that is estimated actually represents only the initial incidence of the increase in costs. Clearly the producers who initially bear these costs may be in a position to pass them forward. Whether they can depends on (1) the extent of the market and the proportion of that market's output represented by the particular firm(s) under analysis, (2) the extent to which other firms in the affected industry bear similar cost increases, (3) the overall elasticity of demand facing the industry, and (4) the elasticity of supply in the industry. Of course if demand facing all affected emitters is perfectly inelastic the entire redistribution measured in this study is actually a redistribution away from consumers not the producers. The opposite result, i.e., all costs are borne by producers, under the assumption of perfectly elastic demand. No attempt is made in this report to measure these elasticities and market factors. Hence no estimates of the final incidence of increased costs are given here.

Second, in estimating the cost associated with each policy instrument transactions costs are ignored. That is, the cost to emitters and to the regulatory agency of establishing, maintaining, and modifying each policy instrument are not included.

Third, the effect of uncertainty on emitters' behavior is also ignored. That is, the approach employed implicitly assumes that emitters expect no changes in either the costs or efficiencies of the abatement alternatives, or in the policy instrument over the planning horizon (assumed to be 20 years).

Finally, only one pollutant, sulfur, is examined. Thus, the interrelationships between sulfur and particulate emission abatement as well as the interrelationships between fuel ash and sulfur content are not covered in this analysis.

1.3 Findings

Successful government intervention in private markets for the purpose of achieving improvements in air quality will have the effect of reallocating society's scarce resources among competing uses. More resources will have to be allocated to process modifications, end-of-stack treatment, and to alternative fuels and less resources (assuming a full employment economy) to other uses. The means of achieving these reallocations is through the use of policy instruments available to government. Comparison of the allocative and distributional effects of the alternative policy instruments that offer potential for achieving the necessary reallocations of resources, requires that measures of the projected effects of each policy instrument be compared using normative criteria. That is, a definition of allocative efficiency and distributional equity must form the basis for judging the relative merits of each policy instrument.

Allocative efficiency is viewed from the perspective of society as a whole, and does not require that everyone would actually be better off or that nobody will be worse off if a given policy instrument is employed. A policy instrument promotes allocative efficiency to the extent that it results in a reallocation of resources which--if costless redistributions of income could be effected--could make everyone better off. Allocatively efficient production is achieved when all resources are allocated in a manner such that any possible reallocation results in a reduction of the output of at least one good without increasing that of any others. As applied to the scope of this inquiry, a policy instrument is allocatively efficient to the extent that projected sulfur emission reductions in each AQCR are achieved at a minimum total expenditure of real resources (i.e., abatement costs).

Allocative efficiency may not, however, provide a sufficient basis for comparing the alternative policy instruments. This is because the distribution of the benefits and costs will vary both across policy instruments and within them for the alternative policy parameters. However, the relative equity of the distribution of costs and benefits is a value judgment; hence, no particular distribution of the effects of a policy instrument can be defined on a purely economic basis as being "equitable." The equity of the distributional effects of policy instruments must be evaluated within the

political process. The distribution of the costs of each policy instrument are, however, measurable. That is, it is possible to project the private costs, on both net and gross basis, of alternative policy instruments. Gross private costs include abatement expenditures plus transfers to government. Net private costs are the actual costs borne by emitters after allowing for the cost-sharing nature of the corporate income tax and abatement equipment depreciation. They must be absorbed by the emitter (i.e., shareholders) and/or shifted to customers. Aggregate resource costs, i.e., true social costs, are gross private costs less transfers to the government.

The specific policy instruments considered in this analysis fall into three broad types: direct controls, price incentives, and hybrid programs.

Each State, in complying with sec. 110(a)(1) of the Clean Air Act of 1970, which requires the submission of "...a plan which provides for implementation, maintenance, and enforcement ..." of the national primary ambient air quality standard for sulfur oxides, has relied on the use of direct controls to achieve the required emission reductions. These direct controls establish emission limitations which are usually termed "emission standards."

Given perfect information regarding current and future abatement costs regulators could establish a system of emission standards such that the emission reductions necessary to attain the ambient air quality standards are achieved at a minimum expenditure of real resources. However, obtaining such information is not costless. Nor is there any incentive for State regulators to include consideration of allocative efficiency in the development of implementation plans. Therefore, it is a reasonable a priori expectation that direct control through emission standards will not achieve the air quality standards at maximum allocative efficiency.

The establishment of price incentives is an attempt to induce firms to reduce discharges of emissions to the atmosphere by altering the cost of abatement or the cost of pollution discharges. A charge on emissions uniformly applied to all emitters within a given geographic area is the most commonly proposed price incentive.

Hybrid programs are an attempt to combine the predictability of direct control with the incentive nature of price incentives.

Since the central focus of this study was to identify the trade-off between allocative efficiency and negative redistributive effects, it is

useful to compare all five policies designed to achieve equivalent emission reductions. (The effects-based emission charge was designed to achieve a reduction in the mortality rate equivalent to that associated with the emission standards.) As an example, the summary figures presented below array the aggregate resource costs and the net private costs which are estimated to accompany various policy parameter combinations that will just achieve that air quality standards in St. Louis. Because the proportional air quality model was assumed, the policy parameter values were chosen to induce emission reductions just equal to, or slightly in excess of, those which are estimated to accompany the emission standards for St. Louis.*

Although these figures present the summary for only St. Louis, not Cleveland, the order-of-magnitude of the resource cost-private cost trade-off in Cleveland is similar to that in St. Louis. For the Cleveland-related detail of the kind presented in the summary figures, the reader is referred to the later chapters and appendixes of this report.

Although somewhat apparent, it's important to note the impreciseness of the empirical results presented. Accurate estimation of the differences in the real resource costs of emission standards and emission charges would ideally require perfect information regarding abatement costs. This study makes no pretense of providing such estimates. What are presented are only first approximations of these costs, based on engineering estimates of abatement hardware costs and statistical analyses of fuel costs.

Figure 1 displays the cost impacts of three alternative policies that can achieve the level of emission reductions in St. Louis required by the emission standards. Those policies are: (1) emission standards, (2) a uniform emission charge (29 cents), and (3) the hybrid program that employs a combined standards-charge approach. With this hybrid program, the emissions limitation required by emission standards at each emission source are proportionally relaxed for all emitters by some fraction, β, of the emission constraint under standards alone. Simultaneously, the emission charge is increased so as to induce the desired

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*The proportional model uses emission reductions as a proxy for air quality. This implied the absence of locational considerations. If sulfur emitters in either of the regions have differential impacts on air quality depending on their spatial distribution, the additional resource costs of emission standards may be either greater or less than indicated.

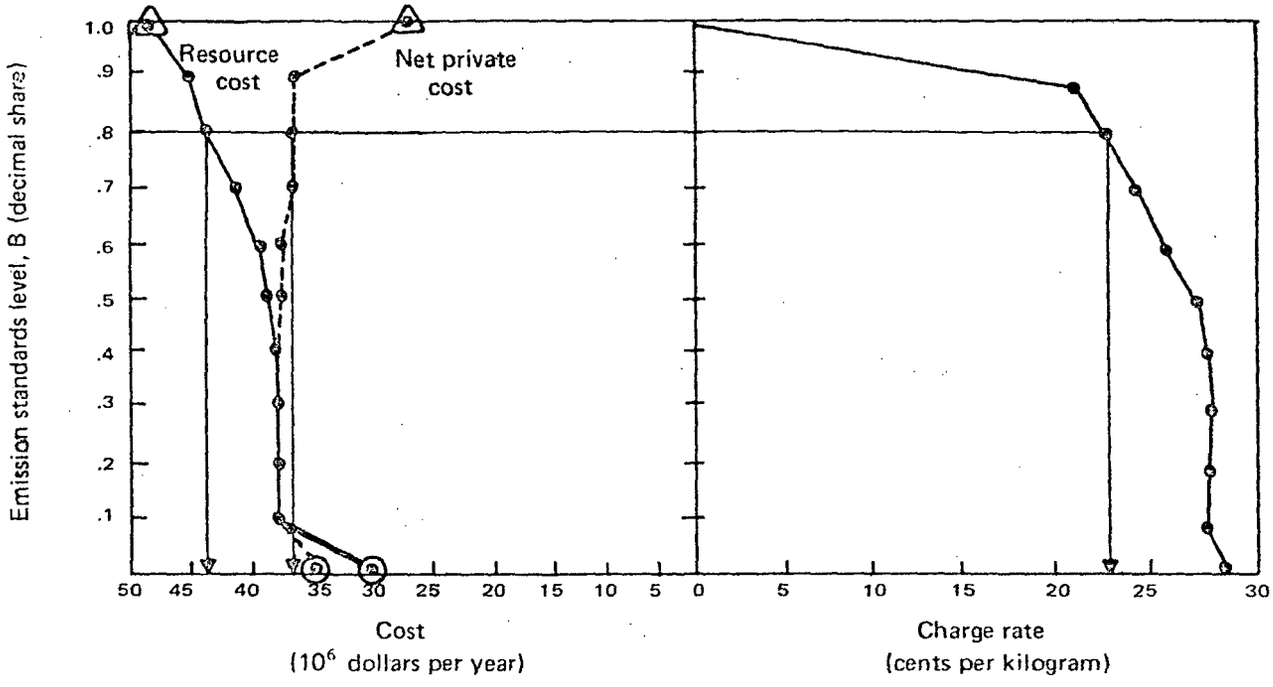

Figure 1. Comparison of the allocative and distributive effects of meeting the St. Louis SO_x air quality goal with: emission standards (Δ), a uniform emission charge (⊙), and a combined standards-charge approach. (Source: Research Triangle Institute)

reductions in emissions. The vertical axis in figure 1 measures the proportion, β, of the existing emission constraints that continue to be applied. The curve in the right panel shows the locus of combinations of β and charge rates where necessary emission reductions are achieved. For example, with no relaxation in the current emission standards in St. Louis (β = 1.0) the required charge rate is of course zero. On the other hand, with complete relaxation of the emission standards, but no change in the air quality goal, an emission charge of 29 cents per kilogram is required to induce the necessary emission reductions. If the emission standards are relaxed for all emitters by 20 percent (i.e., β = 0.8) then the charge rate would have to be set at about 23 cents per kilogram. Emitters must pay an emission charge on all remaining emissions. The aggregate resource cost associated

with this combination of policy parameters is, as shown in the left panel figure 1, about $44 million per year while the net private cost is about $37.5 million per year.

These allocative and distributive effects can be compared with the two extreme cases, i.e. emission standards alone ($\beta = 1$) and an emission charge along ($\beta = 0$). The resource cost of the emission standards alone is about $50 million per year while that of an emission charge alone is about $29 million per year. These estimates imply that the social costs of achieving the St. Louis SO_x air quality goal via the emissions standards approach are about 72 percent higher than through the emissions charge approach. However, largely because the emission charges transfer substantial financial resources away from emitters, the net private costs of emission standards are about 26 percent lower than those of emission charges. The net private costs of standards alone are about $25 million per year and those associated with emission charges are about $34 million per year.

The reason emission charges can be more allocatively efficient and yet at the same time result in higher private costs than standards is that charge payments are paid on unabated emissions. From the perspective of society, these charge payments are not properly part of the resource costs of an emission charge since they are transfers from emitters to government and do not reflect the utilization of scarce resources. Analogously to payments for other inputs to production such as labor and capital, charge payments can be regarded as payments by emitters to government for the use of a public good, the atmosphere, for residuals disposal. The charge payments also provide emitters with an incentive to reduce emissions still further as more economical abatement alternatives approaches are developed.

Arguments based on economic criteria notwithstanding, emission charges have been opposed in some quarters due to their distributional effects. Two variants of emission charges have been suggested to reduce the private costs of charges and yet retain their allocative properties. These are exempting some emissions from charge payments or offering a subsidy for low emission rates. Both have the effect of reducing the charge payments associated with any given charge rate.

Figure 2 presents the allocative and distributive effects of meeting the St. Louis SO_x air quality goal using an emission charge-exemption approach

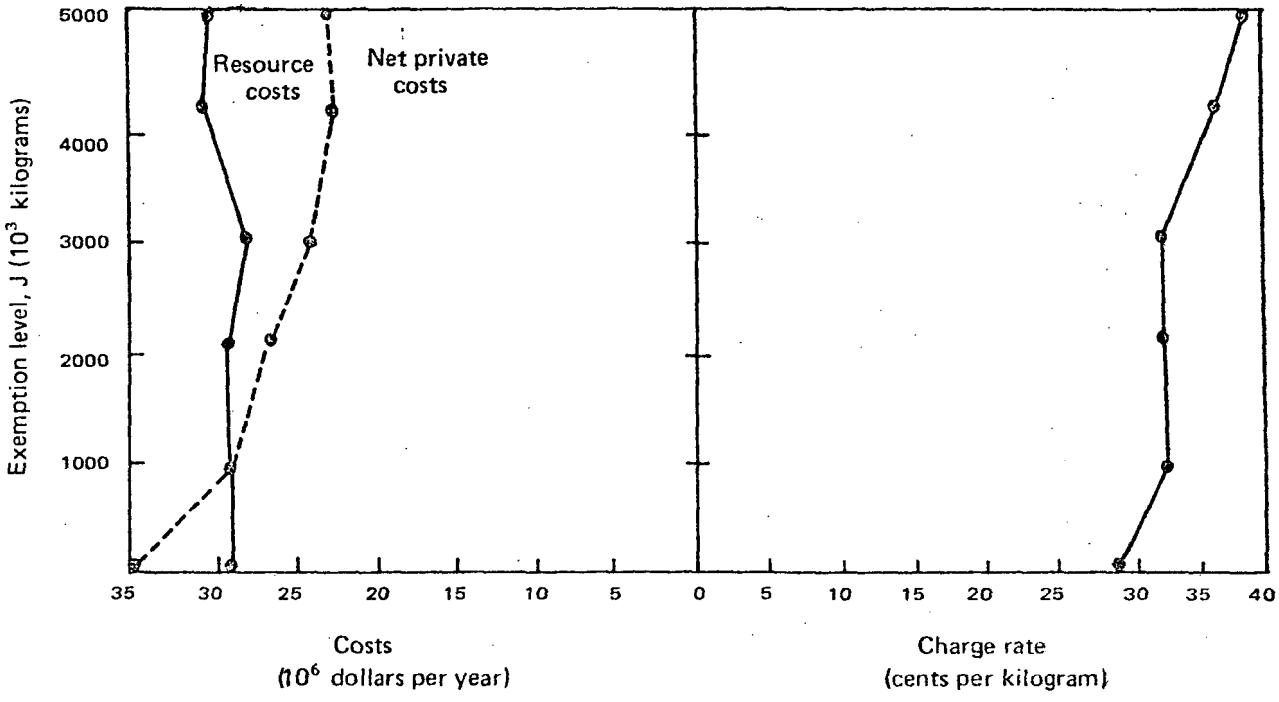

Figure 2. Comparison of the allocative and distributive effects of meeting the St. Louis SO_x air quality goal with an emission charge-exemption approach. (Source: Research Triangle Institute)

alone without emission standards. With this policy none of the point sources which have emission rates below the exemption level is required to pay an emission charge. All point sources with emission rates in excess of the exemption level must pay at the rate of the applicable charge on only the excess over the exemption level. Hence, the exemption level is an absolute emission rate which is applied indiscriminately among all emitters in the region; e.g. the exemption level does not vary by plant size, location, production rate, or other specific attributes.

The range of exemption levels, up to 5 million kilograms per year, is plotted along the vertical axis in figure 2. As shown in the right panel of the diagram, increases in the exemption level must be accompanied by increases in the charge rate to achieve the same level of emission reductions that is required by the emission standards.

This policy approach offers some clear advantages over the others presented. At the highest exemption level, for example, the necessary emission reductions can be achieved with roughly a 39 cents per kilogram emission charge (see figure 2). This policy combination implies aggregate resource costs of about $30 million per year and net private costs of about $22 million per year. This appears to combine the positive features of both the emission standards and the emission charge approaches. On the one hand, the net private costs of the charge-exemption approach are even lower than with the standards, $22 million compared to $25 million. On the other hand, the resource costs associated with this approach are only slightly higher than the standards $30 million compared to $29 million. It should be noted, however, that smaller net private costs in the aggregate does not imply that tney are smaller for all plants in the region. Specifically, since all plants in the region are freely allowed to emit up to the exemption level, the emission charge-exemption approach is likely to impose higher net private costs on large emitters than would be the case with emission standards.

Finally, figure 3 shows the costs associated with the emission-charge-subsidy approach for the St. Louis region with a charge rate of 29 cents per kilogram. With this approach every point source either receives a subsidy (negative emission charge) or pays an emission charge. The amount of the subsidy (negative emission charge) or of the payment is computed with the formula $TCP = CR(K-E)$. CR is the charge rate per kilogram, K is the break-even emission rate, and E is the plant's emission rate. Clearly, all point sources whose emission rates are below K receive a subsidy or negative charge. The more they reduce their emissions below K, the larger is the total subsidy. All point sources with emission rates above K are required to render a charge payment which is simply the product of the emission rate in excess of K and the fixed charge rate.

The emission rates at which the point source just breaks even (neither receives a subsidy nor pays an emission charge) are plotted along the horizontal axis in figure 3. The associated costs are measured along the vertical axis. As shown there, aggregate resource costs in the region are invariant over various values of K because changes in K will not affect the optimal emission abatement policy--assuming that all the existing firms, and only those firms,continue to operate in the region. This is so since the marginal

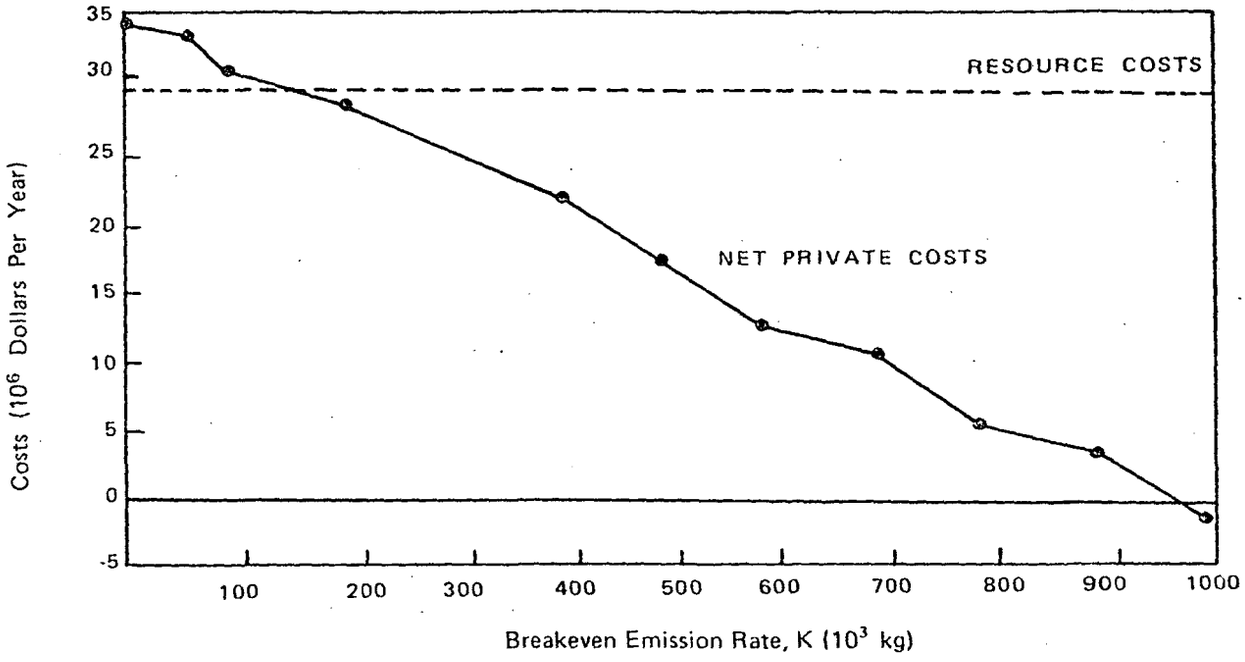

Figure 3. Comparison of the allocative and distributive effects of meeting with the St. Louis SO_X air quality goal with an emission charge-subsidy approach. (Source: Research Triangle Institute)

charge rate, CR, remains constant. Therefore, the same charge rate, 29 cents per kilogram, that effects the necessary emission reductions using the uniform emission charge approach is sufficient to achieve those reductions over all values of K. Consequently, the aggregate resource costs of the charge-subsidy approach are the same as those associated with the uniform emission charge, about $29 million. On the other hand, net private costs are much smaller depending on the choice of K. As shown in figure 3, net private costs may actually become negative for sufficiently large values of K.

Two points are critical to summarize this policy approach more completely. First, as was the case with the charge-exemption approach, aggregate net private costs which are lower than those associated with standards, may obscure increases in net private costs for some large emitters. Second, these estimated responses do not account for a subtle emitter response that may be critical in a real world application, viz., that the existence of a subsidy is likely to increase the number of point sources claiming emitter status. Any "potential emitter" who can convince the environmental authority that he has

cleaned up all his emissions can receive a payment of CR x K. This critical nuance, not incorporated in the estimates shown, requires that the results be interpreted with care.

Chapter 2: INTRODUCTION

2.1 Background

Under certain conditions, prices established in free markets convey all the information necessary to producers and consumers so that resources are allocated in such a manner as to maximize economic welfare.* One of the most important conditions for optimal allocation of resources is the independence of all individuals' consumption and all firms' production decisions (ref. 3). However, when the production or consumption of one good affects the costs of production of other goods, or the welfare of other consumers, and when there is no accompanying compensation, Pigou observed that resource allocation is not optimal.† Economic welfare could be improved by producing more or less of the good in question, depending upon the direction of the effects. Where there are such third party effects externalities are said to exist.‡ Pigou specifically identified the poor

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*This basic thesis was articulated in the "invisible hand" concept of Adam Smith. Writing in 1776 he observed that as each individual labors to maximize his own economic welfare, he

> "...necessarily labours to render the annual revenue of society as great as he can. He generally, indeed, neither intends to promote the public interest, nor knows how much he is promoting it. ...He intends only his own gain, and he is in this, as in many other cases, led by an invisible hand to promote an end which was no part of his intention" (ref. 1).

In contemporary language and terminology "...under perfect competition, all the marginal as well as the second-order conditions of a welfare maximum are automatically satisfied by the market mechanism" (ref. 2).

†"...the essence of the matter is that one person A, in the course of rendering some service, for which payment is made, to a second person B, incidentally also renders services or disservices to other persons C, D, and E, of such a sort that technical considerations prevent payment being exacted from the benefited parties or compensation being enforced on behalf of the injured parties" (ref 4).

‡Externalities that have a beneficial effect on the cost or welfare of others are termed external economies. Conversely, those with a detrimental effect are external diseconomies.

air quality in London* as an example of an external diseconomy, observing that industrialists had no incentive to install "smoke-preventing appliances" because of the difference between private and social costs of production. Industrialists acted to promote their own economic welfare by producing products, presumably employing minimum cost combinations of resource inputs and discarding wastes in the cheapest manner. From their viewpoint the cheapest manner was to discharge them to the atmosphere. The result was "...a heavy uncharged loss on the community, in injury to buildings and vegetables, expenses for washing clothes and cleaning rooms, expenses for the provision of extra artificial light, and in many other ways" (ref. 5).

Ayres and Kneese have argued that, rather than being curious anomalies, external diseconomies are a great deal more common than is usually recognized. In particular, they view the external diseconomies "...associated with the disposal of residuals resulting from the consumption and production process...a normal, indeed, inevitable part of these processes" (ref. 6). Others have observed that the growth and geographic concentration of economic activity which has accompanied industrialization has tended to cause an increase in the incidence of external diseconomies (ref. 7).

Discharges of industrial wastes to the atmosphere quite obviously create external diseconomies. In particular, elevated sulfur oxide concentrations have been shown to be significantly associated with excess mortality and morbidity, reductions in visibility, accelerated corrosion of metals, limestone, marble, roofing slate and mortar, and injury to ornamental and economic crops among other effects (ref. 8). The dollar value of the damages associated with sulfur oxide concentrations is alleged to increase exponentially with decreases in the quality of the atmosphere (increases in discharges of sulfur oxides). The cost of sulfur emission abatement has been shown to increase exponentially with increases in the quality of the atmosphere (decreases in discharges of sulfur oxides) (ref. 9).

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*According to Pigou, a researcher (J. W. Graham, The Destruction of Daylight) had determined that "...in London owing to the smoke, there is only 12% as much sunlight as is astronomically possible, and that one fog in five is directly caused by smoke alone, while all fogs are befouled and prolonged by it." Pigou, A. P., Economics of Welfare, p. 160. See ref. 3.

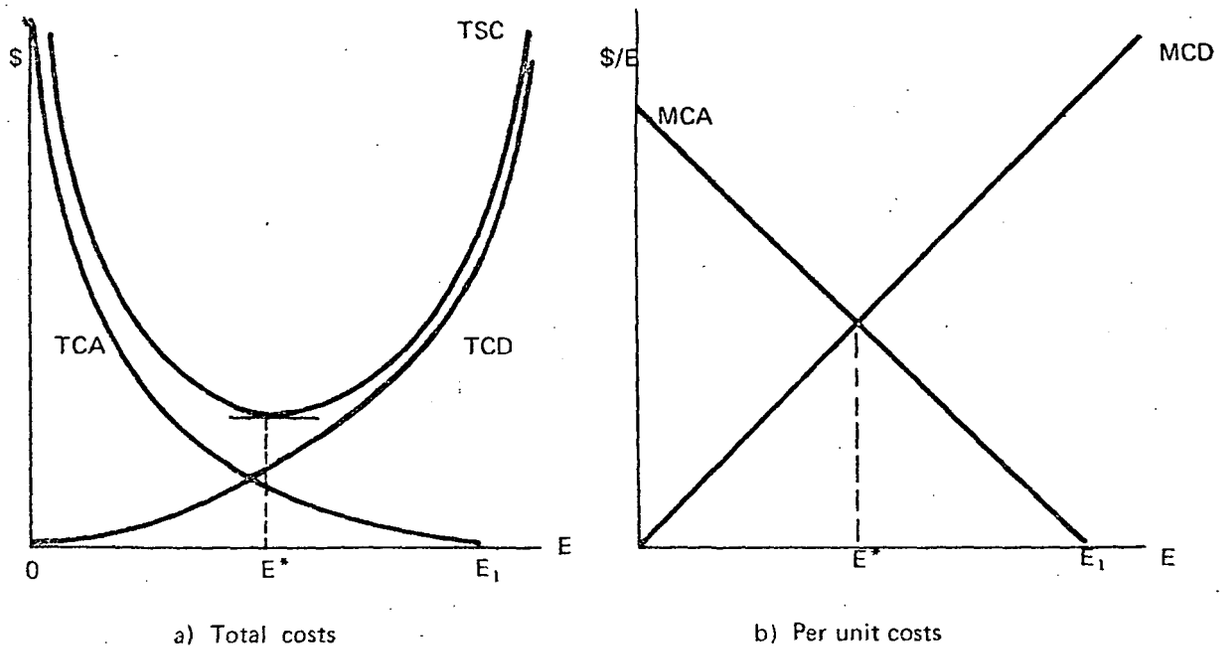

Figure 4. Socially optimum emission rates.

Because abatement of sulfur discharges to the atmosphere is not costless to society, the determination of the socially optimum level of air quality is an economic problem. Improvements in air quality involve the balancing of interests of receptors and emitters.

Assuming no transactions costs,* the socially optimum level of sulfur emissions is that rate at which the total social costs of emissions are minimized or at which the marginal cost to emitters of abatement is exactly equal to the marginal damages to receptors. As an example, suppose, in figure 4, we measure discharges of sulfur to the atmosphere per unit of the time (say kilograms per year) along the abscissa and cost on the ordinate. Abatement of sulfur emission discharges requires expenditures by emitters. Measured on a total basis, these expenditures are represented by TCA in panel (a). On a per-unit basis, the marginal cost of abatement (dC/dE or MCA) increases with decreases in emissions. In the absence of incentives to abate emissions, emitters would choose emission rate E_1, since for emission rates less than E_1, abatement cost is positive.

*These are the informational, enforcement, and administration costs needed to implement a policy instrument.

The total and marginal dollar values of damages, TCD and MCD respectively, decrease with decreases in emissions.*† The socially optimum emission rate which minimizes total social cost (TCS), is E^*. In per unit terms, it is that emission rate at which the cost of the last unit of emissions abatement (MCA) is exactly equal to the value of the last unit of damages avoided (MCD).‡

In situations characterized by external diseconomies, Pigou advocated government intervention (ref. 10). Coase (ref. 11), however, is more conservative, arguing that, regardless of property rights, private negotiation between the damaging and damaged party will result in a Pareto-optimal solution, under certain assumptions.§

The indivisibility of air quality and the large number of receptors, however, preclude the existence of an effective private market for "clean" air. Using Buchanan's criteria, (ref. 12) "clean" air is a public good because the benefits to receptors, i.e., the reduction in damages from

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*For expositional simplicity, the MCA curve is shown to intercept the y axis. However, it may be more realistic to suppose that as MCA approaches the y axis, that is, emissions become very small, the additional per unit cost of abatement becomes infinite.

†How one views MCA and MCD in traditional demand and supply terms depends on his perspective. If receptors are viewed as owning the atmosphere, MCA is the emitters' demand curve for the right to pollute. That is, at any emission rate (E), the curve MCA shows the maximum price emitters would be willing to pay for the right to discharge pollutants to the atomsphere. Thus MCA represents the demand for the rights to emit, or the demand for "dirty" air. The curve MCD shows for any E the minimum marginal payment receptors would have to receive to allow discharges. And MCD represents the supply of rights to emit, or the supply of dirty air. Conversely, if ownership of the atmosphere is vested in emitters, then MCA shows the minimum amount emitters would have to receive at the margin to produce reductions in emissions, and therefore represents the supply of clean air. The curve MCD, being the maximum amount receptors would be willing to pay to avoid discharges represents the demand for "clean" air.

‡This optimum level of E is called a Pareto optimum since at E* "...it is impossible to improve anyone's welfare, in the sense of moving him to a position that he prefers by 'transforming' goods and services through production or exchange, without imparing someone else's welfare." M. Blaug, Economic Theory in Retrospect, Richard D. Irwin, Inc., 1962, Homewood, Illinois, p. 538.

§Most notably, costless operation of the price system and small numbers of dischargers and receptors.

improvements in air quality are indivisible, and therefore receptors' preferences for "clean" air will not be revealed by the market mechanism. Each individual would maximize his own utility by letting others pay for clean air while he enjoys a "free ride", enjoying the benefits without paying the cost (ref. 13).

Assuming that the transactions costs are not so large as to make the status quo optimal, government intervention in private markets may be justified to promote air quality when pollution externalities are present (ref. 14).

Baumol and Oates (ref. 15) have suggested that such government intervention in private markets for the purpose of promoting improvements in environmental quality can be classified into four general types: (1) direct control or regulation; (2) price incentives; (3) moral suasion; and (4) public production (ref. 15). It is very doubtful that either (3) or (4) offer significant potential for achieving improvements in the quality of the atmosphere. However, both direct control and several of the alternative price incentives under certain conditions, do appear to be potentially effective instruments for eliciting reductions in the rate of emission discharges to the atmosphere.

2.2 Alternative Government Policy Instruments for Pollution Abatement

Primary ambient air quality standards for criteria pollutants, including sulfur oxides, have been established by the Administrator of EPA. These air quality standards have been set at a level sufficient to "... protect human health," (ref. 16) and must be attained in all regions of the Nation by 1975, unless exceptions are granted. A second set of ambient air quality standards, referred to as secondary standards, (currently suspended for sulfur oxides) are to be attained within a "reasonable time" (ref. 16).

To a significant extent, therefore, identification of optimal emission rates is of academic interest only--even if such rates could be scientifically determined, which appears unlikely at this time. Determination of the applicability of alternative types of policy instruments and structures to the problem of implementing the ambient air quality standards is relevant, however, since the allocative and distributive effects of candidate policy instruments are likely to vary. Regulation, several types of price incentives,

and hybrid programs that have potential applicability to the problem of providing recommended air quality, are discussed below.

2.2.1 Direct Control

Direct control is the use of government regulatory authority to dictate the residuals management behavior of firms. Direct government control of emissions through the use of emission standards is the primary approach employed by government. Emission standards regulate maximum emissions and are equivalent to granting emission sources a nontransferable right to emit pollutants up to the established limits. Emission standards can be classified into four types: (1) uniform abatement; (2) uniform emissions; (3) emissions as a function of heat input to combustion processes; and (4) emissions as a function of process weight (ref. 17).

Under uniform abatement each emitter is required to abate by some proportion of the emissions at some specified time. Uniform emission standards impose a limit on the emissions of each emitter. For fuel combustion sources, uniform emission standards may be expressed as a function of the heat content or amount of fuels consumed. For industrial process sources of emissions, maximum emissions for each emitter may be expressed as a function of the weight of materials input or process output.

Although there is no universal approach to establishing emission standards, "best technology," "reasonable cost," and "practicality" are frequently cited as important inputs to the standards-setting process. The ability of individual emission standards to achieve the ambient air quality standards is occasionally projected by a complex diffusion model such as the Air Quality Display Model (AQDM) or an equivalent.

The case for direct control in general, and emission standards in particular, usually rests on their predictability. If enforced, direct government control of emissions can induce emission reductions with little uncertainty.*

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*Each type of emission standard has its own allocative and distributive effects. When the standard is based on some variable such as input to or output from production processes, the emission standard is likely to encourage dischargers to increase inputs or outputs, thereby raising the effective emission limit. For steam-electric power plants in particular, it has been shown (ref. 18) that regulation of the emissions from coal-fired boilers has encouraged the substitution of labor for other factors of production, including coal.

Sometimes direct control is also supported because of the supposed equity of the solution which it produces. As an example, a uniform abatement emission standard may require all sources to curtail emissions by an equal percent, say 80, of their emissions in some base period. Since all parties are treated equally with respect to the proportion of reductions required, such a solution is regarded as equitable in some quarters.

Finally, it should be noted that if the regulatory agency has perfect knowledge of the abatement cost functions for each source, emission standards can be designed to achieve the desired abatement at minimum total abatement costs. However, acquisition of this knowledge is not costless, and since abatement costs vary from source to source depending, among other things, on the particular technology employed, size and age of plant, and prices the firm faces for the factors of production, it appears unlikely that the regulators will be able to write regulations which will achieve the desired emission abatement at minimum total abatement costs.

The informational and enforcement costs of direct control, which should be added to abatement costs to determine the total cost to society are likely to be substantial. This is because emitters have an incentive to circumvent the intent of regulations (or any other policy instrument), due to the abatement costs likely to be imposed on them. Techniques employed by emitters for avoiding or attenuating regulations include exercise of political or economic pressures or legal arguments to obtain exemptions, variances, or delays in applying regulations. Also, because emitting up to the standard involves no penalty, and emitting beyond it a high penalty, emitters may be motivated to mislead the regulatory agency when required to show that their emissions do not exceed the specified standards.

The equity of emission standards is an illusory concept. Ordinarily, equal treatment is regarded as the exchange of scarce resources at an equal price which is paid by all buyers of a given quantity (ref. 19). However, emission standards imply different values, or shadow prices, of the atmosphere to different emitters depending on the stringency of the applicable standard and on the firm's abatement costs. Thus the standards impose unequal (inequitable) values on each unit of allowable emissions among firms unless the standards are developed and modified in specific consideration of abatement costs.

A final drawback to emission standards is that, once stipulated emission rates are attained, emissions standards provide no continuing incentive to emitters to seek further abatement.

2.2.2 Price Incentives

The purpose of price incentives is to induce firms to reduce their discharges of emissions to the atmosphere either by altering the plant's cost of abatement or its cost of pollution discharge.

A variety of price incentives has been suggested as offering potential for inducing firms to reduce their discharges of emissions to the atmosphere. Among the most commonly suggested price incentives are subsidization of emission abatement (or cost sharing), sale of a fixed quantity of transferable emission permits, and emission charges.

Because of their theoretical allocative efficiency, emission charges have received especially serious support among the available alternative policy instruments. That support spans over 50 years since Pigou, after observing the existence of external diseconomies, advocated the imposition of taxes when the social cost of production exceeds the private cost.

Today, it is generally recognized that the data needed to estimate the social cost of pollution to society are not available. Indeed, Pigou's precise prescription of a tax equal to the difference between the social and private costs of production is irrelevant with respect to sulfur oxide emissions since air quality standards have been established through the political process. Now it is incumbent upon the States to find ways to meet the standards.

Such a condition does not obviate the possible application of emission taxes. Baumol has argued for the imposition of taxes as a means of inducing the reductions in emissions necessary to meet the air quality standard. He cites the case for the use of a corrective charge instead of regulations as a means of meeting the standard; thus: "...it promises to be operational because it requires far less information for its implementation. It utilizes global measures and avoids direct controls with all of their heavy administrative costs and their distortions of consumer choice and inefficiencies. It does not use the police and courts as the prime instrument to achieve the desired modification of the outputs of the economy. Its effects are long lasting, not depending on the vigor of an enforcement agency, which

all too often proves to be highly transitory. ...it need not add to the mounting financial burdens of the state and local governments. Finally, it can be shown that, unlike any system of direct controls, it promises, at least in principle, to achieve decreases in pollution or other types of damage to the environment at minimum cost to society" (ref. 20).

Several emission charge structures each having potential applicability to air pollution are discussed below. Before examination of the selected charge structures, some general drawbacks to the usage of charges as a means of inducing pollution abatement should be recognized.

One of the major difficulties in the implementation of emission charges is the need for information and enforcement. The cost of obtaining relevant information needed to predict, to the desired level of accuracy, emission rates, abatement cost, and charge payments attendant to an emission charge should be considered in the selection of a policy instrument. Assuming that for any given output level firms minimize cost, the regulatory agency considering the use of an emission charge has the burden of estimating the cost of emitter's alternative abatement schemes as the emitters see them, and not as they may be viewed by the agency. This is not a trivial distinction when one recognizes that the corporate income tax system alone reduces by about 50 percent the net impact on profits of abatement costs and charge payments. Other factors, such as the opportunity cost of capital, depreciation schemes, availability of subsidized loans and the like further cloud the problem. Assuming the ability to properly estimate costs, a second problem, compounding the problem of predicting emitter response to an emission charge, relates to the role that expectations regarding the future may play in current decisions. If emitters expect that the abatement costs, the technological efficiency of abatement techniques, or the emission charge will differ from current values in the future, a simple comparative statics approach to projecting emitter behavior may not be a satisfactory technique.

A second major drawback to the use of emission charges is their potential lack of political support. Environmental groups initially opposed emission charges, regarding them as "licenses to pollute." More recently, however, in testimony given at Senate hearings in 1971 (ref. 21), several environmental groups, including the Sierra Club, Friends of the Earth, and National Audubon Society, favored emission charges.

Industry has generally opposed emission charges, recognizing that the total cost to emitters may well be higher under a charge than with a standards approach since a charge involves payments.

One industry association, the National Association of Manufacturers, went on record at the Senate hearings as opposing charges, arguing (ref. 22):

> The NAM believes that taxes on effluents and emissions represent an unmanageable, uneconomical, and negative approach, and in principle would allow polluters to continue to adversely use our environment by the payment of a tax. On the other hand, a positive approach would involve establishment of a system of accelerated amortization and tax credits.

and

> The Joint Economic Committee should reject the concept of a pollution tax for the following reasons:
>
> First, taking money away from industrial companies will not help the cause of pollution control and will not, in our judgement, facilitate the installation of pollution control facilities or the conduct of pollution control research and development.
>
> Second, a pollution tax is inconsistent with the concept of government by sound and impartial regulation.
>
> Third, a pollution tax would involve major administrative problems related to setting of the tax rates, monitoring of emissions and effluents, and enforcement.
>
> Fourth, contrary to repeated assertions, there is no precedent for a pollution tax.
>
> Fifth, a pollution tax could cause unfortunate and unforeseen economic dislocations, including driving some companies out of business.
>
> Sixth, a pollution tax could be used to achieve Government control of industrial expansion, location, and operation.

2.2.2.1 Emission Charge. The most commonly proposed emission tax is a uniform charge on each unit of emissions. Firms faced with an emission charge are assumed to maximize profits or, at any given level of product output, to minimize costs. The emission charge exploits this behavioral characteristic by encouraging the emitter to minimize the sum of his payments

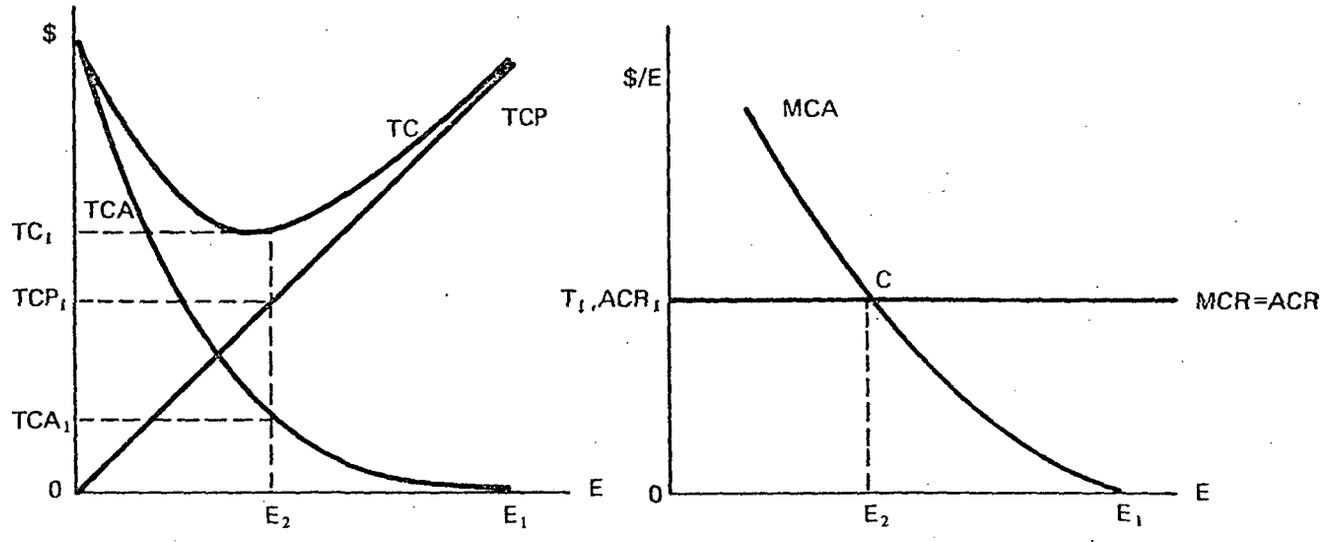

Figure 5. Emission charge.

for abatement practices and emission charges. The cost minimizing emitter will increase his abatement practices until the cost of removing the last unit of potential emissions just equals the emission charge rate.

In figure 5, the emitter's cost-minimizing behavior is illustrated from both total and per unit perspectives. Costs are scaled along the ordinate, and emission rates along the abscissa for a single discharger. Without an emission charge, or other form of government intervention, the firm has no incentive to control emissions and hence discharges amount E_1 annually. Emissions can be reduced from E_1 to lesser rates by expenditures on abatement (TCA, total cost of abatement; MCA, marginal cost of abatement). If an emission charge rate of T_1 dollars per kilogram is imposed, the cost of emissions is shown by TCP in panel (a). The discharger has a cost incentive to reduce emissions, as long as the reductions can be obtained for less cost than the charge. In panel (a) TC is the vertical summation of the two cost curves (TCA & TCP). The firm would abate emissions until TC reached a minimum (TC_1), or from a per unit perspective, until the cost of abating the last kilogram of emissions (MCA) equals the charge rate (T_1). Emissions after imposing the charge would be E_2 annually. The gross cost to the

discharger of an emission charge (TC_1) is the sum of the annual abatement costs (TCA_1 or E_1E_2C) and the charge payment (TCP_1 or $ACR_1 \cdot E_2$).*

The emission charge payment may be regarded as payment for the waste assimilative services of a common property resource, the ambient air. The continued presence of the payment provides dischargers with a perpetual incentive to reduce discharges still further by developing lower-cost abatement techniques.

Besides providing dischargers with an incentive to abate their waste discharges to the atmosphere, emission charges can induce abatement from all dischargers at minimum total resource cost to society. For any desired reduction in emissions from uncontrolled levels, the total resource cost to society† is minimized when the abatement costs of the last kilogram of emission reductions are equated for all sources. In theory, a charge on emissions automatically induces this outcome. Assume two emitters (A and B) with marginal cost of abatement functions MCA_A, MCA_B, as shown in figure 6, and a goal of reducing emissions from the current rate, nine units annually, to say four.

This objective is met at minimum cost to society when discharger A is emitting 1 unit and discharger B, 3 units per year. At these emission rates, the marginal costs of abatement for two dischargers is equated at 2 cents per unit of emissions.

Since an emission charge will induce abatement to the point where the charge equals the marginal cost of abatement, a charge of 2 cents in this example would induce the desired behavior at minimum cost to society.‡

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*ACR_1 is the average charge rate paid on emissions E_2. Since the charge rate is constant over all emission rates, the average (ACR) and marginal (MCR) charge rates are equal.

†Although the emission charge payments are a cost to emitters, they are not a cost to society since their opportunity cost to society is zero. They represent only a redistribution of income from emitters to government.

‡Strictly speaking, since the charge is on emissions and not air quality, an emission charge minimizes the cost of achieving a desired reduction in emissions and not improvement in air quality. To the extent that emissions from all dischargers and air quality at all receptor locations are proportionally related then an emission charge will achieve a desired level of air quality at minimum cost. However, if air quality varies from location-to-location, depending on the spatial distribution of emissions, then a charge on each discharger's marginal contribution to air quality is optimum.

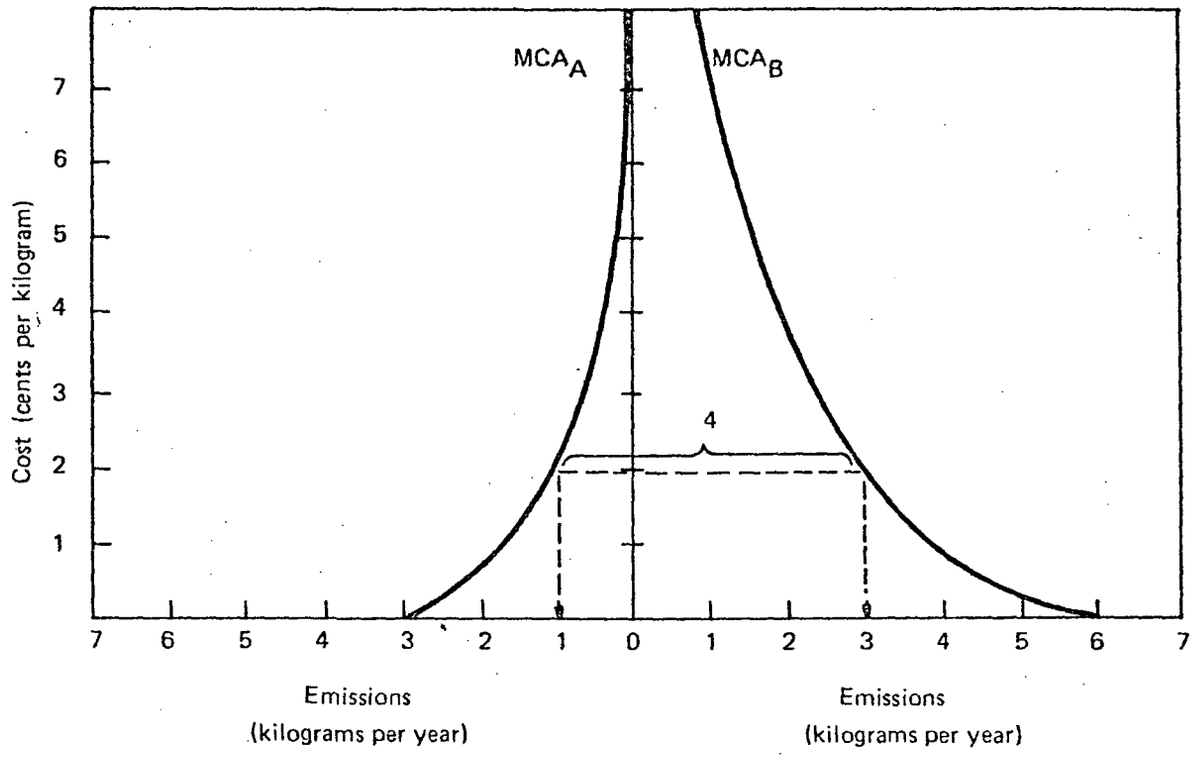


Figure 6. Per unit cost of emission abatement.

Given knowledge of the relationship between ambient air quality and emissions, and between emissions and abatement cost, it is possible to compute the emission charge necessary to meet the Ambient Air Quality Standards. For example, assume one emitter and one receptor location. Further, assume a linear relationship between emissions and air quality as shown in figure 7. Before government intervention, the emitter is discharging E_1 kilograms of the pollutant to the atmosphere annually resulting in ambient pollutant concentrations of A_1.

If an air quality standard is established, it is possible to identify the emission charge necessary to induce the emission reductions necessary to meet the standard. Suppose in figure 7, a reduction in pollutant concentrations from A_1 to A_2 is desired. Using the air quality transformation function, we find that emissions cannot exceed E_2 to achieve air quality A_2. To reduce discharges to rate E_2 annually (a reduction of E_1E_2) the discharger

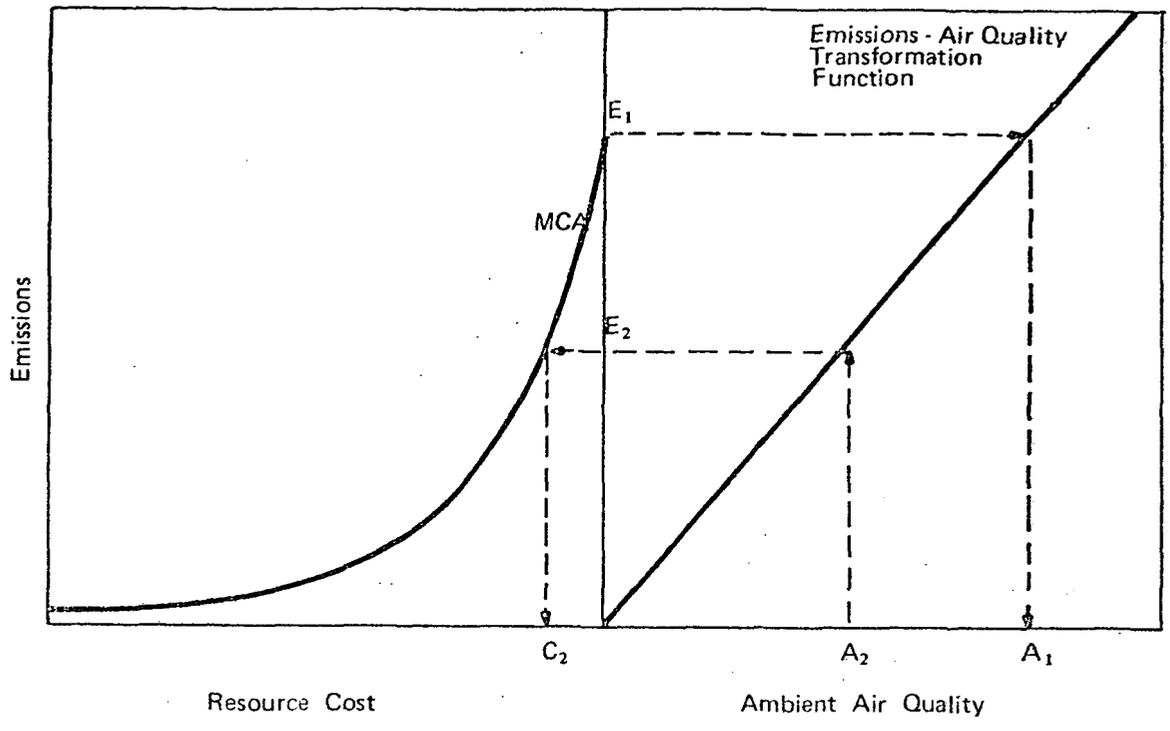


Figure 7. Resource cost and air quality.

incurs a cost of C_2 on the last kilogram of pollutant abated. A charge of C_2 will induce the necessary reduction in emissions.

2.2.2.2 Emission Charge with an Exemption. Recognition that the abatement incentive provided by an emission charge is determined by the marginal charge rate provides scope for consideration of a number of emission charge structures. Since it can be argued that the purpose of emission charges is not to raise revenues but to provide a cost-effective economic incentive to abate emissions, ways of reducing the charge payments while maintaining the marginal charge rate at a sufficient level to induce abatement may merit consideration. One approach is simply to exempt some emissions from charge payments.

As shown in figure 8, the effect of permitting emissions of amount J without any requirement to pay charge payments reduces TC and ACR. As long as $J < E_2$ there is no difference in the resulting emissions rate E_2 and that which would obtain with the emission charge discussed above. However,

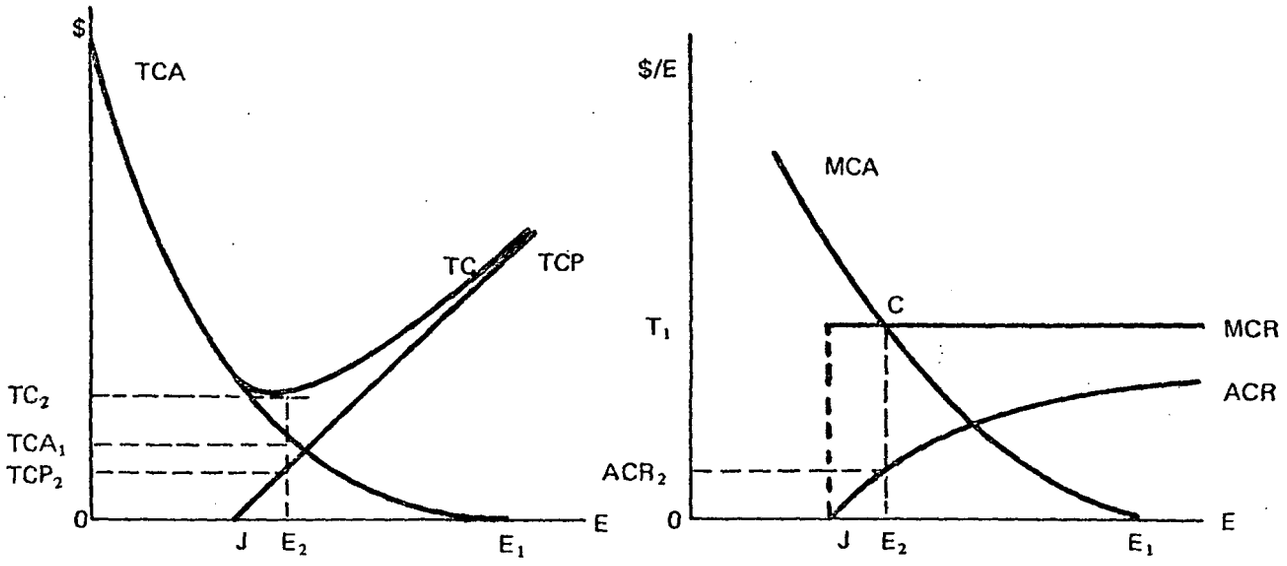


Figure 8. Emission charge with an exemption.

charge payments (TCP_2 or $ACR_2 \cdot E_2$) are less under an exemption policy than under a standard uniform emission charge.

An exemption program has been suggested for application to problems of water quality; it requires variable exemption levels to equalize the per capita charge burden across municipalities (ref. 23). A similar rationale is difficult to apply to problems of air pollution since the incidence of abatement cost and payments is more likely to be on stockholders and customers who are likely to be geographically dispersed rather than on the immediate population in the area. Nevertheless, such a charge may be attractive since it reduces the charge payments.

The exemption proposal is mainly intended to insure minimal redistributions of financial resources away from emitters and concurrently to preserve the allocative efficiency of uniform emission charges. It should be noted, however, that the exemption program implies some tradeoffs between those two policy goals. It does so for the following reason: small emitters whose abatement cost curves (total and marginal) intersect the horizontal axis in

figure 8 at emission rates less than the exemption level, J, face a marginal charge rate (MCR) which differs by the full amount of the nominal charge rate (since in these cases the MCR suddenly drops to zero) from the MCR faced by other, larger emitters. These differentials alone imply that, unless E_2 exceeds the value of J for all emitters in the region, the aggregate resource cost of achieving any given level of emission reductions under an emission charge-exemption approach will always exceed that which is incurred under a simple uniform emission charge.

However, despite the allocative inefficiencies that occur when completely unaffected by the emission charge, offsetting resource savings are possible. Specifically, it is at least arguable that there would be reductions in transactions costs with fewer small emitters to monitor.

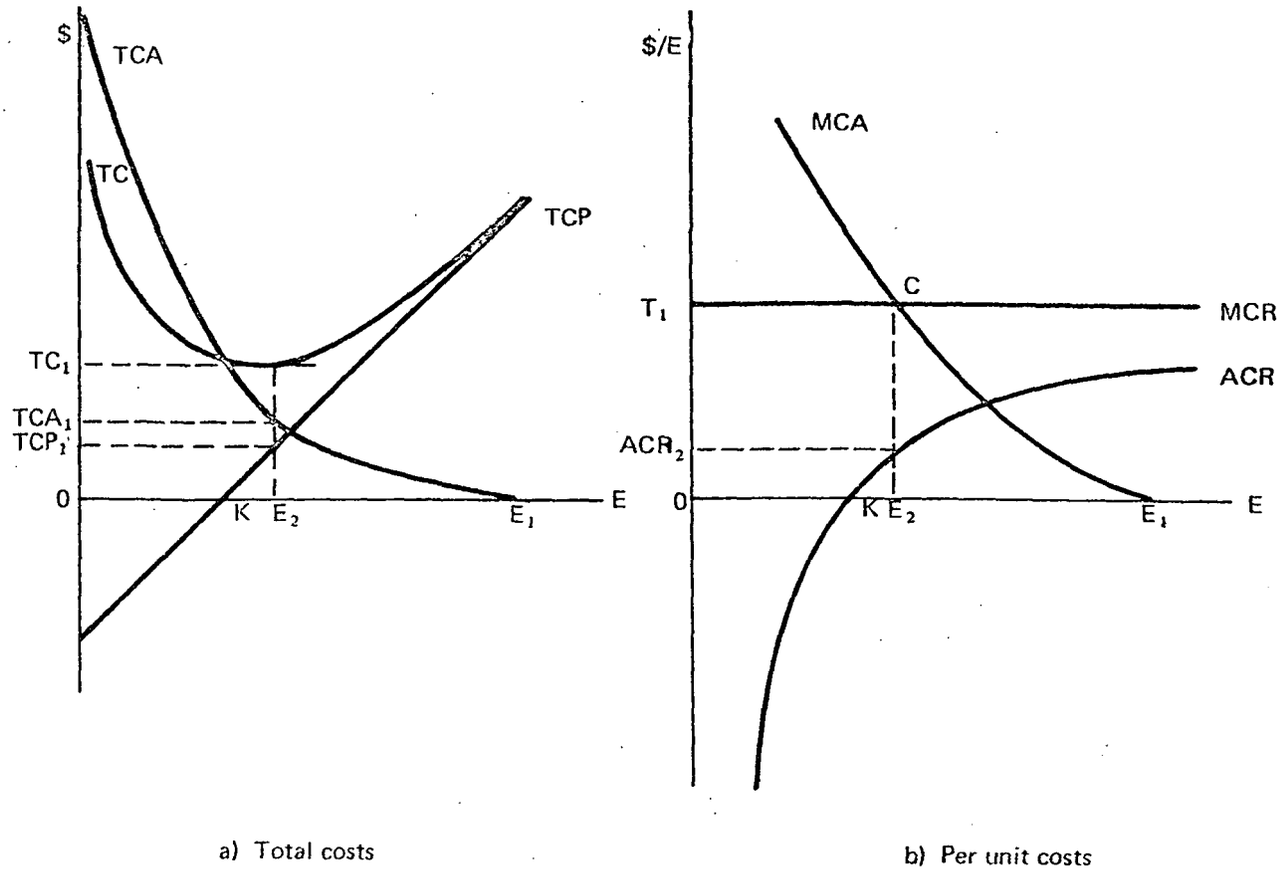
2.2.2.3 Emission Charge with a Subsidy. A second type of emission charge structure which reduces the charge payments burden is to combine emission charges and subsidies. While most commonly proposed subsidies have undesirable properties, one recent melding of charges and subsidies has received considerable support on both theoretical and practical grounds. This is the negative income tax.* A similar approach has been suggested (ref. 24) for application to problems of environmental quality. However, under this scheme the emitter is paid at the rate of T_1 per unit of emission reductions in excess of E_1 - K (see figure 9).

In figure 9; using the same charge rate (T_1) as above and the same value for the x-axis intercept (here labeled K and called the breakeven emission rate), the emitter would also select E_2 as the cost-minimizing emission rate. In this example, charge payments are the same as with the exemption. However, charge payments may become negative. This is shown in figure 10 where all the curves from figure 9, panel (b) are reproduced along with representations of the two conditions under which charge payments may become negative: 1) for higher charge rates, panel (a), or 2) for higher values of K, panel (b).

2.2.3 Hybrid Programs

As has been suggested by Oates and Baumol (ref. 25) as well as others, a combination of policy instruments may be employed. One such approach would be to combine emission standards and emission charges. Presumably, the predictability of emission standards could be used to constrain emissions to some

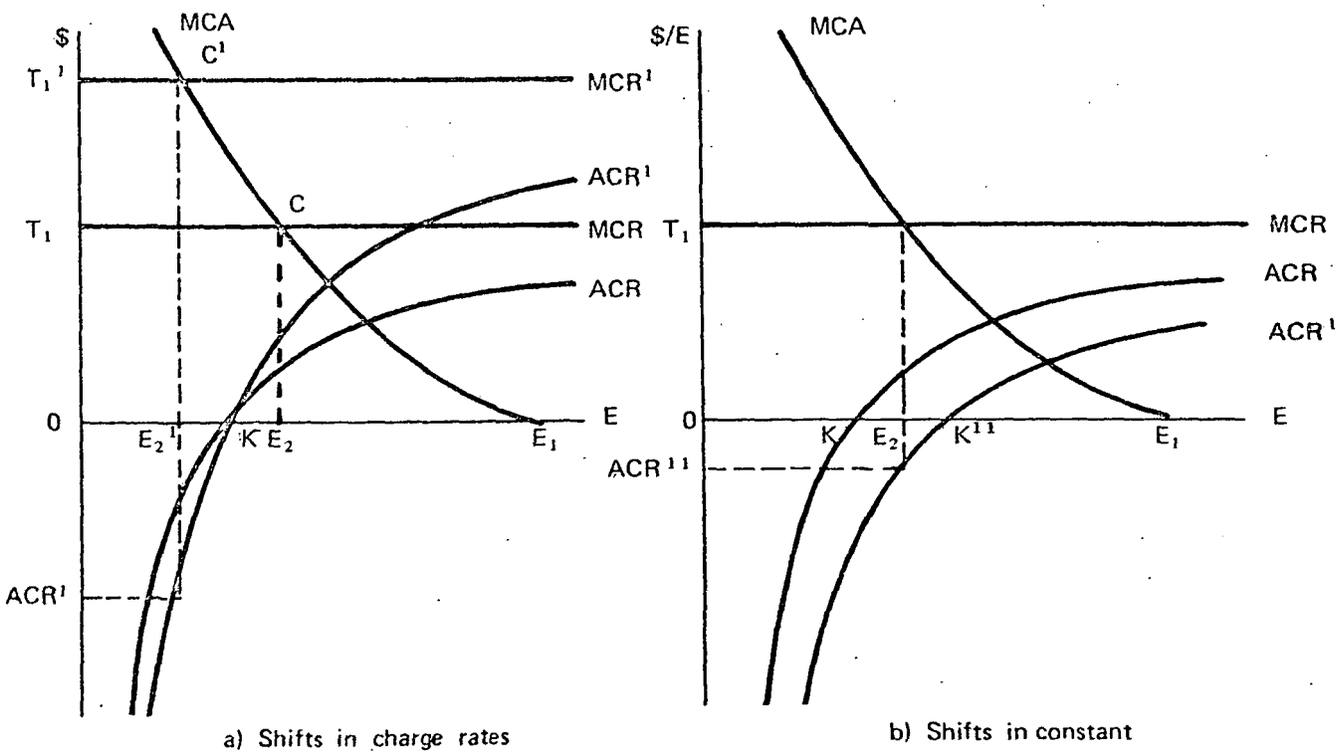
*Under this scheme, individuals are charged at a negative tax rate if their incomes are below some standard level.



a) Total costs

b) Per unit costs

Figure 9. Emission charge with a subsidy.



a) Shifts in charge rates

b) Shifts in constant

Figure 10. Shifts in emission charge rates and subsidy constant.

critical level ($\hat{E}$). Charges could then be imposed on the remaining emissions to induce emitters to exceed the minimum abatement requirements.

Alternatively, because current emission standards frequently embody "best technology," relaxing the emission standards (by some proportion, β) in conjunction with an emission charge may be an administratively simple way of adjusting the constraint and providing emitters more flexibility.

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Chapter 3: METHODOLOGY FOR EVALUATING SELECTED POLICY INSTRUMENTS

3.1 Introduction

Comparison of the selected policy instruments requires the use of criteria and a means to generate estimates, preferably quantitative, of the values of each criterion for the alternative policy instruments. This chapter sets forth evaluative criteria, discusses the model of emitter behavior employed, and identifies selected regions for quantitative analysis.

3.2 Evaluative Criteria

In applied welfare economics, it is common to separate the allocative and distributional effects of policy instruments (ref. 1). Allocative effects are those that affect the aggregate level of real income, assuming a full-employmen economy. A policy that increases the level of real income is, ceteris paribus, unambiguously preferred. For example, to the extent that the benefits of government intervention in private markets for the purpose of reducing the social costs associated with residual discharges to the atmosphere are greater than the costs, such intervention is socially desirable since it increases real income.

Inclusion of considerations relating to the distribution of the benefits and costs of alternative policy instruments, however, significantly reduces the degree of unanimity of agreement regarding the desirability of alternative policy instruments. With discussion of the distributive effects of a policy instrument, the arguments take on an emotive flavor, with each interest group advocating a particular distribution of costs and benefits. The advocacy positions are likely to be based in part on the implied size distribution of private policy costs and in part on the norms of the interest group.

3.2.1 Allocative Effects

Measurement of the allocative efficiency of alternative policy instruments for improving air quality would, ideally, be based on a comparison of the costs and benefits of the policy. Lack of quantitative benefit functions, however, preclude such a comparison. In any event ambient air quality standards for sulfur oxides have been established by the Administrator. Therefore, the relevant measure of the allocative efficiency of the alternative policy instruments

is the degree to which each produces improvements in air quality at a minimum total resource (i.e., abatement) cost to society. It is assumed herein that air quality in a given region is unaffected by the spatial distribution of emission sources, and accordingly emission rates can serve as a proxy for air quality.

3.2.2 Distributive Effects

Since there is no single value system by which society can be generally characterized, this study simply provides estimates of the gross and net private costs to emitters of each policy instrument. Gross private costs (i.e., cost to emitters before allowing for the effects of the corporate income tax and depreciation) include: (1) additional payments for factors of production and (2) transfers between emitters and government. Transfers include emission charge payments and emission-reduction subsidies.

Net private costs are the costs actually borne by emitters. They must either be shifted to consumers or absorbed by shareholders. The difference between the gross and net private costs of a policy instrument represents imputed transfers of the cost of a policy instrument from emitters to government through reductions in Federal and State income tax payments.

3.3 Emitter Response Model

A meaningful quantification of projected emitter responses to alternative emission-reduction policies requires a valid theoretical structure. The model which is discussed in this section and which was employed in this study attempts to provide such a structure. The model basically provides a microsimulation framework within which a finite number of emission-reduction policy options are analyzed. The pivotal component in projecting emitter responses is the assumption that emitters attempt to maximize the present value of their operations in the long run or, equivalently, that they minimize the present value of their costs for given output levels.

It is further assumed that the emitters have abatement reduction options which are functionally separable from other parts of their production process. The only source of interdependence is assumed to be the effluent air stream--its flow rate and sulfur concentrations.

The model that was developed in this study abstracts from many factors that may be more or less important to individual emitters. Hence, a few

caveats are in order. One important simplification disregards potential improvements in sulfur-removal technology and the effect of these improvements on deferring the application of existing abatement strategies (ref. 2). Another is the presumed absence of uncertainty in output levels, emission charge levels, capacity utilization, etc. Indeed, the model assumes that all policy and cost parameters are constant over the emitter's planning horizon. Several other nuances, such as local property and income tax structures and refined engineering constraints, were necessarily not included. Nonetheless, the microsimulation model presented here yields a theoretically sound basis for aggregate comparisons of alternative policy instruments, in addition to providing a good basis for further modeling extentions which relax some of the constraints of the present model.

Figure 11 outlines the general conceptual framework of the microsimulation model. The schematic is subdivided in three general components--inputs, structure, outputs--which are more fully discussed in sections 3.3.1 through 3.3.3.

3.3.1 Model Inputs

The model employs three general sets of input parameters: (1) process and engineering parameters, (2) economic parameters, and (3) policy parameters.

The process and engineering parameters are primarily composed of emission-point source inventory data and abatement-cost function estimates based on engineering and economic analyses. The emission inventory data include individual emitter parameters such as capacities, heat input requirements, and emission factors. These data consist largely of the National Emission Data System Point Source inventory data, augmented with other primary and secondary data. The engineering cost functions are used to estimate investment and variable costs associated with both abatement and boiler conversion. These functions are discussed in further detail in Appendix A.

The economic parameters incorporated as inputs to the model include several important cost factors. One of the most obvious is the fuel price structure, by fuel type and sulfur content (discussed more fully in Appendix A). Another is the corporate income tax structure and the amortization status of the depreciable investment. Others include the length of the firm's planning horizon, the unit value of recovered sulfur, and the opportunity cost of capital.

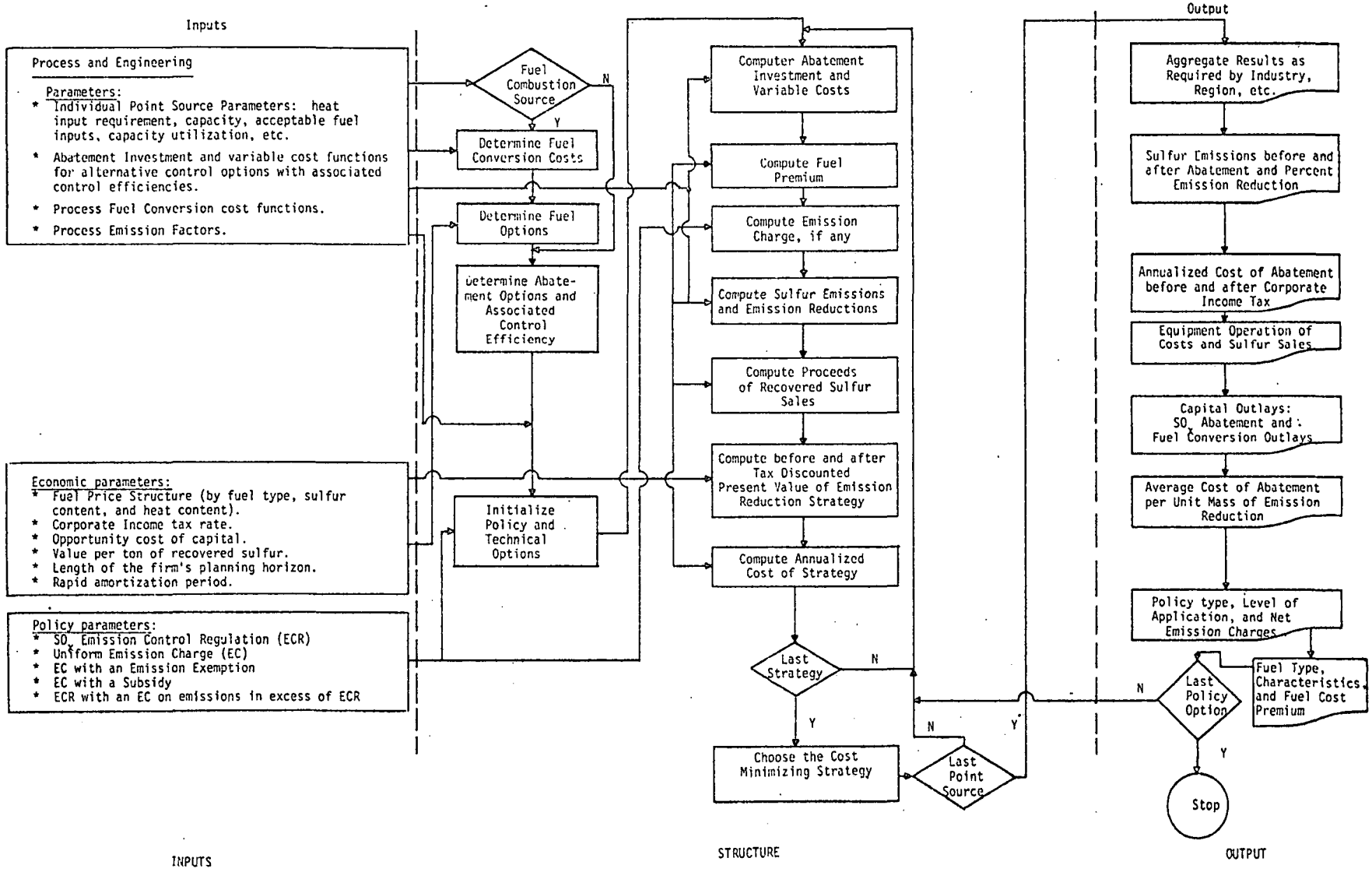

Figure 11. General flow diagram of emitter response model.

Finally, the model provides a framework for the analysis of five alternative sulfur emission reduction policies. These include:

1. Sulfur oxide emission standards,
2. A charge per kilogram of sulfur emissions,
3. A charge per kilogram of sulfur emissions with an emission exemption,
4. A charge per kilogram of sulfur emissions with a subsidy,
5. Sulfur oxide emission standards with a charge per kilogram of sulfur emission on emissions in excess of the standard (or some proportion of the standard).

3.3.2 Model Outputs

The computerized model provides a full array of outputs that are consistent with the general conceptual design discussed below and shown in figure 11. Besides providing the capability to aggregate all results by source type, by geographic region, etc., the computerized model can provide the following major output parameters for each point emission source:

1. Industry and locational characteristics,
2. Sulfur emissions before and after abatement and percent emission reduction,
3. Annualized private costs of the policy instrument before and after corporate income taxes and annualized resource costs of abatement,
4. Policy type, level of application, and emission charge payments,
5. Abatement equipment operating costs and sulfur sales,
6. Capital outlays for sulfur abatement and boiler fuel conversion, if applicable,
7. Average abatement cost per unit mass of emission reduction,
8. Fuel type and characteristics and fuel-cost premium.

The input flexibility of this model and the disaggregations that can be developed in the output list above render an effective vehicle for analyzing the relative efficiency and distributive characteristics of alternative, least-cost, emission-reduction strategies, despite the constraints imposed by simplification of the dynamic setting and uncertainties surrounding individual emitters.

3.3.3 Model Structure

The emission source is assumed to pursue the emission reduction strategy which minimizes the net present value of the costs associated with a policy instrument, given an output level. The present value of costs is net of corporate income taxes, depreciation, and sales of recovered byproducts. Specifically, the model approximates each emitter's strategy by calculating the present value associated with all control options and selecting that strategy with the lowest present value of costs.

Although the functional specification of the discounted present value of net abatement costs varies according to the type of policy instrument that is applied, this decision equation, which is the core of the model structure, can be shown here in general terms.

Both emissions and the net emission charge proceeds under the jth emission reduction strategy can be regarded as functions of an array, Z_j, of policy parameters associated with the jth policy. This array may include the emission charge rate, the subsidy level, the emission control regulation, etc.

$$E_j = E_j(Z_j) = \text{Sulfur emission rate under the } j^{th} \text{ strategy.}$$

$$\pi_j = \pi_j(E_j) = \text{Total emission charge payments under the } j^{th} \text{ strategy.} \qquad (3\text{-}1)$$

The aggregate resource cost of the jth abatement strategy is calculated as the total gross private resource cost less transfers. Since all corporate income tax payments and emission charge payments are transfers, the total discounted present value of the resource costs associated with the jth emission reduction strategy is shown as:

$$PV_j \text{ (aggregate cost)} = K_j + \sum_{t=1}^{n} \left\{ \left(\frac{1}{1+r} \right)^t \; (V_j + F_j - \phi S_j) \right\} \qquad (3\text{-}2)$$

PV_j (aggregate cost) = Present value of the resource costs associated with the jth abatement strategy.

K_j = Investment cost of the jth strategy.

n = Planning horizon, in years.

r = Cost of capital, assumed to be the opportunity cost of funds.

V_j = Annual variable cost under the jth strategy.

F_j = Annual fuel cost premium associated with the jth strategy.

ϕ = Unit value of recovered sulfur.

S_j = Annual flow volume of sulfur recovery using the jth strategy.

Because all variable costs, including emission charges and depreciation, can be deducted from taxable income, the emitter actually incurs a net expense after income taxes that is much lower than gross abatement expenditures. The private cost of the jth strategy can therefore be generally represented as:

$$PV_j \text{ (private cost)} = K_j - \frac{\Theta K_j}{L} \sum_{t=1}^{L} \left(\frac{1}{1+r}\right)^t + (1 - \Theta) \left[\sum_{t=1}^{n} \left\{ \left(\frac{1}{1+r}\right)^t (V_j + F_j + \pi_j (E_j) - \phi S_j) \right\} \right] \quad (3\text{-}3)$$

PV_j (private cost) = Aggregate present value of private costs associated with the jth abatement strategy.

Θ = Corporate income tax rate, $(0<\Theta<1)$.

L = Number of years over which capital is depreciated on a straight-line basis.

The abatement strategy which minimizes the value of equation 3-3 is the one which is selected in the emitter response model, since it is presumed to approximate the emitter's strategy decision function.

The amortization scheme assumed for pollution control facilities in this study was the 60-month straight-line amortization deduction allowed by Federal tax laws for certified pollution control facilities (ref. 3). Therefore the value of L in the preceding equation was set equal to five and held constant. The use of the 60-month amortization deduction is an alternative to the combined use of the investment tax credit and a standard rapid amortization scheme such as double-declining balance (ref. 4). Since the choice of amortization

scheme is highly dependent on an individual plant's financial circumstances, the model used the simpler 60-month amortization scheme (ref. 5).

The annualized cost of the jth strategy, AC_j, is regarded as that constant annual payment over the emitter's planning horizon whose discounted present value equals the computed present value of the cost associated with the strategy. The "before tax" (gross private) and "after tax" (net private) annualized costs facing the emitter are computed using equation 3-3 and two alternative values for Θ: zero and its actual value, respectively.

$$AC_j \text{ (private cost)} = \frac{PV_j(\text{private cost})}{\sum_{t=1}^{n} \left(\frac{1}{1+r}\right)^t} \qquad (3\text{-}4)$$

$AC_j(\cdot)$ = Annualized cost of the jth strategy.

Private costs are defined as gross private costs when calculated for a zero tax rate ($\Theta = 0$); and as net private when calculated for an assumed actual tax rate.

The annualized aggregate cost is computed by subtracting emission charge payments from "before tax" (gross private) costs. Equivalently it follows from equation 3-2 that:

$$AC_j \text{ (aggregate cost)} = \frac{PV_j(\text{aggregate cost})}{\sum_{t=1}^{n} \left(\frac{1}{1+r}\right)^t} \qquad (3\text{-}5)$$

The equations (3-1) through (3-5) are highly simplified versions of their detailed counterparts in the computer model, which tailors the logic for each emission source type. Nonetheless, these equations provide the basic conceptual underpinnings of the simulated emitter responses that are reported in this study.

3.4 Selected Air Quality Control Regions

To provide for the "....abatement prevention, and control of air pollution on a regional basis," (ref. 6) 247 Air Quality Control Regions (AQCR) have been established. The regional boundaries of the AQCRs were to be based on

"....jurisdictional boundaries, urban-industrial concentrations, and other factors, including atmospheric areas necessary to provide adequate implementation of air quality standards" (ref. 7).

Sulfur emitters in two of these AQCR's were selected for analysis in this study. The AQCR's are: the Metropolitan St. Louis Interstate and the Greater Metropolitan Cleveland Intrastate regions. The abatement actions of each emitter in each region in the face of the alternative policy instruments were then projected through the emitter's response model.

As table 1 shows, the land area of the St. Louis AQCR is almost twice (187 percent) that of the Cleveland AQCR, although it has only about three-quarters (73 percent) of the population. However, sulfur emission rates in the two AQCR's are fairly similar.

3.4.1 Major Point Sources of Emissions

For the purposes of this study, it was deemed sufficient to identify the costs and effectiveness of the alternative policy instruments for the major point sources of sulfur emissions. From the National Emissions Data System (NEDS), all steam-electric power plants, industrial, commercial and institutional boilers (point sources only), petroleum refineries, primary nonferrous smelters, and sulfuric acid plants in the two AQCR's were identified. The NEDS data base provided basic data regarding the operating variables of the identified point sources. This data base was supplemented as discussed below:

1. Steam electric power plants--Data from Federal Power Commission (FPC) Form 67 was obtained to provide additional data on the installed generating capacity, net generation, heat rate, fuel consumption by type and sulfur content, and boiler-design fuel types for each group of boilers breeched to a common stack.
2. Industrial, commercial, and institutional boilers--No additional data were used.
3. Petroleum refineries--Data on capacity and processing operations were obtained from The Oil and Gas Journal. Refineries with Claus sulfur plants were identified by EPA.
4. Primary nonferrous smelters--Data on capacity and processing operations were provided by EPA.

Table 1. Characteristics of selected Air Quality Control Regions

	St. Louis AQCR	Cleveland AQCR
Land area (square kilometers)§	16,771	8,961
Population, 1970§	2,476,757	3,383,879
Personal income, 1970 (10^3 1967 $)§	$9,089,950	$12,707,912
Per capita income, 1970 (1967 $)§	$3,670	$3,755
Sulfur emissions (10^6 kilograms per year)	376.103	307.986
Fuel combustion	(286.917)	(280.058)
Steam-electric power plants *	248.083	171.937
Industrial, commercial and institutional boilers *	21.174	37.768
Other fuel combustion sources †	17.660	70.353
Industrial process †	(85.273)	(24.026)
Petroleum refineries *	17.811	9.712
Sulfuric acid plants *	0.863	0.207
Primary nonferrous smelters *	9.466	------
Other industrial process sources †	57.133	14.107
Solid waste disposal †	(0.332)	(0.626)
Transportation †	(3.581)	(3.276)

* Research Triangle Institute.

† 1972 National Emissions Report, U.S. Environmental Protection Agency, Research Triangle Park, N.C., June 1974.

§ U.S. Department of Commerce, Bureau of Economic Analysis Projections of Economic Activity for Air Quality Control Regions, Washington, D.C., p. 17.

Note: All units of weight presented in this study, unless specifically identified otherwise, are in metric measures. Defined as the Systeme International d'Unites (SI), the basic unit of mass (weight) is the kilogram. All other units of weight are officially described as multiples or fractions of a kilogram. The factors for conversion are:

To convert from:	To:	Multiply by:
kilogram	pound	2.205
pound	kilogram	0.454
10^3 kilogram	ton (short; 2,000 pounds)	1.102
ton	10^3 kilograms	0.907

5. Sulfuric acid plants--Data on capacity and processing operations were obtained from the Directory of Chemical Producers, Stanford Research Institute.

In some cases, the data for the operating variables in the sources listed above differed from the data provided in the NEDS file. Where feasible, possible sources of these discrepencies were investigated. In most cases, however, data from the above listed sources were used when there was a conflict with the NEDS data.

The emission rates shown in table 1 for the major point sources may differ somewhat from those employed by EPA field personnel in gathering the NEDS data. They are, however, reasonably accurate and provide a benchwork for comparing the impacts of the alternative policy instruments.

For the St. Louis AQCR, 87 plants with 194 emission points were incorporated in the analysis. In the Cleveland AQCR, 113 plants and 238 emission points were included (table 2). Most of the emission points in each AQCR

Table 2. Summary of emission points

Emission source	St. Louis AQCR		Cleveland AQCR	
	Number of Plants	Number of Emission Points	Number of Plants	Number of Emission Points
Fuel combustion	(83)	(185)	(109)	(228)
Steam-electric power plants	9	30 *	7	26 *
Industrial, commercial, and institutional boilers	74	155	102	202
Industrial processes	(4)	(9)	(4)	(10)
Petroleum refineries	2	6	2	6
Sulfuric acid plants	1	2	2	4
Primary nonferrous smelters	1	1	0	0
Totals	87	194	113	238

* Represents the number of groups of boilers breeched to a common stack.

are associated with fuel combustion. Selected steam-electric power plant characteristics are shown in table 3. For both AQCR's, a similar number of steam-electric power plants and boiler groups are represented in the inventory. The plants in the St. Louis AQCR tend to be larger than those in the Cleveland AQCR. Coal, mainly from the Ohio district, is the only fuel used in the Cleveland region (although small quantities of oil may be used for starting boilers). In the St. Louis AQCR, coal (from the Illinois and Southern Number 2 Districts) is the dominant power-plant fuel, although some residual oil and gas is used.

Table 3. Steam-electric power plant characteristics, 1971

Company	Plant	Installed generating capacity (10^3 kW)	Net generation (10^6 kWh)	Fuel designed for (C=coal O=oil G=gas)	Distribution of Btu consumption (percent)		
					Coal	Oil	Gas
		St. Louis AQCR					
Union Electric Company	Ashley	70.0	22.7	CO	83	17	--
	Labadie	1,110.0	3,805.1	C	99	1	--
	Meramec	800.0	4,660.3	CG	92	--	--
	Sioux	977.6	4,737.5	C	100	--	--
	Chokia	300.0	411.0	CO	56	44	--
	Venice 1	55.0	4.1	OG	--	--	100
	Venice 2	500.0	1,960.4	CG	67	--	33
Illinois Power Company	Wood River	650.1	4,007.3	CG	76	--	24
	Baldwin	623.1	3,394.1	C	100	--	--
Totals:		5,085.8	23,002.5				
		Cleveland AQCR					
Cleveland Electric Illuminating Company	Avon Lake	1,275.0	6,553.5	C	100	--	--
	East Lake	577.0	4,071.1	C	100	--	--
	Lake Shore	514.0	2,597.3	C	100	--	--
Ohio Edison Company	Edgewater	192.9	676.6	C	100	--	--
	Gorge	87.5	426.7	C	100	--	--
Cleveland Department of Public Utilities	Lake Road	160.0	394.4	CO	98	2	--
Painesville Electric Light Department	Painesville	38.0	111.4	C	100	--	--
Totals:		2,844.4	14,831.0				

Source: National Coal Association, Division of Economics and Statistics. Steam-Electric Plant Factors, 1972, Washington, D.C., 1972.

REFERENCES

1. See for example:
   a. Richard A. Musgrave, "Cost-Benefit Analysis and the Theory of Public Finance," Journal of Economic Literature, September 1969, Vol. VII, No. 3, pp. 797-806.
   b. E. J. Mishan, "The Post War Literature on Externalities: An Interpretative Essay," Journal of Economic Literature, March 1971, Vol. IX, No. 1, pp. 1-28.
   c. Arnold C. Harberger, "Three Basic Postulates for Applied Welfare Economics: An Interpretative Essay," Journal of Economic Literature, Spetember 1971, Vol. IV, No. 3, pp. 785-797.
   d. Nicholas Kaldor, "Welfare Propositions of Economics and Interpersonal Comparisions of Utility," The Economics Journal, 49(1939) pp. 549-52.
   e. Tibor Scitosky, "A Note on Welfare Propositions in Economics," The Review of Economic Studies, 9(1941), pp. 77-88.

2. This problem is analyzed in some detail in Appendix G of Tayler H. Bingham, et al., A Projection of the Effectiveness and Costs of a National Tax on Sulfur Emissions, RTI Project No. 41U-757, November 1973.

3. Internal Revenue Service (1971). Amortization of Pollution Control Facilities. Publication 577 (10-71). Washington: U.S. Government Printing Office.

4. Ibid., p. 4.

5. Private conversation with Mr. Tom Quarles, Carolina Power and Light Company, Raleigh, North Carolina.

6. U.S. Environmental Protection Agency, Federal Air Quality Control Regions, Rockville, Md., January 1972, p. 1.

7. 1967 Amendment to the Clean Air Act of 1963, Section 107 (a)(2).

Chapter 4: ANALYSIS OF SELECTED POLICY INSTRUMENTS

4.1 Introduction

The estimated allocative and distributive effects of the selected policy instruments as applied to the major sulfur-emission sources in the St. Louis and Cleveland AQCR's are presented in this chapter. These estimates are developed using the emitter-response model described above (section 3.3) and the emission point abatement costs presented in Appendix A. The policy instruments examined (see section 2.2) include:

1. Emission standards,
2. Emission charge,
3. Emission charge based on effects,
4. Emission charge with an exemption,
5. Emission charge with a subsidy,
6. Hybrid programs.

The sulfur emission sources included in this analysis are:

1. Steam-electric power plants,
2. Industrial, commercial, and institutional boilers,
3. Petroleum refineries,
4. Sulfuric acid plants,
5. Primary nonferrous smelters.

The following economic variables are treated as constants in this analysis:

1. The cost of capital (r) = 15 percent,
2. The value of recovered sulfur (SU) = $10 per ton,
3. The corporate income tax rate (Θ) = 53 percent,
4. The firm's planning horizon (t) = 20 years,
5. The rapid depreciation period (d) = 5 years.

Each of these parameters represents a reasonable average of actual current values. The assumed corporate income tax rate is the sum of the Federal rate, 48 percent, and an assumed average State rate, 5 percent.*

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*Although the Federal corporate income tax rate is somewhat lower for small incorporated businesses, 48 percent is the generally prevailing rate that would apply to the companies covered by this analysis.

4.2 Emission Standards

The term "emission standards" is used to characterize the regulatory approach employed by all States to set maximum emission rates for sources in each AQCR consistent with the attainment of the ambient air quality standards for sulfur oxides. In the case of the St. Louis AQCR which is an interstate AQCR, regulatory authority is divided between the States of Illinois and Missouri.

Table 4 presents the emission standards for existing sulfur oxide emission sources in the two AQCR's. In practice, emission standards are subject to modification, local interpretation, variances, and varying degrees of enforcement. For these reasons and for purposes of providing a computationally feasible specification of the standards for estimating abatement costs, the standards shown in table 4 and our interpretation of them may not represent the precise emission standards for the two AQCR's. However, they are reasonable approximations of the emission standards and will serve for the purposes of this analysis.

The emission standards for fuel-combustion sources are based on heat inputs for both the Illinois portion of the St. Louis AQCR and the Cleveland AQCR, and on process weight for the Missouri portion of the St. Louis AQCR. For the purpose of this analysis, all fuel-combustion-source emission standards have been converted to a process weight (i.e., maximum sulfur content) base. It should be noted that the standard based on heat content can be expected to encourage the consumption of relatively higher heat content fuel; the standard based on weight would encourage the consumption of relatively heavier fuels as combustion sources seek to minimize the costs associated with the emission standards. However, neither of these responses is simulated in this analysis because the marked increases in associated data and modeling requirements appeared more costly than anticipated improvements in the predictions.

By using average fuel heat contents,* heat input emission standards were converted to the process weight rate standards shown in table 5.

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*The heat content of a barrel of residual oil used in this analysis is 6,287,000 Btu, with the fuel weight of 336 pounds per barrel (8 pounds per gallon); for coal, 11,670 Btu per pound has been used.

Table 4. Existing source emission standards

Emission Source	St. Louis AQCR Illinois Portion	St. Louis AQCR Missouri Portion	Cleveland AQCR
Fuel combustion			
Residual Oil (maximum lb $SO_2/10^6$ Btu)	1.0	-	1.0
Distillate Oil (maximum lb $SO_2/10^6$ Btu)	0.3	-	1.0
Coal (maximum lb $SO_2/10^6$ Btu)	1.8	-	1.0
Oil (maximum percent Sulfur)	-	2.0	-
Coal (maximum percent Sulfur)	-	2.0	
Industrial processes			
Sulfuric acid plants: mist (lb Sulfur/ton 100 percent acid)	0.15	3	0.5
SO_2(lb SO_2/ton 100 percent acid)	none*	3	6.5
Sulfur recovery plants (lb Sulfur/lb input)	none*	none*	0.01
Primary nonferrous smelters (lb SO_2/hr)			
Copper	none*	none*	0.02x
Lead	none*	none*	$0.98x^{0.77}$
Zinc	none*	none*	$0.564x^{0.85}$

*No emission standards established.

x = total sulfur feed to smelter (lb/hr).

Source: The Mitre Corporation, Analysis of Final State Implementation Plans-Rules Regulations, Environmental Protection Agency, Research Triangle Park, N. C., July 1972.

Table 5. Implied process weight rate emission standards for fuel combustion sources (effective maximum sulfur content, percent)

Fuel	St. Louis AQCR Illinois portion	St. Louis AQCR Missouri portion	Cleveland AQCR
Residual Oil	0.9	2.0	0.9
Coal	1.1	2.0	0.6

Source: Research Triangle Institute.

For the industrial processes, emission standards are based on process or product weights. To provide a computationally feasible specification of the costs of meeting the industrial process emission standards, specific abatement technologies are assumed. These technologies represent the highest level of control for the industries, or processes within industries, for which emission standards have been promulgated. To meet the sulfur-mist emission standards, sulfuric acid plants are assumed to employ tubular fiber demisters. For gaseous emissions, sodium sulfite scrubbing is assumed. Petroleum refineries are assumed to install four-stage Claus plants with a tail gas unit. A limestone scrubber on the lean steam is assumed for smelters.

For fuel-combustion sources, the emission standards are assumed to represent maximum allowable emission rates for each point source. The point source is assumed to select the minimum cost combination of stack-gas desulfurization and fuel switching consistent with the emission standard.

In the St. Louis AQCR, coal-fired steam-electric boilers meet the emission standards primarily by application of stack-gas desulfurization systems (double alkali scrubbers). As shown in table 6, the weighted average sulfur

Table 6. Fuel sulfur content before and after emission standards (percent)

	St. Louis AQCR			Cleveland AQCR		
	Coal	Residual oil	Average	Coal	Residual oil	Average
Steam-electric power plants						
Before emission standards	2.73	2.22	2.73	2.58	0.16	2.58
After emission standards	2.82	0.72	2.80	0.59	0.16	0.59
Industrial, Commercial, and Institutional Boilers						
Before emission standards	3.31	1.92	2.47	2.99	1.08	2.88
After emission standards	2.62	0.88	1.65	0.63	0.71	0.63
Totals						
Before emission standards	2.75	1.97	2.70	2.65	1.06	2.63
After emission standards	2.82	0.85	2.71	0.60	0.70	0.60

Source: Research Triangle Institute

content for steam-electric power plants in the St. Louis region is virtually unaffected by the emission standards, since several large boilers offset the cost of stack-gas dusulfurization by burning higher sulfur-content and hence, lower-cost coal.

Emission standards are projected to reduce the combined emissions from the sulfur emission sources included in this analysis by 55 and 78 percent in the St. Louis and Cleveland AQCR's respectively (table 7). The largest absolute reductions in sulfur emission are for steam-electric power plants.

4.2.1 Allocative Effects

The annualized aggregate resource costs of complying with emission standards are $50 million in the St. Louis AQCR and $46 million in the Cleveland AQCR (table 8). In both regions, steam-electric power plants have the highest total resource (i.e., abatement) costs.

The average resource costs, which are dominated by fuel-combustion sources, are $304 per 10^3 kilograms of emission reductions in the St. Louis region and $265 in the Cleveland AQCR. Within each region, large variations in these per unit costs are shown.

A larger average percentage reduction at a lower average cost is estimated for Cleveland, because the price of coal for any given sulfur content is lower in Cleveland than in St. Louis (see Appendix A). In St. Louis, four of the larger steam-electric boilers are projected to control emissions employing stack-gas desulfurization systems (double alkali scrubbing). Although the marginal costs (i.e., the addition to total cost attributable to the removal of the last 10^3 kilograms of sulfur emissions) of emission standards are not directly measurable, they are greater than average costs and would exhibit similar, or more likely even greater, variability across sources.

4.2.2 Distributive Effects

Net private cost, that is the cost to emitters after Federal corporate income tax and depreciation allowances, is about half of the gross private costs (table 9). Since emission standards do not require financial transfers such as emission charges, the total gross costs to emitters, gross private costs, are equal to the total cost of abatement practices, aggregate resource costs. All of the remaining policies to be analyzed in this study do involve transfers of financial resources. Therefore it is important to observe the distinction between these two aggregate cost measures.

Table 7. Sulfur emission estimates under emission standards

Emission source	Sulfur emissions after abatement (10^6 kilograms/year)	Reductions in sulfur emissions (10^6 kilograms)	Reductions in sulfur emissions (percent)
St. Louis AQCR			
Fuel combustion			
Steam-electric power plants	124.101	123.982	49.98
Industrial, commercial and institutional boilers	7.728	13.446	63.50
Industrial processes			
Petroleum refineries	0.447	17.364	97.53
Sulfuric acid plants	0.044	0.819	94.90
Primary nonferrous smelters	2.272	7.194	76.00
Total	134.591	163.065	54.78
Cleveland AQCR			
Fuel combustion			
Steam-electric power plants	39.302	132.635	77.14
Industrial, commercial and institutional boilers	7.603	30.164	79.87
Industrial, processes			
Petroleum refineries	0.624	9.088	93.57
Sulfuric acid plants	0.012	0.195	94.36
Primary nonferrous smelters	---	---	---
Total	47.450	172.083	78.35

Source: Research Triangle Institute

Table 8. Allocative effects of emission standards

Emission source	Reductions in sulfur emissions (percent)	Resource costs: Total cost of abatement (10^6 dollars/year)	Resource costs: Average cost of abatement (dollars/10^3 kilograms of reductions in sulfur emissions)
St. Louis AQCR			
Fuel combustion			
Steam-electric power plants	49.98	$31.689	$255.59
Industrial, commercial and institutional boilers	63.50	6.485	482.31
Industrial processes			
Petroleum refineries	97.53	10.600	601.09
Sulfuric acid plants	94.90	0.134	164.12
Primary nonferrous smelters	76.00	0.604	83.91
Total	54.78	$49.511	$303.63
Cleveland AQCR			
Fuel combustion			
Steam-electric power plants	77.14	$31.682	$238.86
Industrial, commercial and institutional boilers	79.87	6.307	209.10
Industrial processes			
Petroleum refineries	93.57	7.369	810.94
Sulfuric acid plants	94.36	0.158	811.42
Primary nonferrous smelters	---	---	---
Total	78.35	$45.516	$264.50

Source: Research Triangle Institute.

Table 9. Distributive effects of emission standards

Emission source	Reductions in sulfur emissions (percent)	Net private cost (10^6 dollars/year)	Gross private cost: Annualized cost (10^6 dollars/year): Total	Variable cost: Fuel cost premium	Variable cost: Abatement equipment operating cost	Variable cost: Credit for sulfur sales	Fixed cost	Capital outlays for abatement equipment (10^6 dollars)
St. Louis AQCR								
Fuel combustion								
Steam-electric power plants	49.98	$16.494	$31.689	$10.111	$12.415	$ 0	$ 9.163	$57.353
Industrial, commercial and institutional boilers	63.50	3.097	6.485	5.197	1.005	0	0.283	1.769
Industrial processes								
Petroleum refineries	97.53	5.090	10.600	---	10.172	0.194	0.622	3.894
Sulfuric acid plants	94.90	0.086	0.134	---	0.014	0.009	0.129	0.809
Primary nonferrous smelters	76.00	0.387	0.604	---	0.091	0.079	0.592	3.705
Total	54.78	$25.154	$49.511	$15.308	$23.697	$0.283	$10.789	$67.529
Cleveland AQCR								
Fuel combustion								
Steam-electric power plants	77.14	$14.890	$31.682	$31.682	0	0	0	0
Industrial, commercial and institutional boilers	79.87	6.370	2.970	6.225	0.050	0	0.033	0.207
Industrial processes								
Petroleum refineries	93.57	7.369	3.518	---	7.160	0.100	0.309	1.937
Sulfuric acid plants	94.36	0.100	0.158	---	0.015	0.002	0.145	0.908
Primary nonferrous smelters	---	---	---	---	---	---	---	---
Total	78.35	$21.477	$45.516	$37.906	$7.225	$0.102	$0.487	$3.051

Source: Research Triangle Institute.

However, in the Cleveland region where the steam-electric boilers are smaller than those in St. Louis and where the cost of coal is lower, the emission standards are met entirely by burning low-sulfur coal. Therefore, the application of emission standards in Cleveland induces a reduction in the average sulfur content of power plant fuels from 2.58 to .59 percent (table 6).

4.3 Emission Charge

An emission charge on all emitters is the most commonly proposed price incentive for inducing emission reductions. The emission charge analyzed here is based on the estimated weight of sulfur emissions from each point source identified in the two AQCR's. The charge is assumed to be uniformly applied to all sources in each AQCR, regardless of their location. Specific emission charge rates have been selected for tabular presentation in Appendix B. In the graphical data that are presented, the reader is cautioned that the continuous curves simply connect coordinate points that were estimated. Because of the discrete nature of the abatement cost functions coordinate values on those connecting curves are only approximations of model output values.

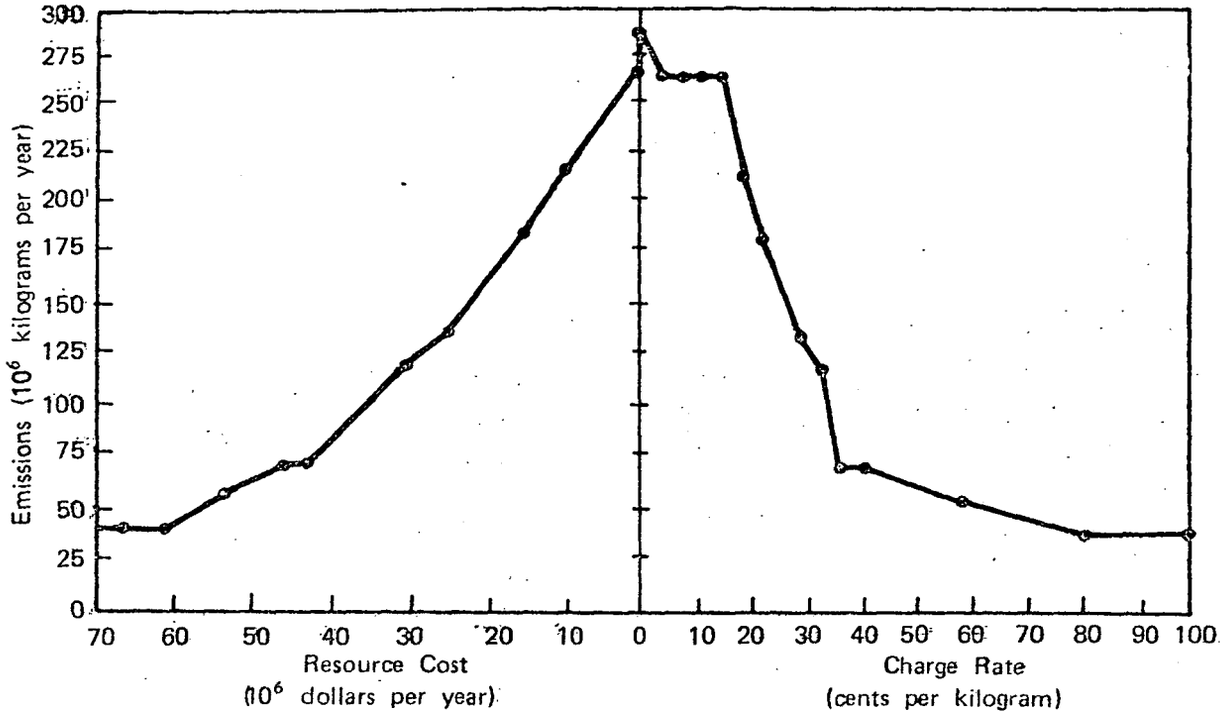
The combined response of all sulfur emitters in the two AQCR's to selected emission charge rates (expressed in cents per kilogram) are shown in figure 12 (see Appendix B, table B-1 for tabular data). In both regions emitters are most responsive to the charge up to a rate of 40 cents per kilogram of emissions. Above that rate the percentage emission reductions elicited by a fixed percentage increase in the charge rate fall dramatically. This illustrates empirically the exponentially rising marginal cost of abatement function. (Note that the right panels of both figures 12a) and b) can be interpreted as the regional MCA curves such as that shown in figure 6.)

4.3.1 Allocative Effects

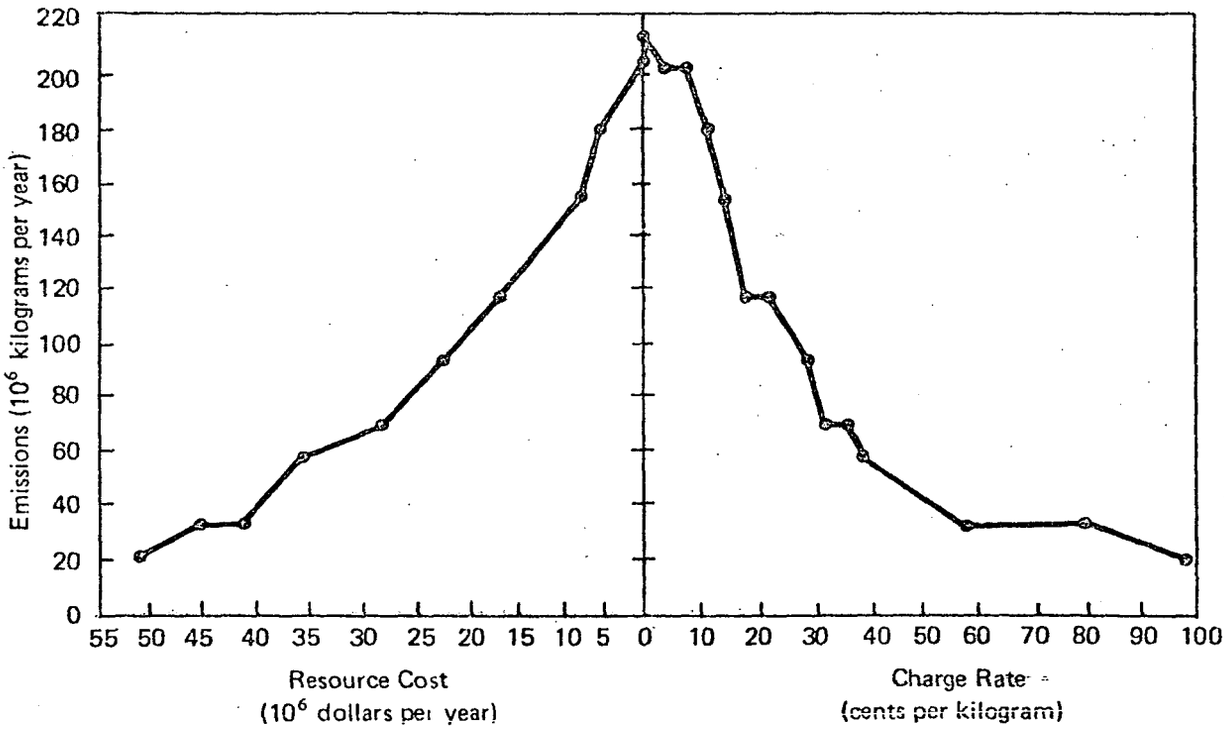
An emission charge induces emission reductions at a minimum total cost of abatement, after allowing for depreciation and the corporate income tax. This cost minimization property follows from the theoretical properties of the emission charge discussed in section 2.2.2.1. The two panel graphs (figure 12) show the aggregate resource costs and emissions induced by various charge rates. Both total and per-unit costs of abatement for the selected emission charge rates are shown in Appendix B, table B-2.

4.3.2 Distributive Effects

Both the net and gross private costs of an emission charge increase at



a) St. Louis AQCR



b) Cleveland AQCR

Figure 12. Resource cost and effectiveness of an emission charge. (Source: Research Triangle Institute)

a decreasing rate over all charge rates, since emission reductions are induced by the tax (figure 13). The gross private costs are larger than the total resource costs because of financial transfers (i.e., charge payments) to government. In both regions, charge payments have an inverted-U shape with respect to the charge rate, reaching a maximum at a rate of about 24 cents per kilogram of emissions as shown in figure 13.

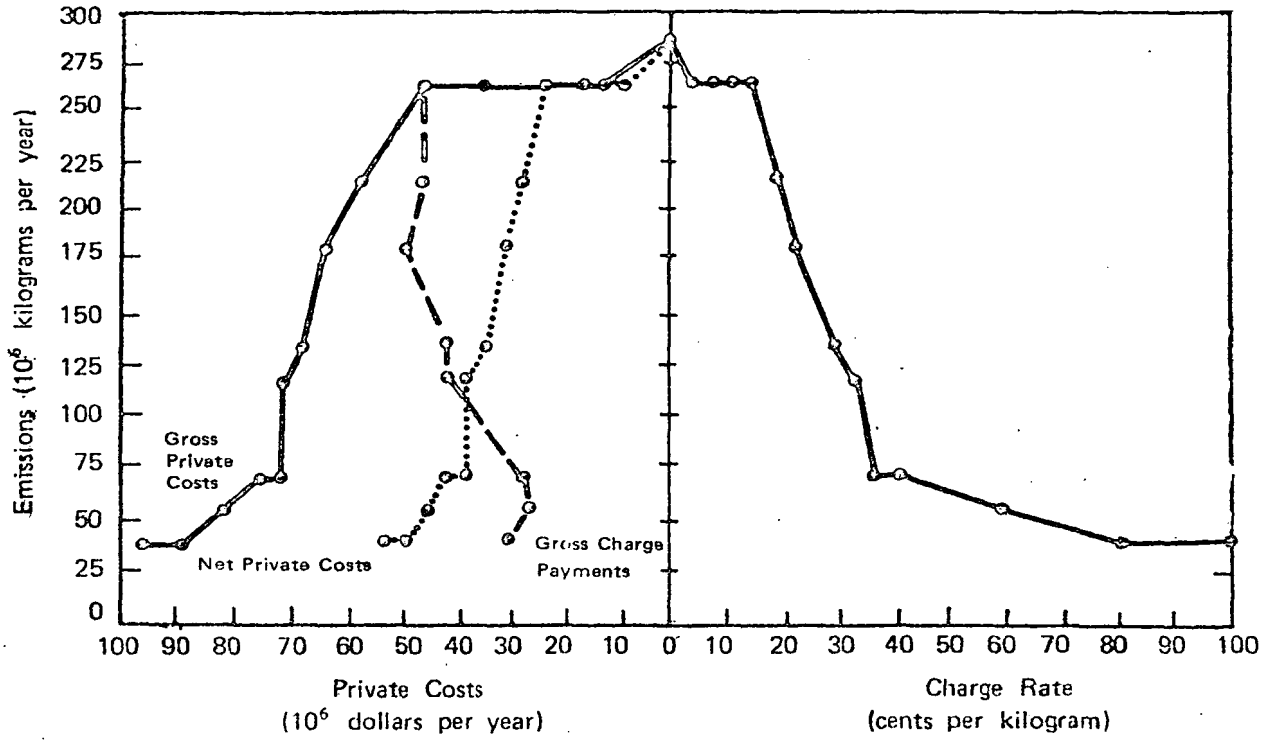
The horizontal distance between charge payments and gross private costs in figure 13 represents the aggregate resource costs of emission reductions. These horizontal distances measure the identical aggregate resource costs that are shown in the left panels of figure 12. These costs include expenditures for purchase, installation, and operation of abatement equipment and fuel-cost premiums, all measured on an annualized basis, net of credits for sales of recovered sulfur.

In the St. Louis region, steam-electric power plants burn somewhat lower sulfur-content coal at low emission charge rates. Beginning with rates of 20 cents, however, stack-gas desulfurization using double alkali scrubbers becomes economical for large boilers. Since these scrubbers are projected to be 95 percent efficient in removing sulfur from stack gases, it is cost minimizing for boilers on which such systems are installed to burn higher sulfur-content (and cheaper) coal. This fuel choice offsets some of the scrubber equipment costs. Industrial, commercial, and institutional boilers are not generally large enough to exploit the pronounced economies of scale associated with stack-gas desulfurization systems. As a result, except for a few large boilers, emission control is achieved by burning low-sulfur fuels.

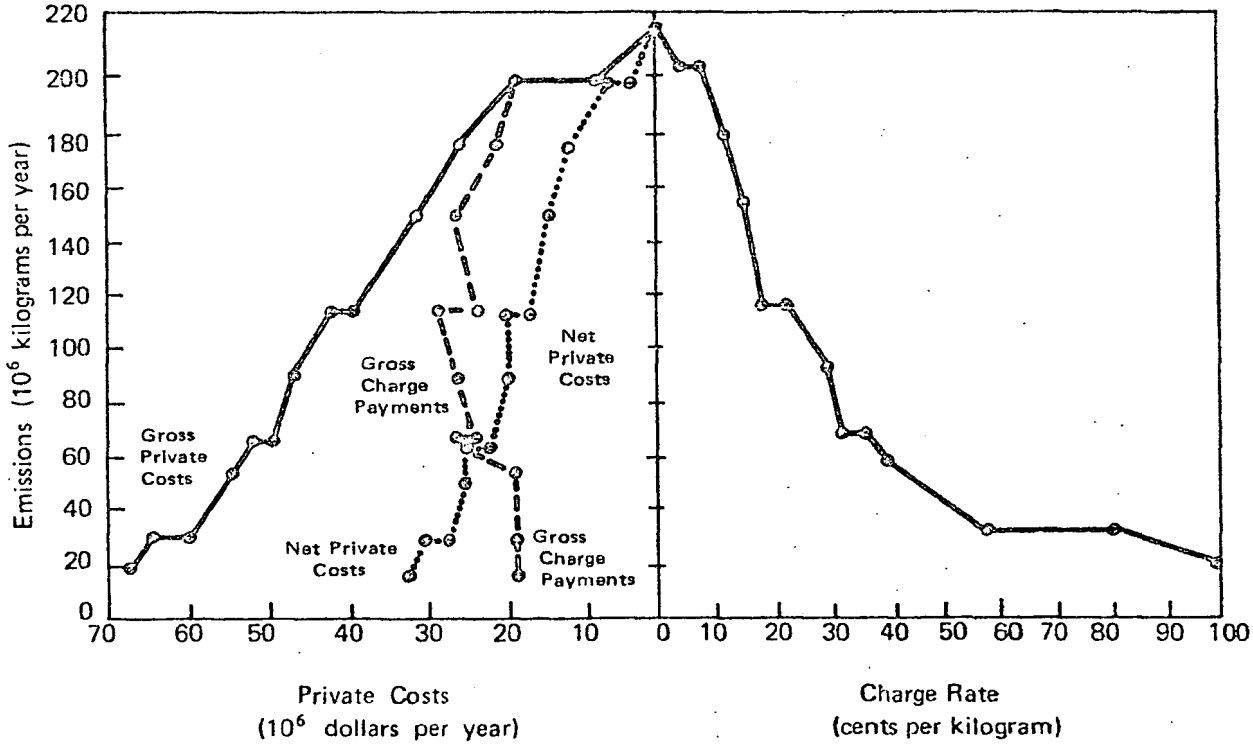
In the Cleveland AQCR, steam-electric boilers tend to be smaller and coal cheaper than in the St. Louis AQCR. Therefore, substitution of low-sulfur coals is the only control strategy employed over most charge rates examined.

4.4 Emission Charge Based on Effects

A number of studies have been completed which provide evidence of a relationship between air quality and human health. Given a policy goal of providing improvements in health by improving air quality, emission charges could be tailored across regions, given sufficient cost and benefit information, to induce the necessary reductions in emissions at a minimum total resource cost to society. Such an approach would imply that air quality



a) St. Louis AQCR



b) Cleveland AQCR

Figure 13. Private costs and effectiveness of an emission charge. (Source: Research Triangle Institute)

across regions would vary in response to regional differences in abatement costs and health effects.

To relate resource costs to health benefits ideally would require information regarding the relationships between: emissions and air quality, air quality and health effects, health effects and their dollar valuation, and emissions and abatement costs. All this information, of course, is not available at present. However, there is enough information to develop some preliminary indications of the regional differences in emission charges under several assumptions.

The relationships between emission charges, resource costs, and sulfur emissions for the St. Louis and Cleveland AQCR's were presented above (figure 12). By assuming a proportional model of emission dispersion--a unit of emissions affects air quality identically regardless of source, location, etc.--these emissions can be related to air quality.

The research of Lave and Seskin (ref. 1) provides a preliminary indication of the health effects of air pollution. Specifically, they analyzed the relationships between mortality rates and various contributory factors, including air pollution, using cross-sectional data from 117 Standard Metropolitan Statistical Areas in 1960. The resulting estimated relationship was (values of the t-statistic are shown in parentheses):

$$MR = 19.607 + \underset{(2.53)}{0.041a_1} + \underset{(3.18)}{0.071a_2} + \underset{(1.67)}{0.008a_3} + \underset{(5.81)}{0.041a_4} + \underset{(18.94)}{0.687a_5} + e$$

$$R^2 = 0.827$$

where

MR = annual mortality rate of per 10,000 population,

a_1 = arithmetic mean of 26 suspended particulate readings in $\mu g/m^3$,

a_2 = smallest of 26 biweekly sulfate, SO_4, readings in $\mu g/m^3$,

a_3 = population per square mile,

a_4 = percent of population who are nonwhite,

a_5 = percent of population 65 and older,

e = error term.

Thus, if the minimum sulfate level (a_2) were lowered by 1 $\mu g/m^3$, the annual total number of deaths would fall by 0.071 persons per 10,000 population.

Table 10. Emissions, air quality, and population estimates

	St. Louis AQCR	Cleveland AQCR
Emissions (10^6 kilograms/year)	376.103	307.986
Air quality ($\mu g/m^3$ SO_2, annual arithmetic mean) *	100	157
Population (10^4)	247.676	338.388

*Monitoring and Reports Branch, Environmental Protection Agency working files, December 8, 1973.

Table 10 presents data on sulfur emissions, air quality, and the population at risk in each AQCR. Because the above equation employs sulfation (SO_4) levels, it was necessary to convert estimated SO_2 levels to a corresponding measure of SO_4 concentrations. Therefore, it was assumed that the conversion of SO_2 to SO_4 follows the simple equation:

$$SO_2 + O_2 = SO_4.$$

Under this assumption 1.5 units of SO_4 is formed for each unit mass of SO_2.* By using a proportional model of air quality, and ignoring background concentrations, it was estimated that a reduction in sulfur emissions of 1×10^6 kilograms would lower average ambient SO_4 concentrations by 0.399 and 0.765 $\mu g/m^3$ in the St. Louis and Cleveland regions, respectively.

By assuming that the average concentrations approximate the smallest of the 26 biweekly sulfate readings, the Lave and Seskin equation was used, along with the population values reported in table 10, to estimate mortality rate differentials. In St. Louis and Cleveland a reduction in sulfur emissions of

*The relationship between SO_2 and SO_4 in the atmosphere is a very complex one and not presently fully understood. The presence of other pollutants, humidity, temperature, and photochemical activity, however, are all believed to influence the relationship.

1×10^6 kilograms was estimated to reduce the annual number of deaths by 7.02 and 18.38, respectively.

The data presented in Appendix B, table B-2, were used to compute the marginal costs per unit reduction in the mortality rate. These were computed by dividing the units-adjusted charge rates, marginal costs per kilogram, by 7.02 and 18.38, marginal deaths avoided per 10^6 kilogram for St. Louis and Cleveland, respectively. The resulting marginal costs per death avoided are measured on the vertical axis of figure 14. The emissions reductions corresponding to each charge rate in the numerator of those calculations (from Appendix B, table B-1) were multiplied by 7.02 and 18.38 to get the corresponding reductions in mortality in St. Louis and Cleveland, respectively; these are measured on the horizontal axis in the right panel of figure 14. Overall, the right panel of figure 14 shows the marginal cost per death avoided for each AQCR. Also shown is horizontal summation of the two regional marginal costs curves (ΣMC). Given a policy goal of reducing the total mortality rate in both AQCR's by the lowest total cost, the ΣMC curve shows the lowest marginal cost of achieving the goal.

The left panel of figure 14 shows the linear relationship between emission charge rates (marginal costs per kilogram) and marginal costs per death avoided. This linear relationship is evident because of the way the latter variable is computed.

4.4.1 Allocative Effects

The upper half of table 11 presents data on the number of deaths avoided and the associated costs under the assumptions stated above as well as the assumption that the emission standards are applied in both St. Louis and Cleveland. The data indicate that the number of deaths avoided by the application of standards in those two cities would be 1163 and 3230, respectively, or a total of 4393. At the resource cost levels implied by the standards, the average resource cost per death avoided is $42,562 in St. Louis and $14,087 in Cleveland; the average for both regions is $21,625 per death avoided.

Assume now that alternative least cost policies are considered for reducing the numbers of deaths by the same amount, 4393, that is implied by the emission standards, i.e. assume that the alternatives are based on effects

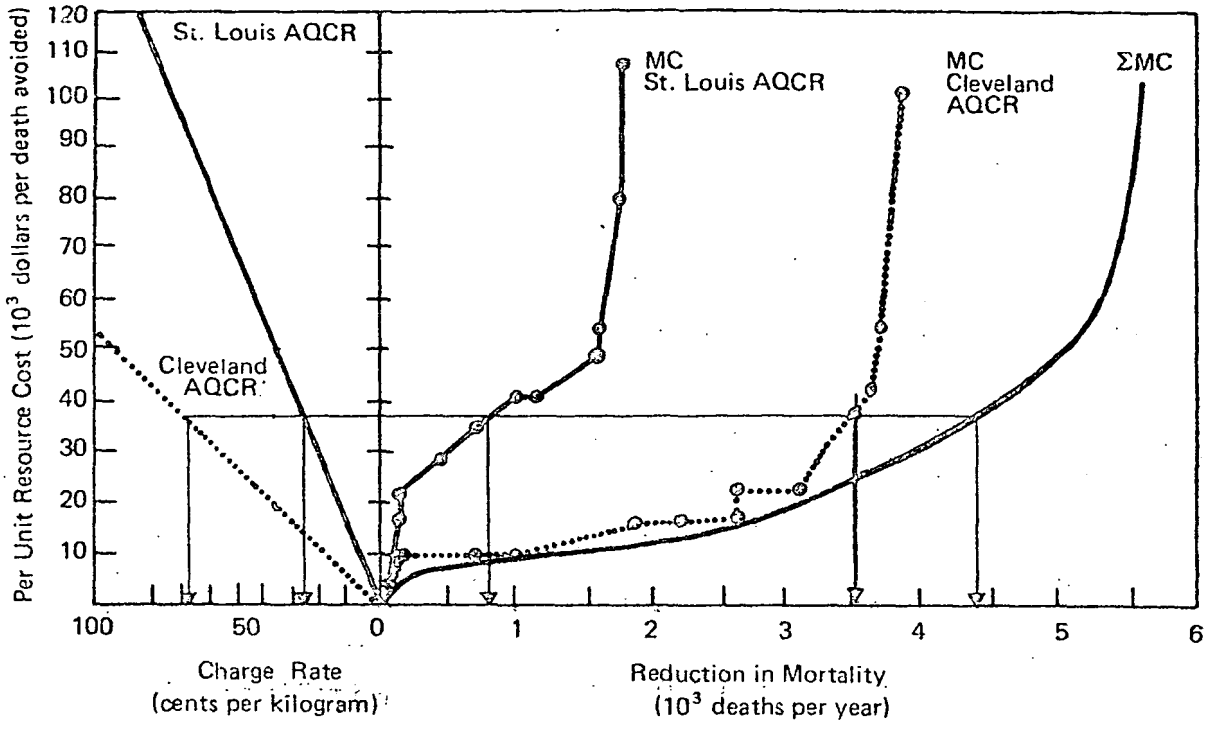


Figure 14. Resource cost of reductions in mortality. (Source: Research Triangle Institute)

Table 11. Allocative and distributive effects of an emission charge based on effects compared to emission standards*

	Emission reduction		Deaths avoided		Total costs (10^6 dollars per yr.)		Average costs (per death avoided)		Marginal costs (per death avoided)	Charge rate (cents per kg)†
	Percent	10^6 kg	Per 10^6 kg reduction	total	Aggregate resource	Net private	Aggregate resource	Net private	Resource	
Emission standards:										
St. Louis	54.8	163.0	7.02	1,163	49.5	25.2	$42,562	$21,668	n.a.	---
Cleveland	78.4	172.1	18.38	3,230	45.5	21.5	14,087	6,656	n.a.	---
Total	64.8	335.1	---	4,393	95.0	46.7	21,625	10,630	n.a.	---
Emission charge:										
St. Louis	41.4	123.3	7.02	869	19.9	32.0	22,900	36,823	36,482	26
Cleveland	87.3	191.7	18.38	3,524	42.7	30.5	12,117	8,655	36,482	67
Total	60.9	315.0	---	4,393	62.6	62.5	14,250	14,227	36,482	---

*These data are based on linear interpolations of the data in Appendix B.

†The emission charge in each region is chosen to meet two conditions: (a) that the marginal cost per death avoided is identical in both regions and (b) that the total number of deaths avoided is the same as estimated when the emission standards apply.

which are denominated in terms of the number of deaths avoided. For example, what are the comparable costs of meeting that policy objective using an emission charge approach? Figure 14 shows the charge rates that are required in each city to equalize the marginal cost per death avoided. The curve ΣMC shows that this objective would be achieved when the marginal cost per death avoided is approximately $36,500. The corresponding number of deaths avoided in St. Louis and Cleveland would be 869 and 3524, respectively. As the left quadrant shows, the desired emission abatement in each city would be induced by emission charge rates of 26 cents per kilogram in St. Louis and 67 cents per kilogram in Cleveland.

The lower half of table 11 shows the corresponding aggregate cost and emission detail for the effects-based emission charge approach. The first thing to notice is that the aggregate resource cost of meeting the same policy objective--4393 deaths avoided--is $32.4 million per year (or 34 percent) lower when an emission charge approach is used instead of emission standards. Overall, the average resource cost is reduced from $21,625 to $14,250 per death avoided. The corresponding reduction in St. Louis is from $42,562 to $22,900 per death avoided, and in Cleveland the average cost per death avoided is reduced from $14,087 to $12,117.

4.4.2 Distributive Effects

Three distributive factors are important when this effects-based emission charge is compared to an emission standard. These include the distribution of emissions, deaths avoided, and costs.

First, because of the equalization of marginal costs per death avoided in both cities, the overall percentage emission reduction under the effects-based emission charge falls from 64.8 percent to 60.9 percent. However, this overall decline aggregates the effects of a large decline in St. Louis, from 54.8 to 41.4 percent, a substantial increase in Cleveland, from 78.4 to 87.3 percent. The obvious implication, under the assumption that the application of emission standards just meets the air quality standards, is that air quality would be worse than the standards in St. Louis and better in Cleveland when a least cost approach is used to achieve the same aggregate reduction in the mortality rate implied by the application of the emission standards.

This alteration in regional emission rates also naturally implies mortality rate changes. It is cost effective, assuming an equal value is placed on a death avoided regardless of geographic location, to avoid more deaths in

Cleveland (3524 instead of 3230) and fewer in St. Louis (869 instead of 1163) if the policy goal of 4393 deaths avoided is held constant.

It is important to point out, however, that if policymakers were willing to commit the same aggregate level of resources under the effects-based emission charge as under the standards, i.e. $95 million/annually, at least as many deaths, 1163, could be avoided in St. Louis and more than 3524 could still be avoided in Cleveland.

Unfortunately the final negative distributional feature of the emission charge remains. Because of the emission charge transfers net private costs are higher than under the emission standards. Overall, the average net private cost rises from $10,630 to $14,227 per death avoided. This problem can be solved, however, with the novel emission charge approaches discussed in the following sections.

The reader is cautioned that the above analysis contains a number of simplifying assumptions. Further, the effects of sulfur emissions are not limited to health, nor are the health effects limited to mortality. However, the approach is illustrative of the application of cost and effects data and use of a policy instrument to achieve a given policy objective.

4.5 Emission Charge with an Exemption

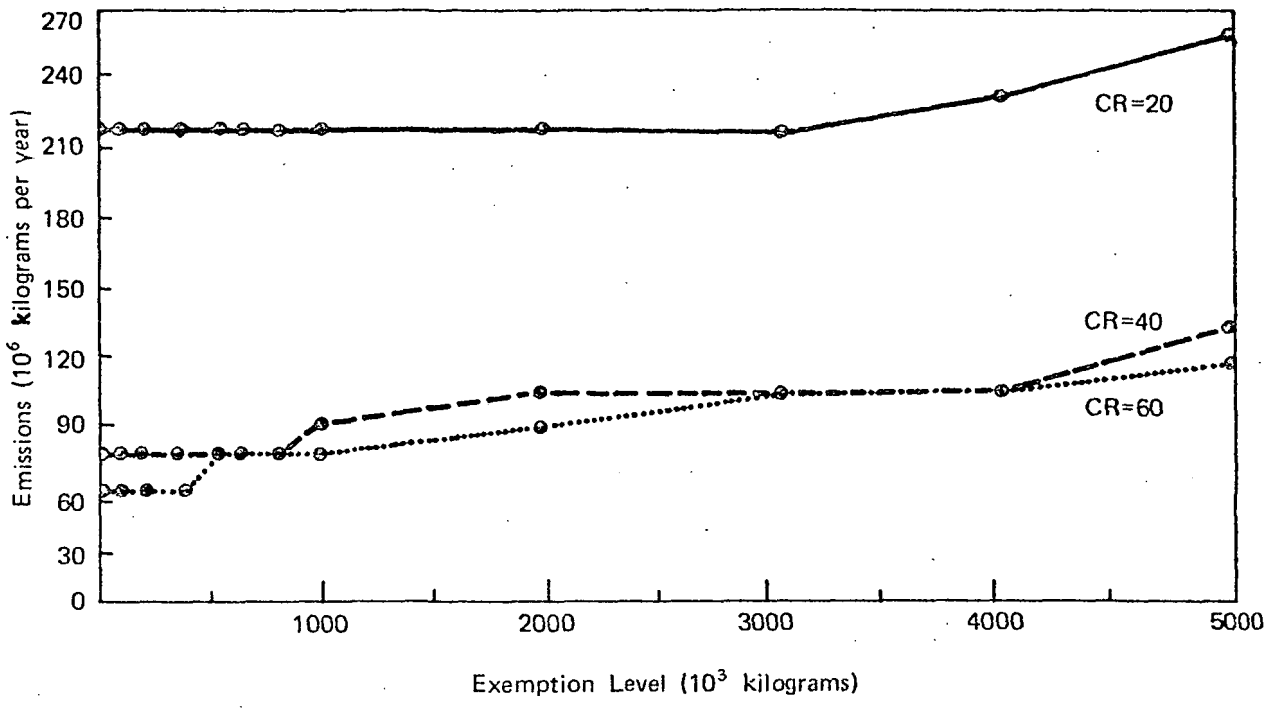
Emission charges are sometimes critized because the charge payments would result in income redistributions from emitters to the government. If the purpose of an emission charge were only to induce emission reductions then exempting some emissions would reduce the charge payments.

For this analysis, several exemption levels (J) are simulated between 0 and 5,000 x (10^3) kilograms for three charge rates--20, 40, and 60 cents per kilogram. These exemption levels are applied on a point-by-point basis.

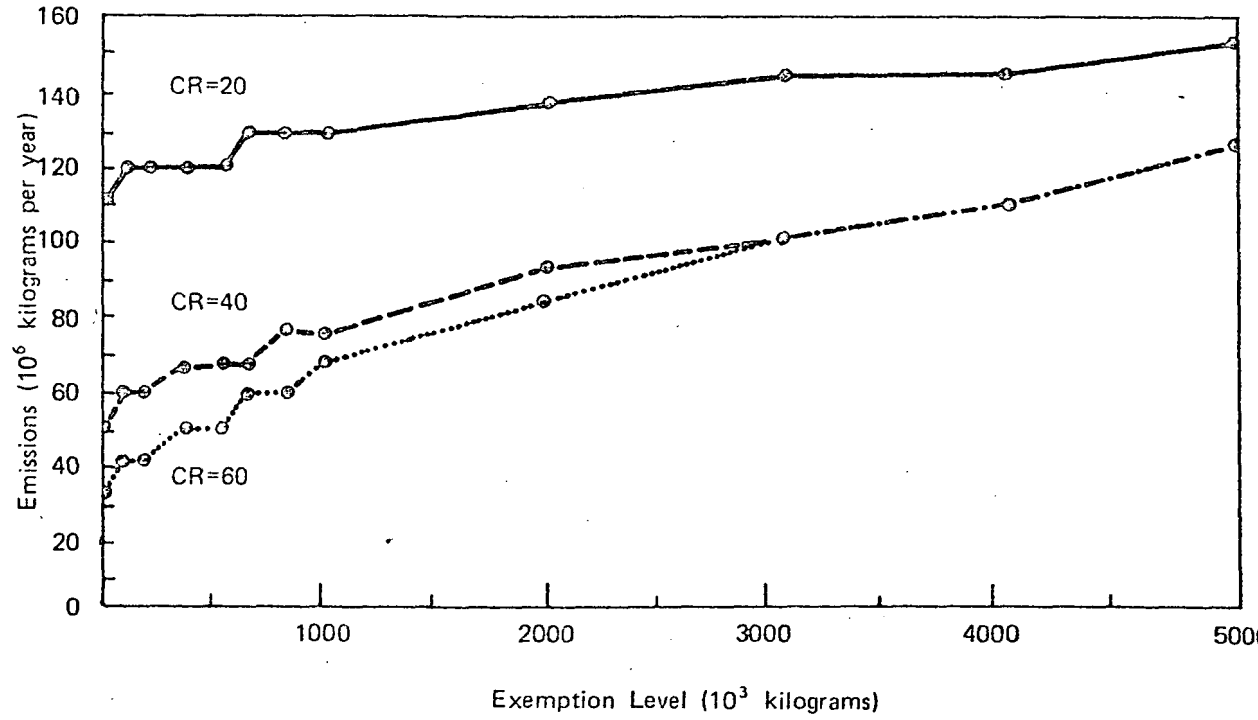
As shown in figure 15 (and in Appendix C, table C-1), these exemption levels have only a minimal impact on the effectiveness of the emission charge in inducing emission reductions. Larger exemption levels, however, would significantly erode the effectiveness of the emission charge.

4.5.1 Allocative Effects

As shown in figure 15 an increase in the exemption level, holding the charge rate constant, effectively relaxes the emission constraint and accounts for the accompanying emission rate increases. Specifically, this relaxation



a) St. Louis AQCR



b) Cleveland AQCR

Figure 15. Effectiveness of an emission charge with an exemption. (Source: Research Triangle Institute)

of the emission constraint results because increases in the exemption level allow more small emitters to avoid all emission constraints. (In terms of figure 8 the intersections of the abatement cost curves and the horizontal axis for small emitters occurs at emission rates which are less than the exemption level, J.) Exemption level increases are likely to drop the effective marginal charge rate to zero for small emitters and, hence, to increase regional emissions since the marginal charge rate does not change for other, larger emitters.

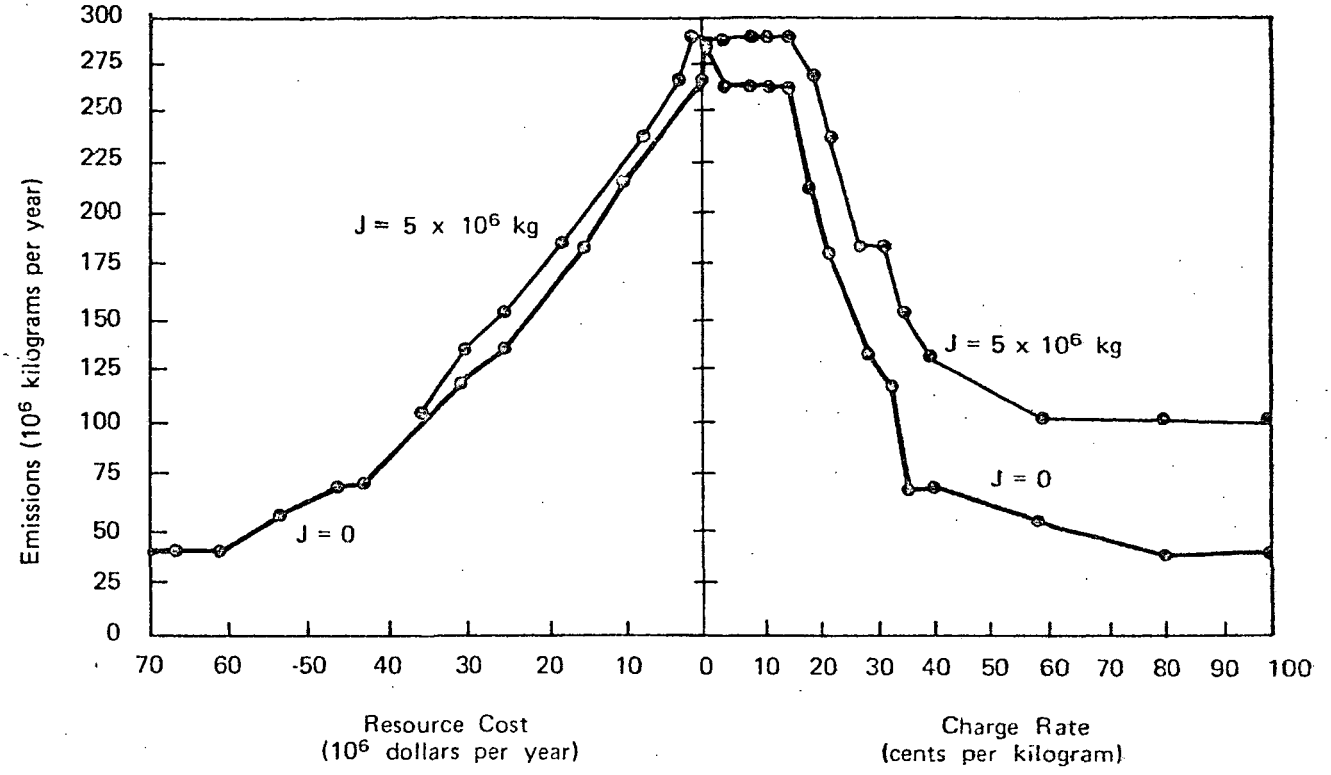
Figure 16 shows the resource costs and emission rates associated with the two extreme exemption levels--zero and 5×10^6 kilograms per year--at various charge rates. An increase in the exemption level at a constant charge rate obviously decreases aggregate resource costs as emissions rise. For example, in figure 16a), at a charge rate of 40 cents per kilogram, emissions are about 66 and 46 $\times 10^6$ kilograms per year at exemption levels of zero and 5×10^6 kilograms, respectively, in St. Louis. The corresponding aggregate resource costs fall from about \$47 to \$31 $\times 10^6$ per year, respectively.

However, at a constant emission rate, the average resource cost per kilogram of emission reductions increases with the exemption level. For example, resource costs would fall from about \$31 to \$29 $\times 10^6$ dollars per year if an annual emission rate of 131 $\times 10^6$ kilograms were achieved with a 29 cent tax and no exemption rather than with a 40 cent tax with a 5×10^6 kilogram per year reduction (see figure 16a).

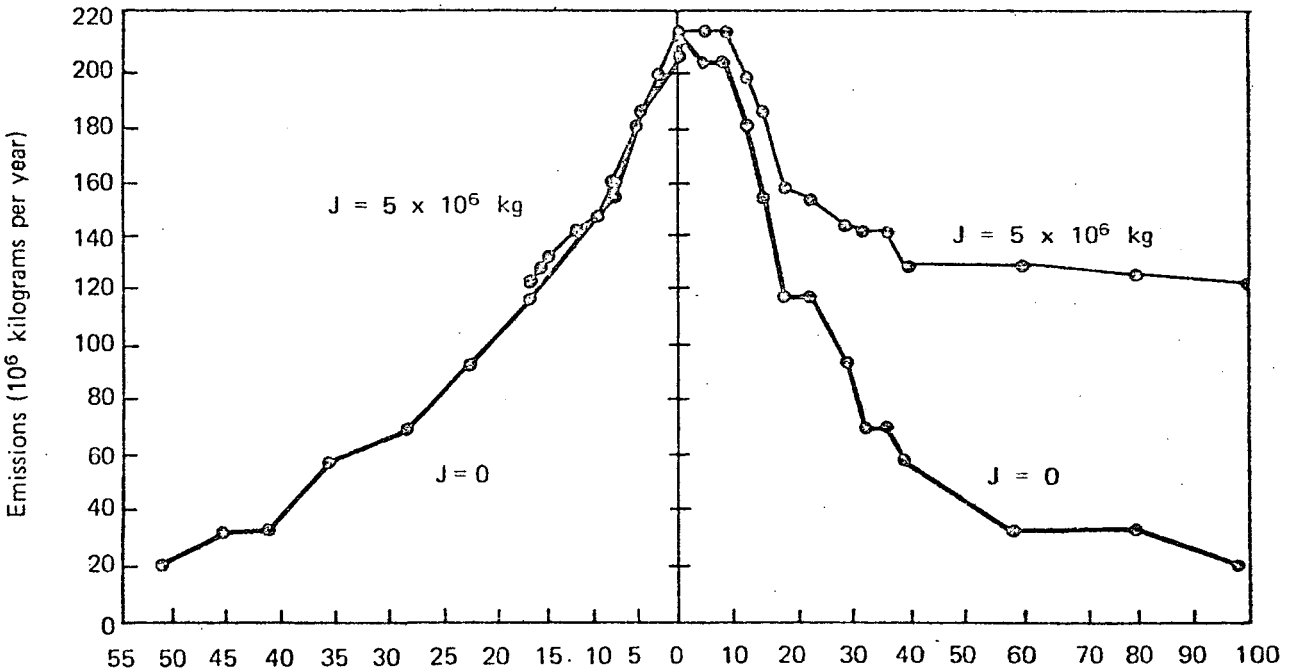
4.5.2 Distributive Effects

As expected, the private costs of an emission charge are significantly affected by the exemption (table C-3, figures 17 through 19). In particular, charge payments are reduced (figure 19) since some sources are exempted outright while all others would have lower payments for any charge rate.

As an illustration of the magnitude of the trade-off between the resource cost penalty and the savings in net-private costs, it is interesting to observe that, at a 29 cent tax without an exemption, net private costs are about \$34.4 $\times 10^6$ per year while at a 40 cent tax with a 5×10^6 kilogram exemption they are about \$21.9 $\times 10^6$ per year. This represents a 36 percent decrease in net private costs at the same emission level. However, the corresponding increase in resource costs from \$29 to \$31 $\times 10^6$ per year is only about seven percent.

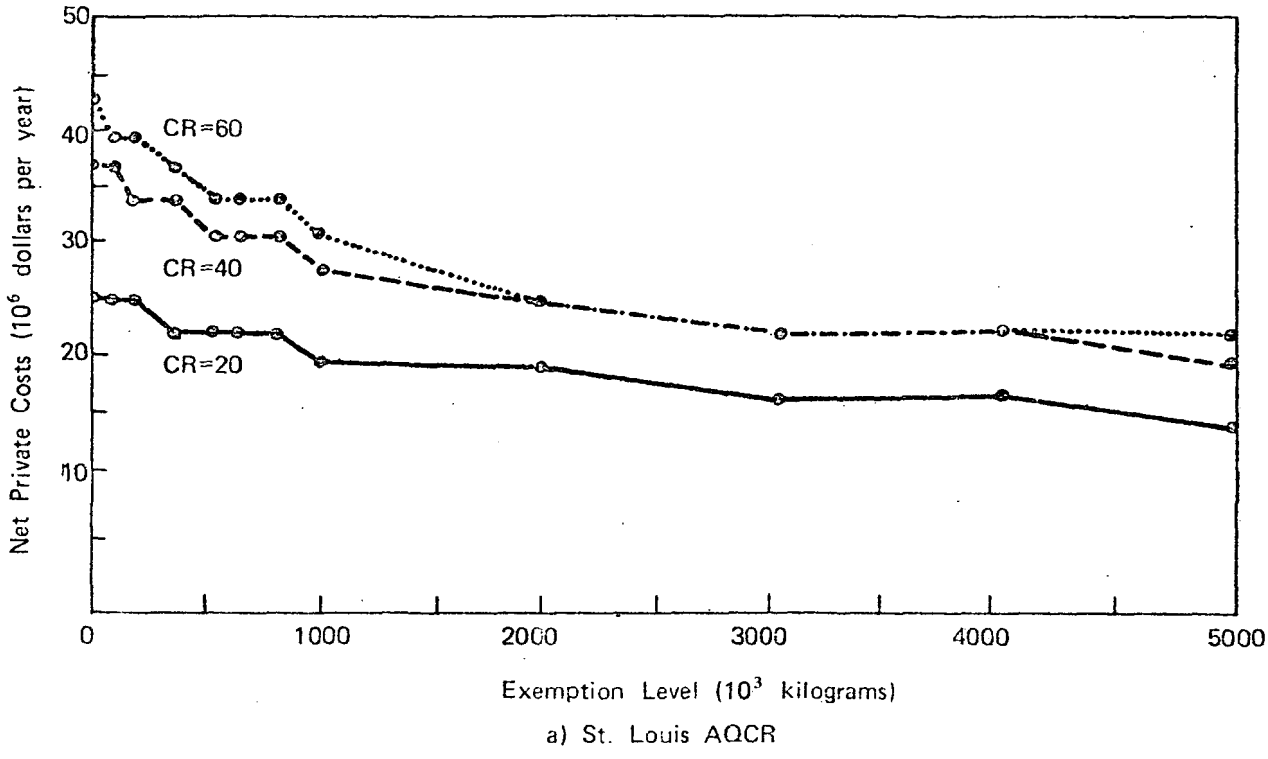


a) St. Louis AQCR

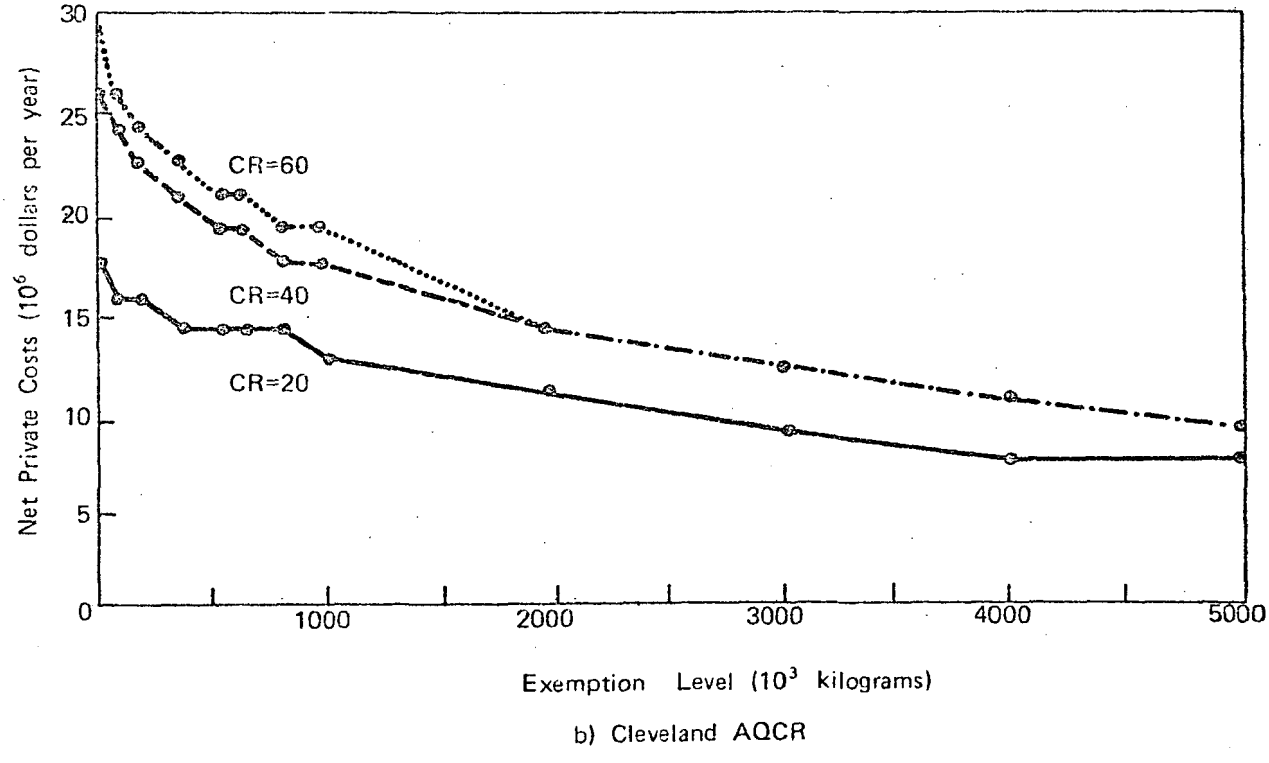


b) Cleveland AQCR

Figure 16. Resource cost and effectiveness of an emission charge with an exemption.
(Source: Research Triangle Institute)

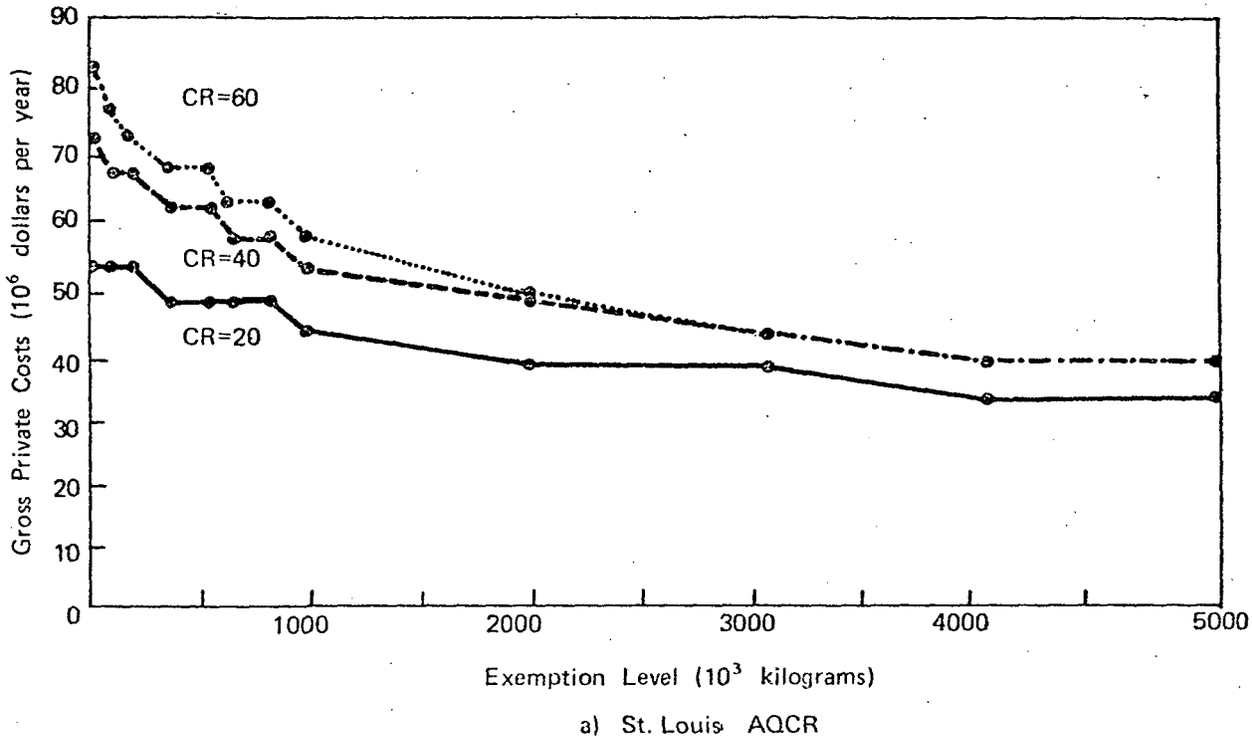


a) St. Louis AQCR

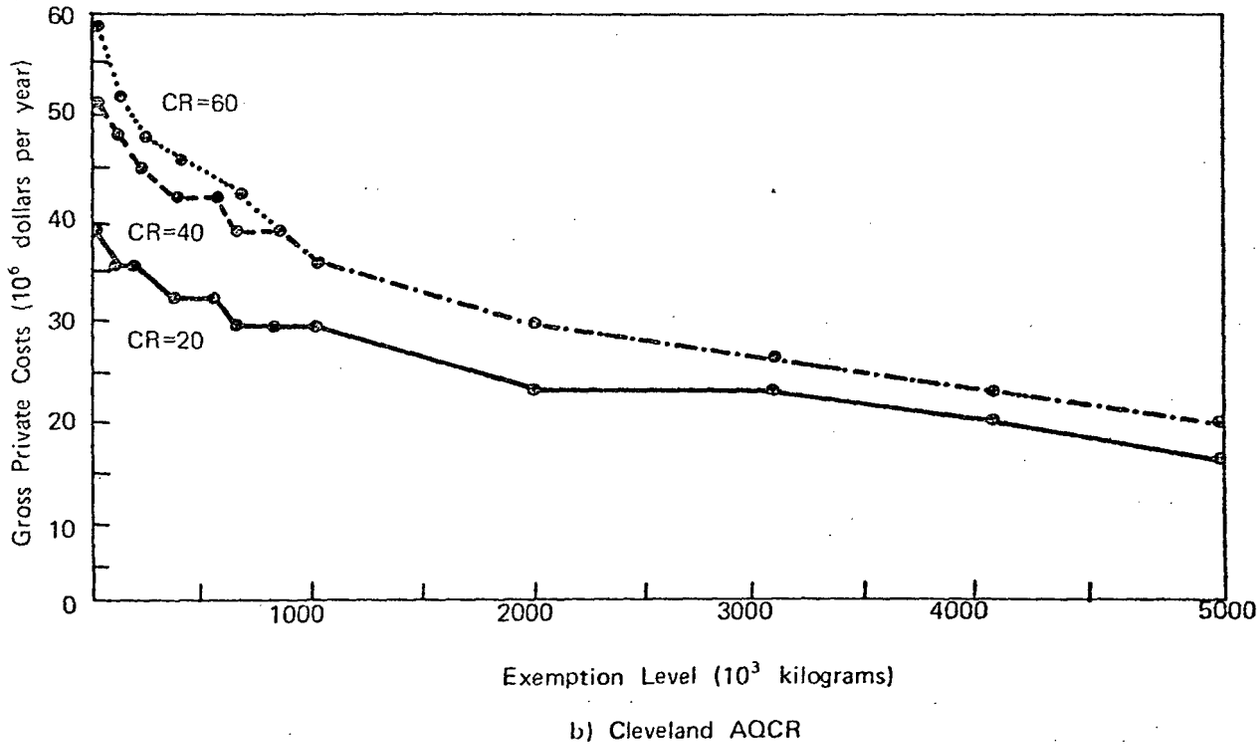


b) Cleveland AQCR

Figure 17. Net private costs of an emission charge with an exemption. (Source: Research Triangle Institute)

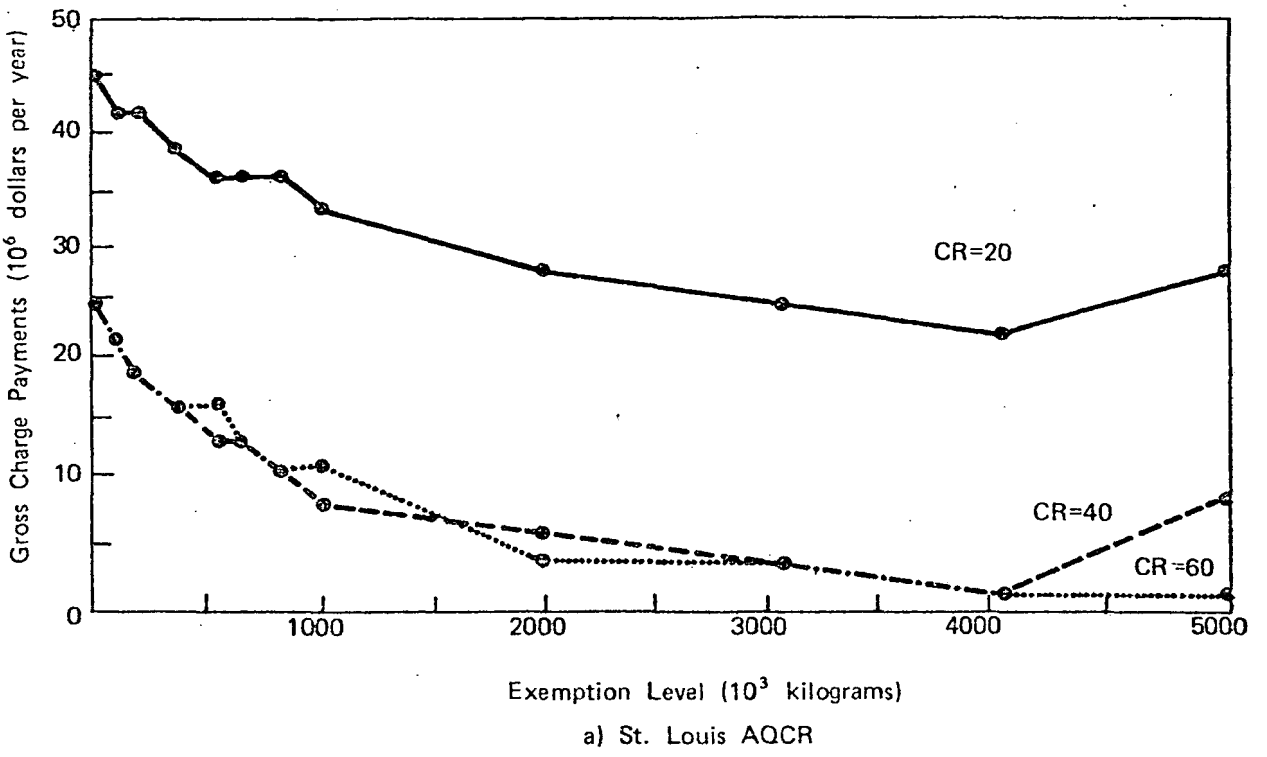


a) St. Louis AQCR

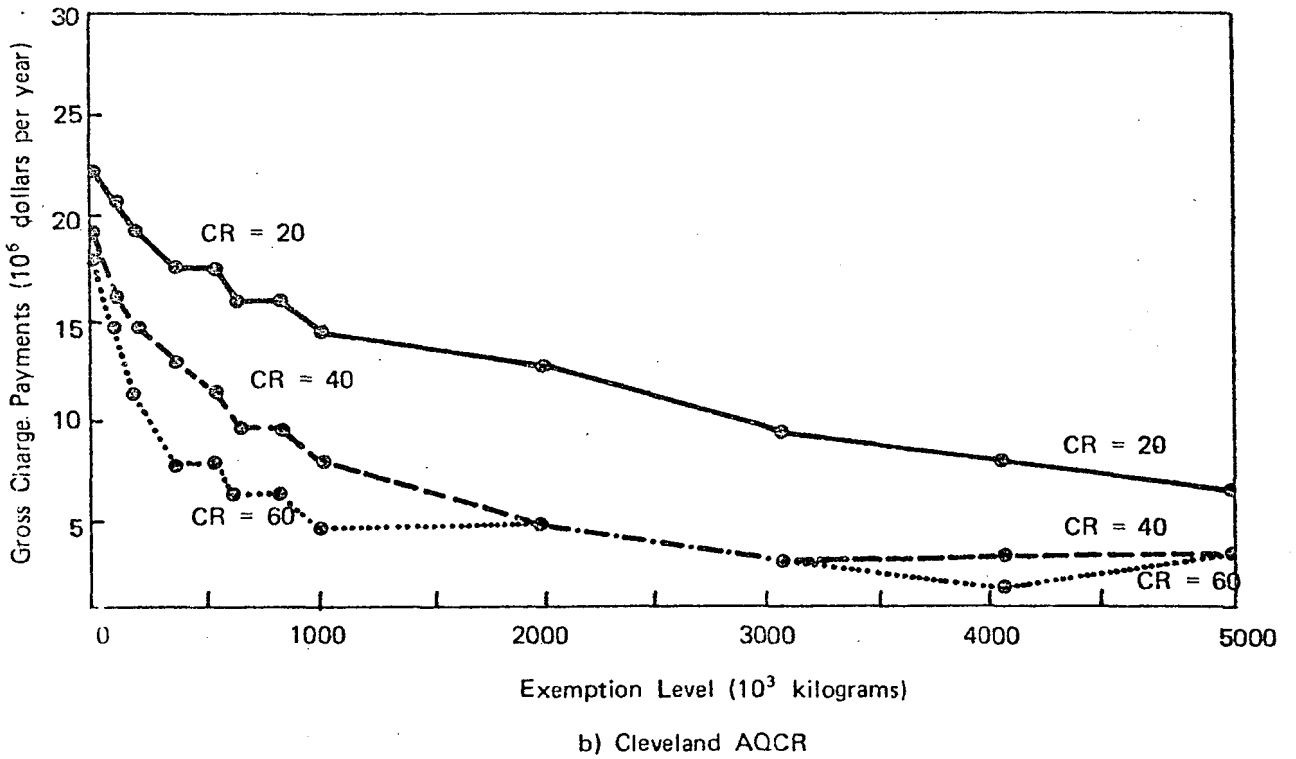


b) Cleveland AQCR

Figure 18. Gross private costs of an emission charge with an exemption. (Source: Research Triangle Institute)



a) St. Louis AQCR



b) Cleveland AQCR

Figure 19. Charge payments of an emission charge with an exemption. (Source: Research Triangle Institute)

4.6 Emission Charge with a Subsidy

The emission charge with a subsidy is a novel emission abatement approach that either charges or subsidizes emitters depending on their emission rates. Charge payments, TCP, are computed with the formula TCP = CR(E-K), where CR is the charge rate, E is the emission rate, and K is the breakeven parameter. Thus, sources emitting less than K annually would receive a subsidy equal to CR(K-E). Sources emitting more than K annually would have a charge payment to CP(E-K).

Selection of the appropriate value for K is a distributional, hence political, issue. For this analysis, four values, expressed in 10^3 kilograms of sulfur emissions, have been chosen: 50, 100, 150, and 200.

4.6.1 Allocative Effects

Since, for any given emissions charge rate, changes in the parameter K cause only vertical shifts in the minimum total cost function, the emissions and the allocative efficiency associated with the uniform emission charge (discussed in section 4.3 above) are not affected by the incorporation of a subsidy. The distributive effects, however, are altered by the subsidy.

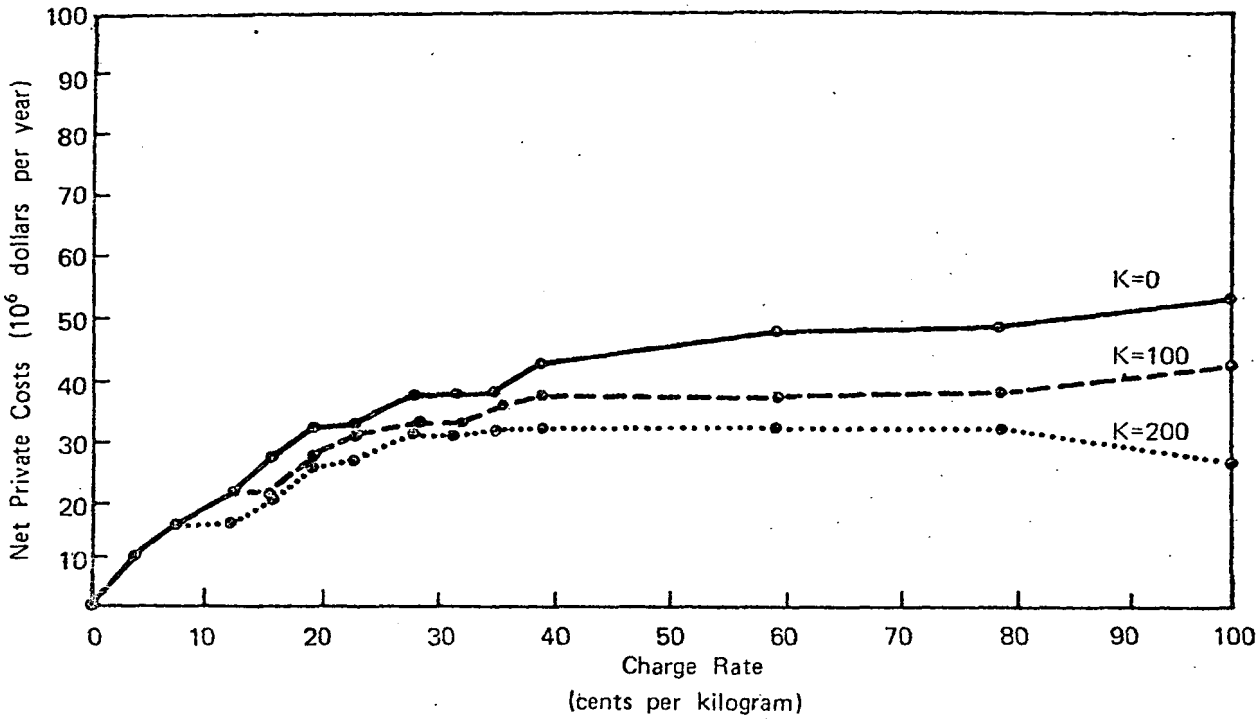
4.6.2 Distributive Effects

Incorporation of the subsidy reduces the charge payments for all sources with emissions greater than K. Sources with emissions less than K would receive a payment from the government. The result is that charge payments, hence total private costs, are reduced below those projected with the emission charge. Judicious selection of the value for K could reduce net transfers between the aggregate of all sources combined and the government to zero. However, redistributions among sources would still occur.

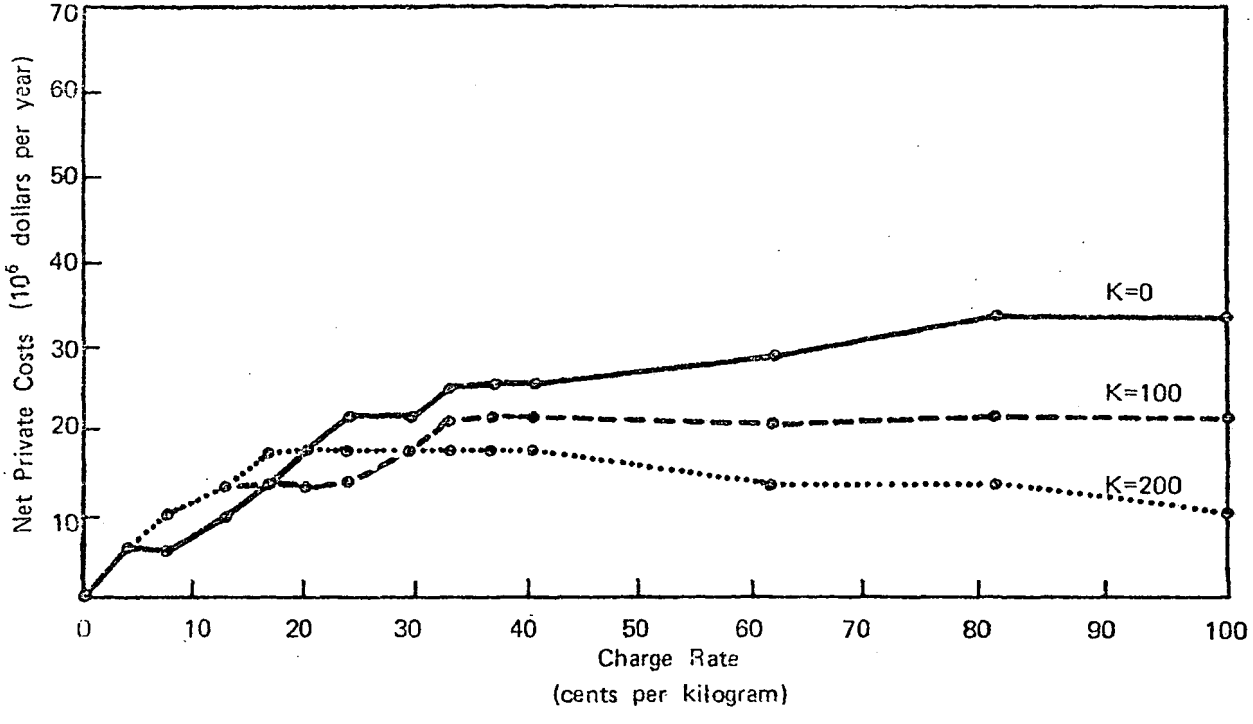
As shown in figures 20 through 22 (and in Appendix D, table D-1), increases in the value of K reduce the private costs of an emission charge. For high values of K and emission charge rates, the net charge payments even become negative.

4.7 Hybrid Program

Combining price incentives with direct controls could provide a ceiling on emission rates as well as a continued incentive for emitters to reduce their emissions still further. A large number of potential combinations of direct control and price incentives are conceivable. Here one possibility is examined--combining emission standards and charges.

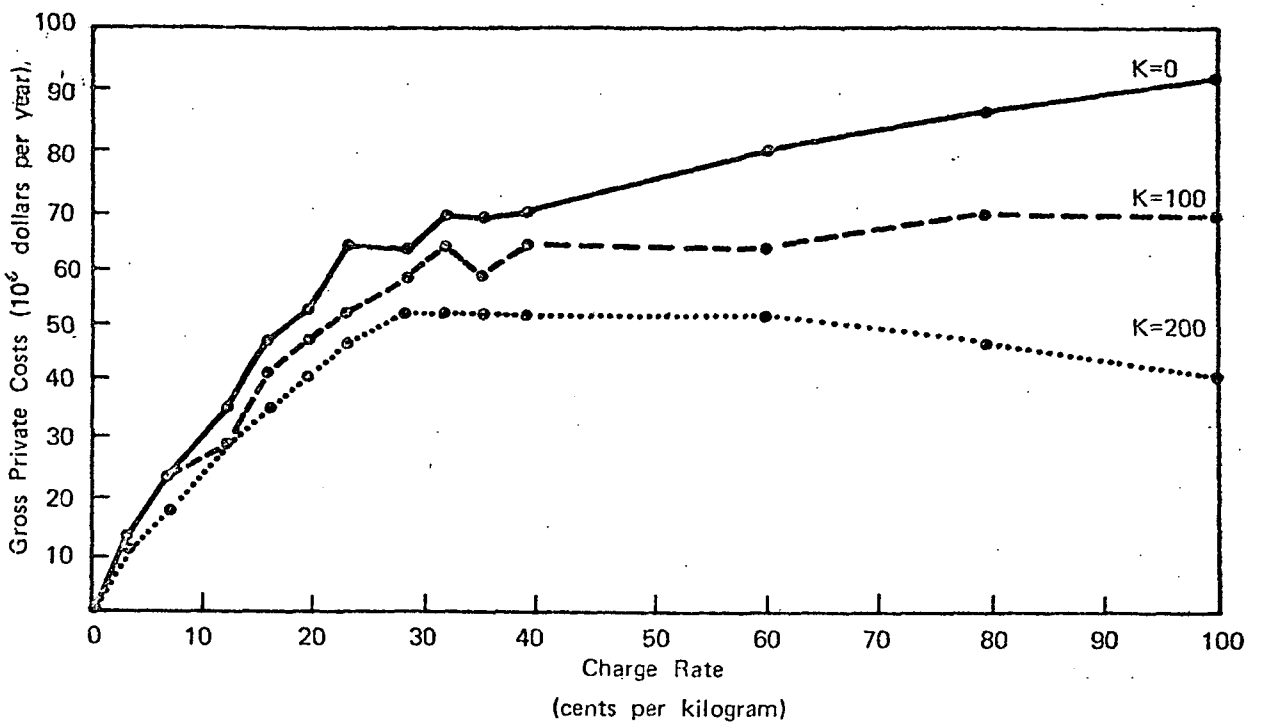


a) St. Louis AQCR

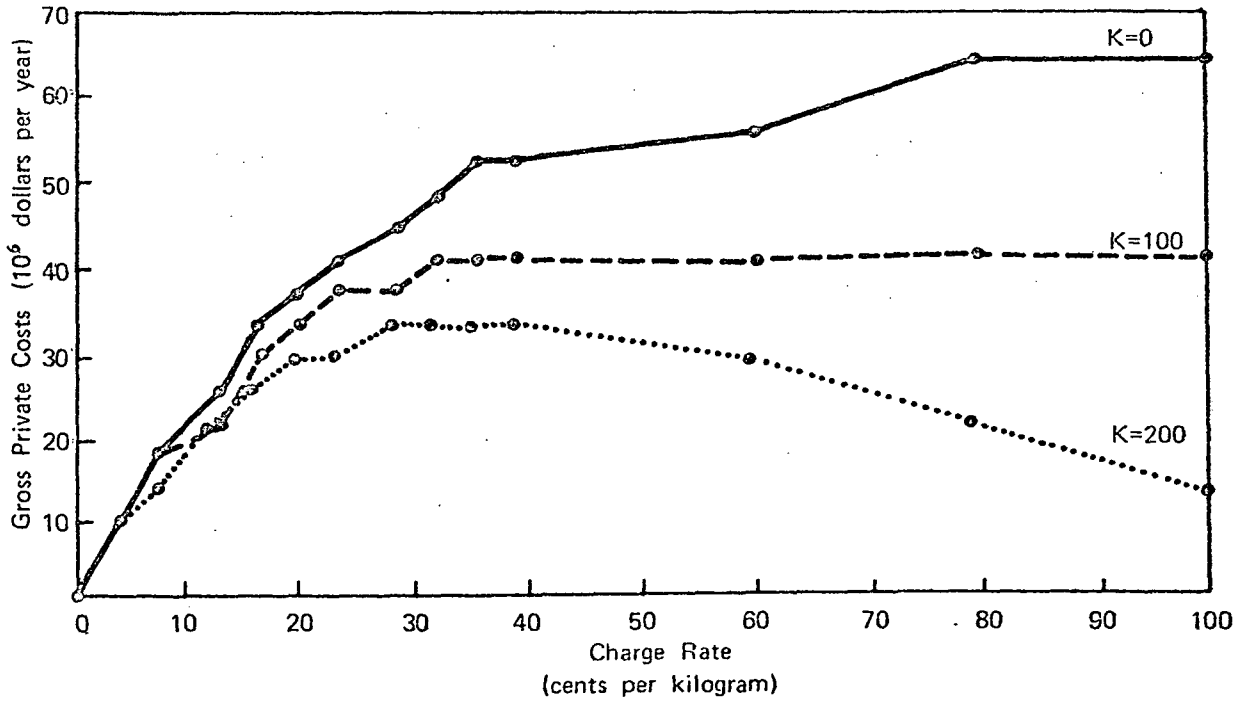


b) Cleveland AQCR

Figure 20. Net private costs of an emission charge with a subsidy. (Source: Research Triangle Institute)

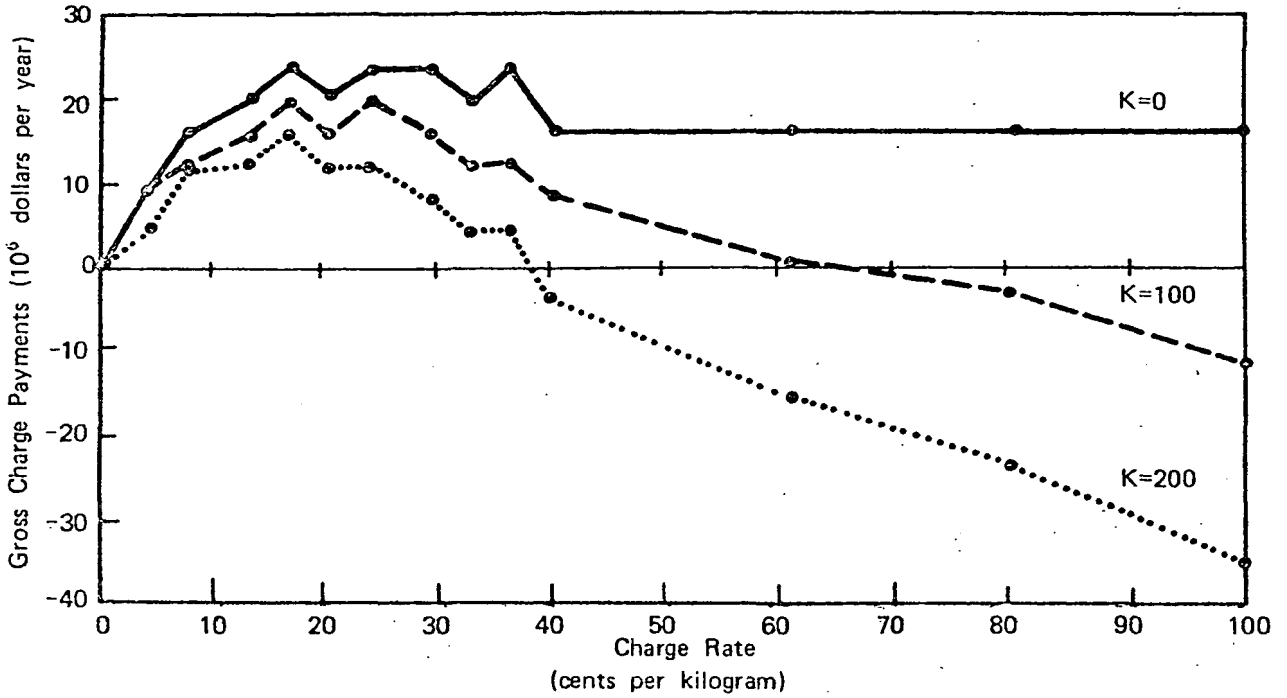


a) St. Louis AQCR

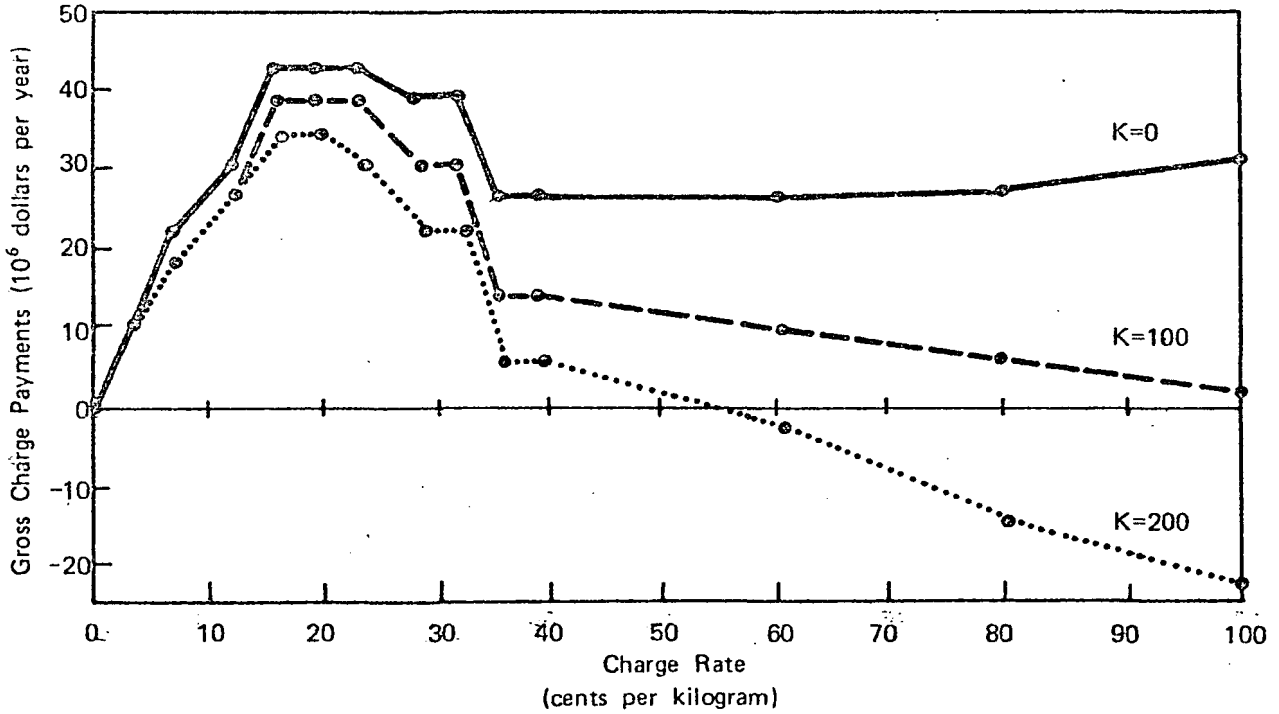


b) Cleveland AQCR

Figure 21. Gross private costs of an emission charge with a subsidy. (Source: Research Triangle Institute)



b) Cleveland AQCR



a) St. Louis AQCR

Figure 22. Charge payments of an emission charge with a subsidy. (Source: Research Triangle Institute)

Emission charges could be imposed along with existing emission standards. Or, because the standards may already incorporate the requirement for a high level of emissions control, the standards may be relaxed by some proportion (β). Below, the effects of three values for β are simulated--1.0, 0.8, and 0.6--and compared against the emission charge along ($\beta = 0$). Because of the limited number and high efficiencies of the abatement alternatives included in the model, the industrial process sources are not affected by the values of β chosen for analysis. Fuel combustion sources, however, are affected.

As can be seen in figure 23, lowering the value of β requires higher emission charge rates to induce the same level of abatement. For example, at a β value of 0.6, a charge of 28 and 40 cents per kilogram would be required in the St. Louis and Cleveland AQCR's, respectively, to achieve the emission rate of the standards.

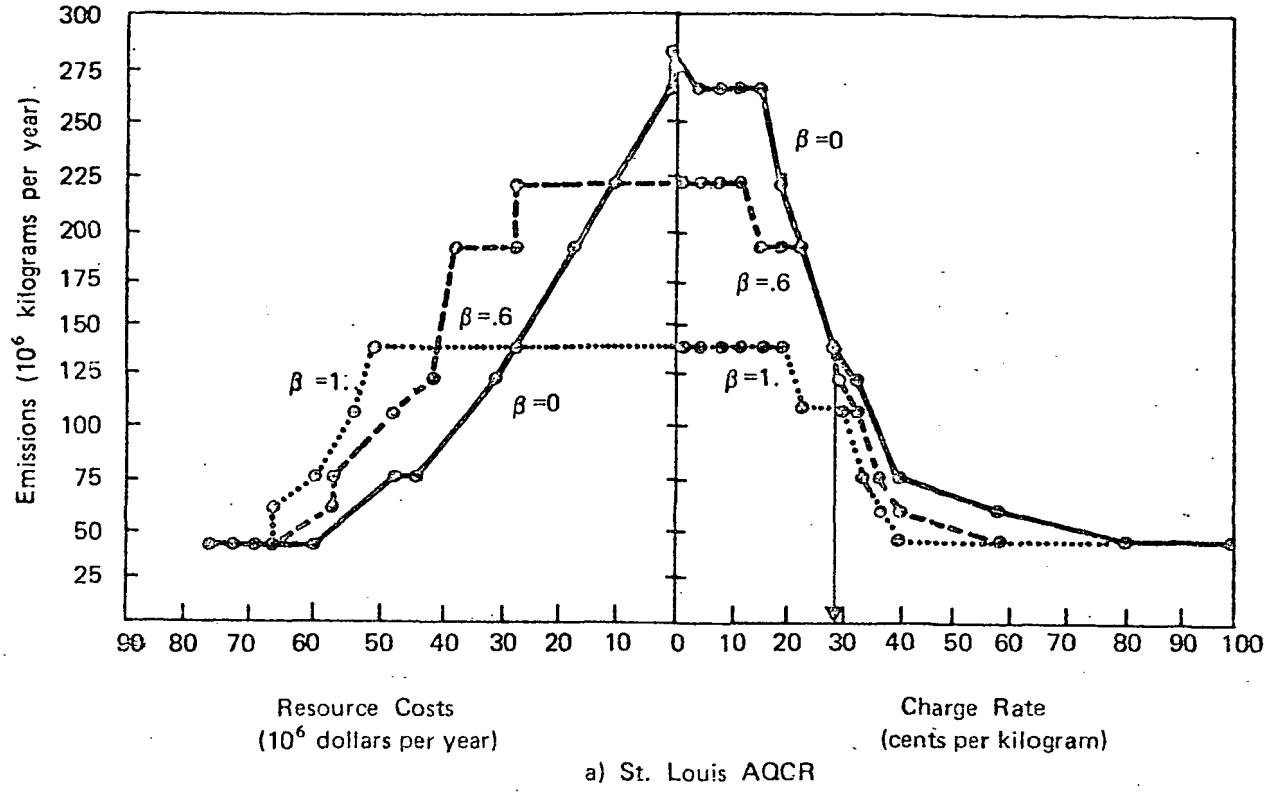
4.7.1 Allocative Effects

Since emission standards are estimated to impose some extra resource costs on society, lowering β and raising the charge rate to the point where the emission rates under the emission standards are obtained results in reductions in the resouce costs. Again, using the above example ($\beta = 0.6$, charge rates of 28 and 40 cents) the savings in resource costs by relaxing the standards and imposing a charge would amount to \$8 and \$4 x 10^6 annually in the St. Louis and Cleveland AQCR's respectively (figure 24). These savings are roughly 16 and 9 percent of the cost of emission standards in St. Louis and Cleveland as discussed in section 4.2 above.

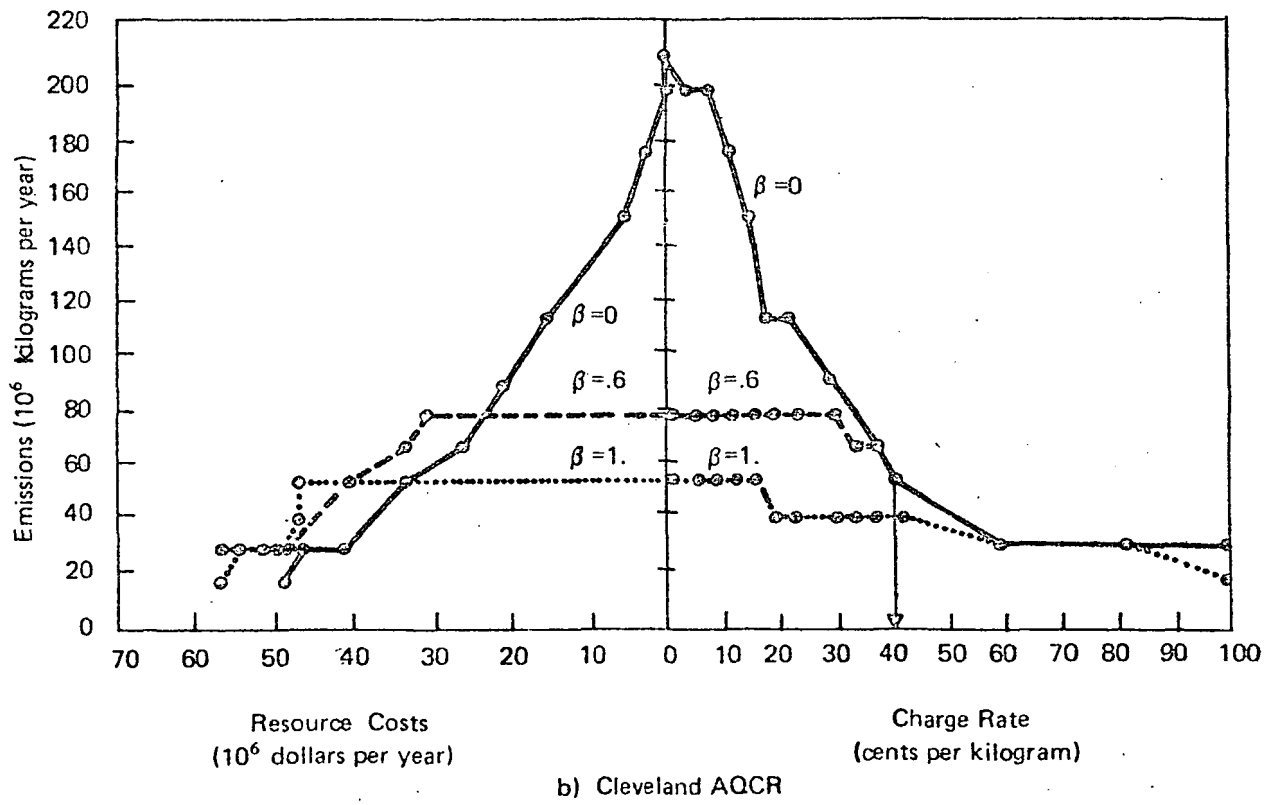
4.7.2 Distributive Effects

Figure 24 can be used to illustrate the effect of changes in β and the charge rate on net private costs. For example, assume the policymaker wishes to relax the standards by 40 percent, i.e., $\beta = .6$. From figure 23 it was apparent that the charge rates in St. Louis and Cleveland will have to be 29 cents and 40 cents, respectively, to achieve the same emission reductions as the standards alone. In figure 24 it is clear that this policy raises net private costs by about \$14 and \$8 x 10^6 (28 and 17 percent) annually. In fact, when $\beta = .6$ net private costs are above those of standards alone for all charge rates above 12 cents in St. Louis and 19 cents in Cleveland (see figure 24).

In general, relaxing the emission standards and imposing emission charges increases private costs over those for emission standards alone. For example,

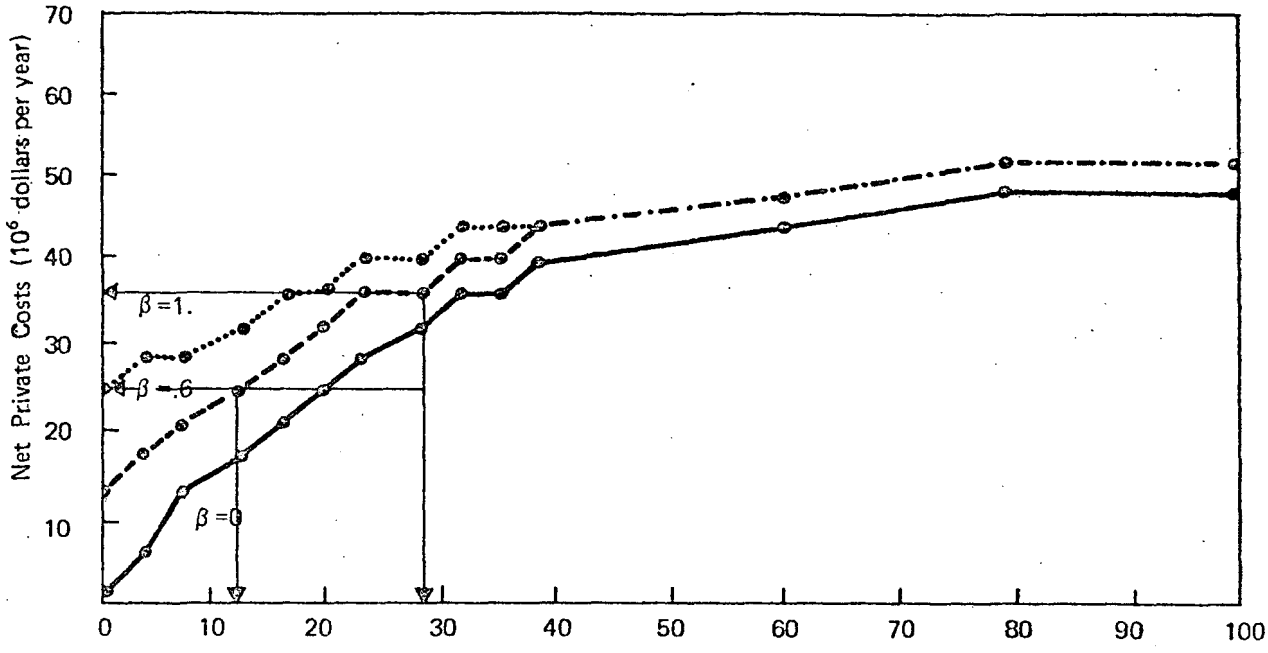


a) St. Louis AQCR

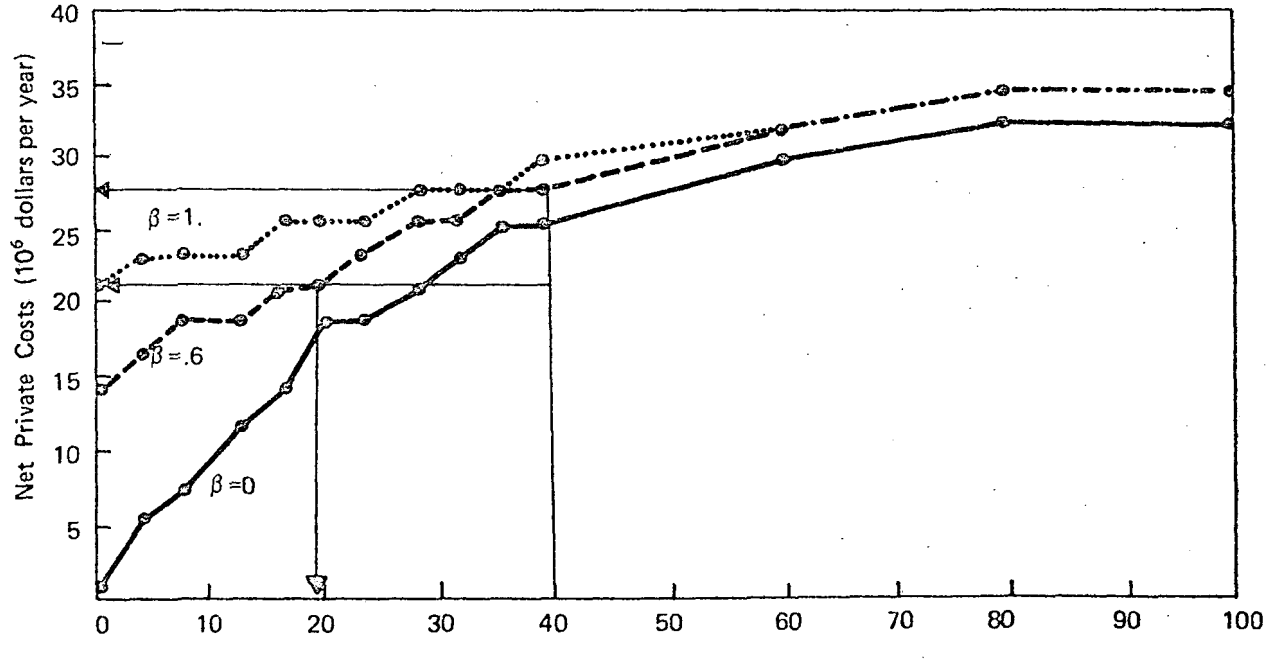


b) Cleveland AQCR

Figure 23. Resource costs and effectiveness of emission standards and charges combined.
(Source: Research Triangle Institute)



a) St. Louis AQCR



b) Cleveland AQCR

Figure 24. Net private costs of emission standards and charges combined. (Source: Research Triangle Institute)

as shown in figure 25, the gross private costs of a uniform tax alone ($\beta = 0$) exceed those of emission standards alone ($\beta = 1$) for any charge rate above 20 cents in the St. Louis region and above 29 cents in the Cleveland region. Yet the emission rate reductions implied by the standards are not achieved until the charge rate is raised to 29 cents and 42 cents for $\beta = 0$ in St. Louis and Cleveland respectively. The portion of gross private costs represented by charge payments are shown in figure 26.

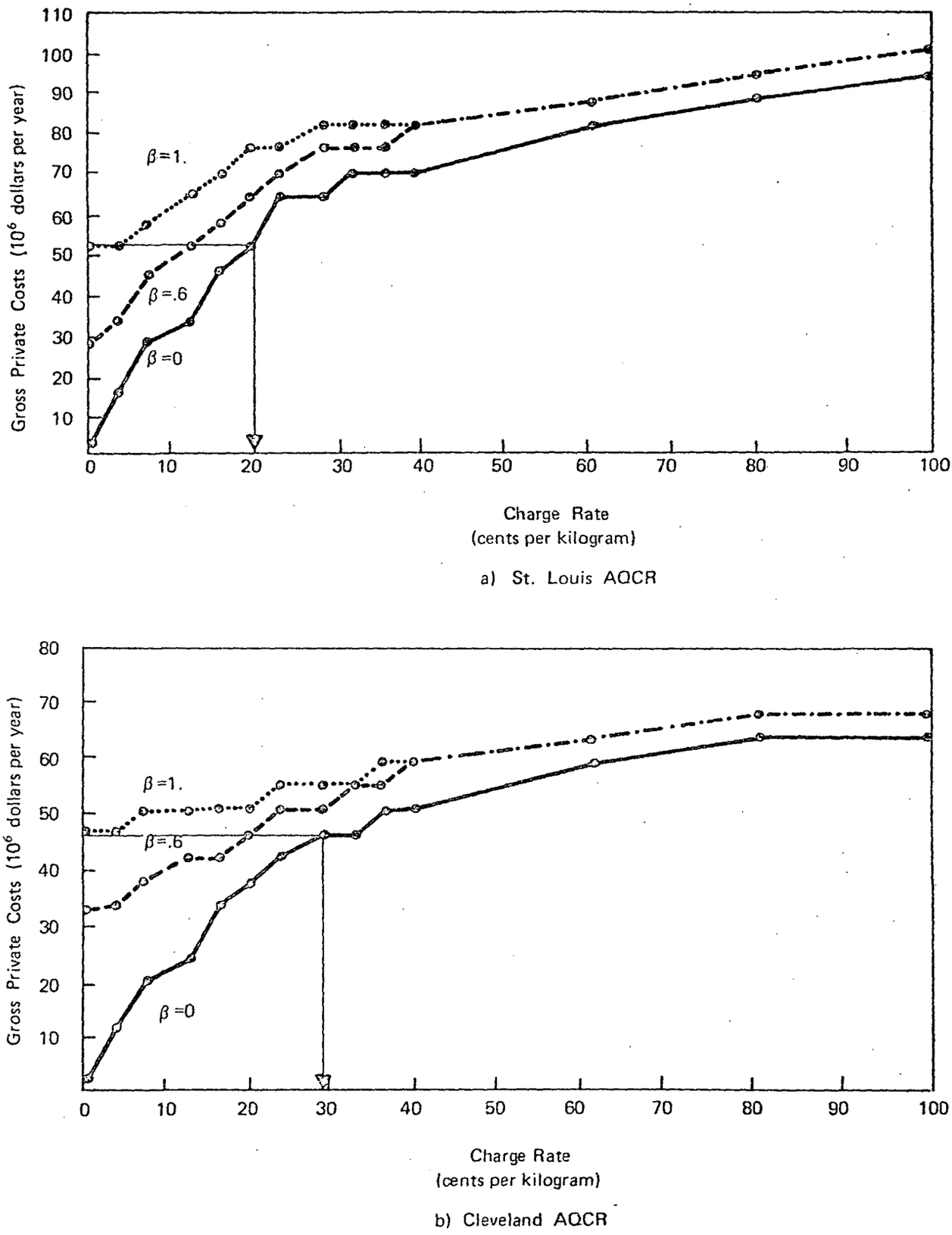


Figure 25. Gross private costs of emission standards and charges combined. (Source: Research Triangle Institute)

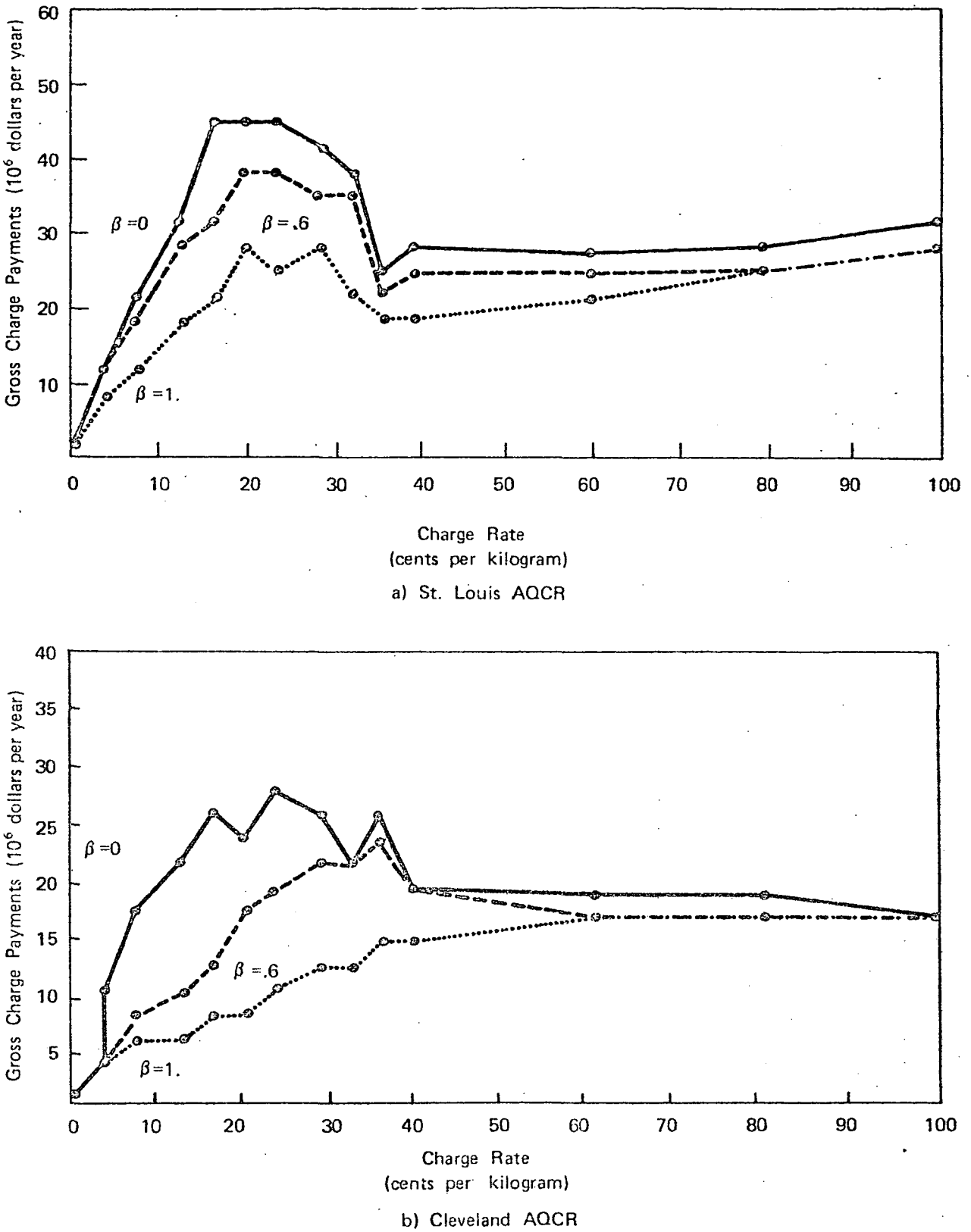


Figure 26. Charge payments of emission standards and charges combined. (Source: Research Triangle Institute)

Appendix A: SULFUR EMISSION ABATEMENT COSTS

Appendix A: SULFUR EMISSION ABATEMENT COSTS

A.1 Introduction

For purposes of estimating the behavior of sulfur emitters under alternative policy instruments abatement cost functions are needed. This appendix sets forth the abatement costs and efficiencies associated with the various abatement options available, or projected to be available in the late 1970's, to fuel combustion sources and the major industrial process sources of sulfur emitters.

Abatement costs are divided into two broad components-initial capital outlays and annually recurring variable cost.

A.2 Fuel Combustion

Sulfur emissions from fossil fuel combustion--principally coal and oil--can be abated by substitution of low sulfur fuels and by desulfurization of stack gases emitted to the atmosphere.

A.2.1 Fuel Substitution

Sulfur is a naturally occuring constituent of fossil fuels. Sulfur emissions from fossil fuel combustion are in direct proportion to the sulfur content of the fuels (usually expressed as a percent by weight). Distillate and residual oils are assumed to weigh 0.82 and 0.96 kilograms per liter (6.83 and 8.00 pounds per gallon) respectively. The sulfur content of gas is negligible, however, both coal and oil combustion typically result in the emission of large quantities of sulfur oxides to the atmosphere.

The sulfur content of coal and oil varies due to the geologic circumstances of their formation and when the fuels are processed. Most coal is "cleaned" prior to being marketed. This process results in the removal of the inorganic (pyritic) sulfur. Currently there is no economically feasible way of removing the organic sulfur which usually represents about 50 percent of the total sulfur content. The supply of low-sulfur coals is, therefore, currently highly dependent upon the natural availability of low-sulfur coals. Oil, however, can be desulfurized, although refinery capacity is limited.

Most low-sulfur eastern coal reserves are coking coals owned by the steel industry. These coals carry a price premium over other coals. Large reserves of low-sulfur coals are available in the western United States. However, low extraction costs (since they are subject to strip-mining) are more than

offset by the high transportation costs required to deliver these coals to markets in the more populous East. These transportation costs are high due not only to the long distances involved but also because Western coals have lower heat contents (Btu's per pound) than coals found in the East.

The result of these supply conditions plus probable outward shifts in the demand for low sulfur fuels due to emission regulations has resulted in a structure of delivered prices for coal and oil where price (in dollars per Btu) is inversely related to the fuel sulfur content (in percent).

By using FPC form 423 data, an equation of the following form was fitted to 1972-73 coal and oil fuel purchase data for steam electric power-plants:

$$P = e^{a}S^{b} \qquad \text{(A-1)}$$

where

P = delivered fuel price in cents per 10^6 Btu,

S = sulfur content of the fuel,

a, b = parameters.

The result provided one statistically significant equation for both the St. Louis and Cleveland AQCRs, combined in the case of residual oil, and for each AQCR for coal. Because of the successful cartelization of Mideast oil-producing nations, however, the historical (i.e., 1972-73) data used to fit the equations was not considered to be an accurate representation of postcartelization fuel prices. Since some incomplete postcartelization price data was available, it was decided to use that data to shift the entire price schedules. Accordingly, the intercept of the coal price equation was increased using the percentage change in the wholesale price index for coal from the 1972-73 period to the first quarter of 1974. The midcontinent, first quarter 1974 price of 0.3 percent residual oil, as reported in the Oil and Gas Journal, was used to shift the oil price equation until it intersected with the reported value. It is recognized that the resulting equations provide only a rough first approximation of the actual prices fuel combustion sources face in the two AQCRs. Further, these exogenously introduced price schedules are relevant only if we assume all emission sources are price-takers. A priori, this assumption does not seem unreasonable given the national character of the fuels market, and the small share of that market which the fuel combustion sources in the two AQCRs represent.

The resulting equations used in the model were:

for residual oil

$$P_1 = (66.954)S^{-0.216} \quad \text{(A-2)}$$

for coal in the St. Louis AQCR

$$P_2 = (47.276)S^{-0.392} \quad \text{(A-3)}$$

for coal in the Cleveland AQCR

$$P_3 = (48.279)S^{-0.134}. \quad \text{(A-4)}$$

For utility boilers designed to burn both coal and residual oil, the only costs associated with interfuel substitution are those associated with the delivered prices of the fuels. In the case of boilers configured to burn only coal or residual oil, boiler conversion costs would be incurred to switch across fuels.

The available utility boiler conversion cost data is very incomplete. Further, the cost of boiler conversion for any particulate boiler is likely to vary significantly from that estimated using a generalized engineering equation, as plant and boiler parameters which affect conversion costs vary widely. Where boilers were previously converted from coal to oil or oil to coal, and where the previous fuels' storage and handling equipment are still available, conversion costs would be negligible. Converting boilers which have never previously burned the alternative fuel is likely to be substantially more expensive. Two simple boiler conversion equations have been developed for use in this analysis:

$$\text{coal to oil:} \quad C = 51{,}800\ (kW)^{0.65} \quad \text{(A-5)}$$

$$\text{oil to coal:} \quad C = 20{,}000\ (kW)^{0.65} \quad \text{(A-6)}$$

where

C = the capital investment,

kW = the rated capacity of the boiler in kilowatts.

Cost of industrial, commercial and institutional boiler conversion data is even less readily available. Again, a simple equation reflecting scale economics has been employed. In this case one equation for coal to oil and oil to coal conversion has been employed.

$$C = 12{,}000\ (BC)^{0.60} \qquad \text{(A-7)}$$

where

BC = boiler design capacity, 10^6 Btu/hr.

A.2.2 Stack-Gas Desulfurization

There are several candidate processes for removing sulfur oxides from stack gases in various stages of development and/or demonstration. Most processes are applicable to large (i.e., utility) boilers, however, and not small industrial, commercial or institutional boilers.

Three stack-gas desulfurization processes have been selected and costed for this analysis for utility boilers (table A-1). These processes represent both demonstrated technology and probable full-scale acceptance within the next 5 years.

The general form of the initial capital investment (C) and annually recurring variable (V) costs for all three processes applicable to steam-electric power plants is:

$$C = a\ b\ \left(\frac{kW \cdot P}{1000}\right)^{c} + d\ \left(\frac{HR \cdot S \cdot R \cdot kW \cdot P}{HV \cdot 1000}\right)^{f} \qquad \text{(A-8)}$$

$$V = g(FC \cdot S \cdot R \cdot P) + H\ \frac{kWh \cdot P}{8760} + iC + j(kW \cdot P) + k \qquad \text{(A-9)}$$

where

a, b, c, d, f, g, h, i, j, k = parameters of the processes,
kW = rated capacity, kW,
P = proportion of total stack-gas treated by the processes (always assumed to be 1),
HR = heat rate, Btu/kWh,
S = sulfur content of the fuel, decimal proportion,
r = removal efficiency of the processes, decimal proportion,
HV = heating values of the fuel, Btu/lb,
FC = fuel consumption, tons/year,
kWh = power generation, kWh/year.

The cost equations for each abatement alternative were developed from EPA cost studies (ref. 1), specific process cost estimates made by Catalytic, Inc.

(ref. 2) and by the Tennessee Valley Authority (ref. 3). The resulting equations apply to retrofit (i.e., existing) plants only.

The capital cost component of all three technologies represents economies of scale. That is, capital cost increase at a decreasing rate with respect to increases in boiler size. Table A-1 provides the parameter estimates for each abatement alternative.

Cost data for stack-gas desulfurization of industrial, commercial and institutional boilers is less available than for utility boilers although a number of processes are receiving attention. Because of its modular approach, which offers potential economies in shop fabrication of system elements, and the availability of data based on operating experience already gained in Europe and Japan, the Research Cottrell Bahco throwaway lime scrubbing system was selected and costed for this study.

The capital and variable cost equations developed are:

$$C = 11{,}600(BC)^{0.80} \qquad \text{(A-10)}$$

$$V = BC(8760)\ 0.0613 + 32{,}040\left(\frac{5}{HV}\right) + 0.06\ c \qquad \text{(A-11)}$$

where

BC = boiler capacity, 10^6Btu/hr.

Table A-1. Sulfur emission abatement cost for steam-electric utilities

Emission source	Abatement description	Alternative efficiency (R)	Abatement cost parameters									
			a	b	c	d	f	g	h	i	j	k
all coal- or oil-fired boilers	limestone scrubbing	0.85	1.7	51,700	0.85	950,000	0.67	24.16	2.08	0.06	0.20	60,000
	magnesia slurry scrubbing	0.90	1.7	51,700	0.85	1,195,000	0.67	21.59	2.15	0.06	0.16	200,000
	double-alkali	0.95	1.7	28,000	0.85	880,000	0.67	51.64	1.84	0.06	0.09	45,000

Source: Research Triangle Institute.

A.3 Industrial Processes

On a national basis, petroleum refineries, sulfuric acid plants and primary nonferrous smelters are significant sources of sulfur oxide emissions. Engineering cost estimates as developed for an earlier study (ref. 4) were used herein for these sources. In all cases, the resulting cost equations, tables A-2 through A-4, indicate significant scale economies.

Table A-2. Sulfur emission abatement cost for petroleum refineries

Emission source	Sulfur emission factor (pounds of sulfur per year)	Abatement alternative: Description	Efficiency	Recovered sulfur (proportion of abated emission)	Abatement cost (10^6 dollars): Investment	Variable
catalyst regenerator						
fluid cat cracker	$E_1 = 105(CCC^*)$	hydrodesulfurization of cat cracker feedstock	0.900	7.57	$I_1 = 1123.0(CCC^*)^{0.6471}$	$V_1 = 365.1(CCC^*)^{0.9283}$
thermofor and houdriflow cat cracker	$E_2 = 12(CCC^*)$	hydrodesulfurization of cat cracker feedstock	0.900	70.34	$I_2 = 1123.0(CCC^*)^{0.6471}$	$V_2 = 365.1(CCC^*)^{0.9283}$
fuel oil combustion	$E_3 = 24(CC^*)$	hydrodesulfurization of residual fuel oil	0.900	1.00	$I_3 = 105.9(CC^*)^{0.6224}$	$V_3 = 19.4(CC^*)^{0.9216}$
refineries without Claus plant	$E_4 = 260(CC^*)$	two-stage Claus plant	0.900	1.00	$I_{4_1} = 2777.5(CC^*)^{0.4669}$	$V_{4_1} = 88.2(CC^*)^{0.6275}$
		four-stage Claus plant	0.950	1.00	$I_{4_2} = 1989.9(CC^*)^{0.5117}$	$V_{4_2} = 93.2(CC^*)^{0.6328}$
		four-stage Claus plant with tail gas unit	0.995	1.00	$I_{4_3} = 3924.5(CC^*)^{0.5117}$	$V_{4_3} = 49.7(CC^*)^{0.7178}$
refineries with two-stage Claus plant	$E_5 = 26(CC^*)$	add two stages	0.950	1.00	$I_{5_1} = 11.9(CC^*)^{0.8010}$	$V_{5_1} = 8.0(CC^*)^{0.6546}$
		add two stages with tail gas unit	0.995	1.00	$I_{5_2} = 1598.7(CC^*)^{0.5441}$	$V_{5_2} = 3.7(CC^*)^{0.8365}$

*Where: CC = crude capacity, barrels per day; CCC = cat cracker capacity, barrels per day.

Source: Developed by Research Triangle Institute from data presented in:

1. Research Triangle Institute, Control Technology for Sulfur Oxide Pollutants, 2nd ed., November 20, 1972.
2. L. Aalund, "Hydrodesulfurization Technology Takes on the Sulfur Challenge," Oil and Gas Journal, September 11, 1972, p. 79.
3. B. B. Barry, "Reduce Claus Sulfur Emission," Hydrocarbon Processing, April 1972, p. 102.
4. "Characterization of Claus Plant Emissions," Preliminary draft of final report prepared for the Environmental Protection Agency by Process Research, Inc., Cincinnati, Ohio, September 1972.
5. Environmental Protection Agency, Compilation of Air Pollutant Emission Factors, Research Triangle Park, N.C., February 1972, pp. 9-1, 9-2.

Table A-3. Sulfur emission abatement cost for sulfuric acid plants

Emission source	Sulfur emission factor (pounds of sulfur per year)	Abatement alternative: Description	Efficiency	Recovered sulfur (proportion of abated emission)	Abatement cost (10^6 dollars): Investment	Variable
gaseous, all plants	$E_1 = [249{,}295\text{-}2493(CE^*)][PC^*]$	dual absorption	0.900	1.00	$I_{1_1} = 23{,}129.7(PC^*)^{0.6002}$	$V_{1_1} = 949.9(PC^*)^{0.7509}$
		sodium sulfite scrubbing	0.950	1.00	$I_{1_2} = 28{,}189(PC^*)^{0.6003}$	$V_{1_2} = 1106.9(PC^*)^{0.8264}$
mist, normal plants	$E_2 = 3069(PC^*)$	dual mesh pad demister	0.900	1.00	$I_{2_1} = 816.4(PC^*)^{0.7336}$	$V_{2_1} = 82.3(PC^*)^{0.7759}$
		tabular fiber demister	0.995	1.00	$I_{2_2} = 3253.9(PC^*)^{0.6528}$	$V_{2_2} = 165.3(PC^*)^{0.7581}$
mist, oleum plants	$E_3 = 918(PC^*)$	dual mesh pad demister	0.750	1.00	$I_{3_1} = 816.4(PC^*)^{0.7336}$	$V_{3_1} = 82.3(PC^*)^{0.7759}$
		tabular fiber demister	0.995	1.00	$I_{3_2} = 3253.9(PC^*)^{0.6528}$	$V_{3_2} = 165.3(PC^*)^{0.7581}$

*Where: PC = plant capacity, tons of sulfuric acid processed per day; CE = conversion efficiency, in percent.

Source: Developed by Research Triangle Institute from data presented in:

1. Background Information for Proposed New Source Performance Standards, APTD-0711, Environmental Protection Agency, August 1971.
2. Chemico Construction Corporation, Engineering Analysis of Emissions Control Technology for Sulfuric Acid Manufacturing Processes, NAPCA, March 1970 (NTIS No. PB-190 393).
3. Paul A. Boys, Environmental Protection Agency (private communication), November 1972.
4. D. B. Buckhardt, VonBree, Inc. (private communication), October 1972.
5. R. Walsh, Environmental Protection Agency (private communication), September 1972.
6. D. Carey, Environmental Protection Agency (private communication), September 1972.
7. Compilation of Air Pollutant Emission Factors, U.S. Environmental Protection Agency, Research Triangle Park, N.C., February 1972, pp. 5-18.

Table A-4. Sulfur emission abatement cost for lead smelters

Emission source	Sulfur emission factor (pounds of sulfur per year)	Abatement alternative			Abatement cost (10^6 dollars)	
		Description	Efficiency	Recovered sulfur (proportion of abated emission)	Investment	Variable
plants with updraft sintering machines with an acid plant only on the strong off-gas stream	$E_1 = 25{,}450(SC^*)$	limestone scrubber on lean stream	0.760	0	$I_1 = 54{,}443.2(SC^*)^{0.6290}$	$V_1 = 13392.5(SC^*)^{0.6290}$

*Where: SC = smelter capacity, tons of lead processed per day.

Source: Developed by Research Triangle Institute from data presented in:

1. Arthur G. McKee and Co., Systems Study for Control of Emissions, Primary Nonferrous Smelting Industry, VII, Final report to National Air Pollution Control Administration, Contract PH86-65-85, June, 1969.

2. Arthur D. Little, Inc., Economic Impact of Anticipated Pollution Abatement Costs on the Primary Lead Industry, September 1962.

3. U.S. Environmental Protection Agency, Compilation of Air Pollutant Emission Factors, Research Triangle Park, N.C., February 1972, pp. 5-18.

Appendix B: TABLES FOR AN EMISSION CHARGE

Table B-1. Sulfur emission estimates under an emission charge

Policy instrument parameters: Charge rate (cents/kg)	Sulfur emissions after abatement (10^6 kg/year)	Reductions in sulfur emissions: (10^6 kg)	Reductions in sulfur emissions: (percent)
	St. Louis AQCR		
4	284.078	13.578	4.56
8	283.568	14.088	4.73
12	276.168	21.448	7.22
16	276.168	21.448	7.22
20	228.126	69.530	23.36
24	193.926	103.730	34.85
28	145.184	152.472	51.22
29*	132.033	165.623	55.64
32	122.226	175.430	58.94
36	72.253	225.403	75.73
40	66.217	231.439	77.75
60	45.886	251.770	84.58
80	36.116	261.540	87.87
100	30.494	267.161	89.76
200	22.015	275.641	92.60
	Cleveland AQCR		
4	213.269	6.354	2.89
8	210.823	8.800	4.01
12	179.488	40.135	18.27
16	160.931	58.632	26.70
20	116.423	103.199	46.99
24	116.422	103.201	46.99
28	94.449	125.173	57.00
32	69.261	150.361	68.46
36	69.160	150.463	68.51
40	48.361	171.261	77.98
42*	43.881	175.742	80.02
60	30.542	189.081	86.09
80	23.031	196.592	89.51
100	16.904	202.719	92.30
200	11.134	208.489	94.93

*Approximate emission charge necessary to induce same total reductions as emission standards.

Source: Research Triangle Institute.

Table B-2. Allocative effects of an emission charge

Policy instrument parameters: Charge rate (cents/kg)	Reductions in sulfur emissions (percent)	Resource costs: Total cost of abatement (10^6 dollars/year)	Resource costs: Average cost of abatement (dollars/10^3 kg of reductions in sulfur emissions)
	St. Louis AQCR		
4	4.56	$ 0.562	$ 41.40
8	4.73	0.587	41.68
12	7.22	1.204	56.05
16	7.22	1.204	56.05
20	23.36	9.087	130.69
24	34.85	15.597	150.36
28	51.22	26.301	172.49
29*	55.64	29.119	175.82
32	58.94	31.386	178.91
36	75.73	44.436	197.14
40	77.75	46.685	201.72
60	84.58	55.495	220.42
80	87.87	61.634	235.66
100	89.76	66.264	248.03
200	92.60	78.158	283.55
	Cleveland AQCR		
4	2.89	$ 0.095	$ 14.89
8	4.01	0.252	28.65
12	18.27	3.791	94.40
16	26.70	6.419	109.49
20	46.99	14.557	141.05
24	46.99	14.557	141.05
28	57.00	20.059	160.25
32	68.46	26.673	177.39
36	68.51	26.695	177.42
40	77.98	34.241	199.93
42*	80.02	35.432	201.62
60	86.09	41.185	217.82
80	89.51	45.645	232.18
100	92.30	50.359	248.42
200	94.93	57.806	277.26

*Approximate emission charge necessary to induce the same total reductions as emission standards.

Source: Research Triangle Institute.

Table B-3. Distributive effects of an emission charge

Policy instrument parameters: charge rate (cents/kilogram)	Reductions in sulfur emissions (percent)	Net private cost (10^6 dollars/year)	Gross private cost: Annualized cost (10^6 dollars/year): Total	Variable cost: Charge payments	Variable cost: Fuel cost premium	Variable cost: Abatement equipment operating cost	Variable cost: Credit for sulfur sales	Fixed cost	Capital outlays for abatement equipment (10^6 dollars)
St. Louis AQCR									
4	4.56	$ 5.630	$ 11.924	$11.361	$ 0.383	$ 0.173	$0.142	$ 0.148	$ 0.928
8	4.73	10.965	23.269	22.681	0.383	0.187	0.148	0.166	1.036
12	7.22	16.273	34.339	33.134	0.383	0.285	0.229	0.766	4.794
16	7.22	21.464	45.384	44.179	0.383	0.285	0.229	0.766	4.794
20	23.36	26.597	54.703	45.616	-2.628	6.863	0.229	5.081	31.805
24	34.85	30.787	62.129	46.533	-4.311	11.060	0.238	9.086	56.871
28	51.22	33.884	66.944	40.643	-4.292	16.973	0.238	13.857	86.738
29*	55.64	34.427	67.137	38.018	-6.960	19.867	0.238	16.451	102.973
32	58.94	36.339	70.491	39.104	-8.631	21.888	0.238	18.368	114.972
36	75.73	37.904	70.441	26.006	-13.171	30.381	0.238	27.464	171.907
40	77.75	39.227	73.166	26.481	-11.871	31.086	0.238	27.708	173.431
60	84.58	44.550	83.021	27.526	-10.377	34.454	0.245	31.663	198.186
80	87.87	48.322	90.521	28.887	-6.085	34.889	0.245	33.075	207.030
100	89.76	51.398	96.753	30.489	-4.187	36.791	0.259	33.919	212.309
200	92.60	63.371	122.180	44.021	10.235	34.139	0.259	34.043	213.084
Cleveland AQCR									
4	2.89	$ 4.068	$ 8.624	$ 8.529	$ 0	$ 0.083	$0.069	$ 0.083	$ 0.517
8	4.01	8.061	17.114	16.862	0.133	0.096	0.073	0.096	0.604
12	18.27	11.920	25.325	21.533	3.672	0.096	0.073	0.096	0.604
16	26.70	15.138	32.172	25.753	6.300	0.096	0.073	0.096	0.604
20	46.99	17.799	37.836	23.280	14.437	0.096	0.073	0.096	0.604
24	46.99	19.988	42.492	27.935	14.438	0.096	0.073	0.096	0.604
28	57.00	21.871	46.499	26.440	19.940	0.095	0.073	0.096	0.604
32	68.46	23.540	48.831	22.159	18.577	4.794	0.073	3.374	21.119
36	68.51	24.840	51.587	24.892	18.525	4.838	0.073	3.405	21.314
40	77.98	26.031	53.581	19.341	22.971	6.486	0.073	4.857	30.400
42*	80.02	26.475	53.859	18.426	20.352	8.500	0.073	6.653	41.646
60	86.09	29.595	59.507	18.322	21.196	10.752	0.077	9.314	58.301
80	89.51	32.087	64.066	18.422	22.034	12.374	0.077	11.313	70.815
100	92.30	33.890	67.260	16.901	22.987	14.401	0.088	13.060	81.747
200	94.93	40.080	80.068	22.263	29.576	14.301	0.088	14.017	87.738

*Approximate emission charge necessary to induce the same total reductions as emission standards.

Source: Research Triangle Institute.

Appendix C: TABLES FOR AN EMISSION CHARGE WITH AN EXEMPTION

Table C-1. Sulfur emission estimates under emission charges with an exemption

Policy instrument parameters		Sulfur emission after abatement	Reductions in sulfur emissions	
Charge rate (cents/kg)	Exemption level (10^3 kg)	(10^6 kg/year)	(10^6 kg)	(percent)
		St. Louis AQCR		
20	0	228.126	69.530	23.36
	1,000	229.536	68.120	22.88
	2,000	230.100	67.556	22.70
	3,000	230.100	67.556	22.70
	4,000	234.608	63.048	21.18
	5,000	270.619	27.037	9.08
40	0	66.217	231.439	77.75
	1,000	73.060	224.596	75.46
	2,000	90.783	206.873	69.50
	3,000	94.676	202.980	68.19
	4,000	102.346	195.310	65.62
	5,000	131.108	166.548	55.95
60	0	45.886	251.770	84.58
	1,000	66.293	231.363	77.73
	2,000	76.206	221.450	74.40
	3,000	91.108	206.548	69.39
	4,000	101.375	196.281	65.94
	5,000	103.860	193.796	65.11
		Cleveland AQCR		
20	0	116.423	103.199	46.99
	1,000	132.467	87.156	39.68
	2,000	139.053	80.570	36.69
	3,000	146.893	72.730	33.12
	4,000	152.875	66.748	30.39
	5,000	157.979	61.644	28.07
40	0	48.361	171.261	77.98
	1,000	75.640	143.983	65.56
	2,000	91.718	127.905	58.24
	3,000	104.160	115.463	52.57
	4,000	115.730	103.892	47.30
	5,000	127.718	91.904	41.85
60	0	30.542	189.081	86.09
	1,000	61.417	158.205	72.04
	2,000	84.429	135.193	61.56
	3,000	100.400	119.223	54.28
	4,000	113.905	105.717	48.14
	5,000	127.718	91.904	41.85

Table C-2. Allocative effects of an emission charge with an exemption

Policy instrument parameters		Reductions in sulfur emissions (percent)	Resource costs	
Charge rate (cents/kg)	Exemption level (10^3 kg)		Total cost of abatement (10^6 dollars/year)	Average cost of abatement (dollars/10^3 kg of reductions in sulfur emissions)
		St. Louis AQCR		
20	0	23.36	9.087	130.69
	1,000	22.88	8.913	130.85
	2,000	22.70	8.804	130.32
	3,000	22.70	8.804	130.32
	4,000	21.18	8.569	135.91
	5,000	9.08	3.027	111.94
40	0	77.75	46.685	201.72
	1,000	75.46	44.811	199.52
	2,000	69.50	40.362	195.11
	3,000	68.19	39.206	193.15
	4,000	65.62	37.896	194.03
	5,000	55.95	31.520	189.25
60	0	84.58	55.495	220.42
	1,000	77.73	48.081	207.81
	2,000	74.40	44.066	198.99
	3,000	69.39	40.972	198.37
	4,000	65.94	38.377	195.52
	5,000	65.11	37.301	192.48
		Cleveland AQCR		
20	0	46.99	14.557	141.05
	1,000	39.68	12.345	141.64
	2,000	36.69	11.391	141.38
	3,000	33.12	10.155	139.62
	4,000	30.39	9.322	139.67
	5,000	28.07	8.592	139.39
40	0	77.98	34.241	199.93
	1,000	65.56	28.282	196.42
	2,000	58.24	24.592	192.27
	3,000	52.57	21.575	186.86
	4,000	47.30	19.133	184.16
	5,000	41.85	16.012	174.22
60	0	86.09	41.185	217.82
	1,000	72.04	33.262	210.25
	2,000	61.56	27.212	201.28
	3,000	54.28	23.323	195.63
	4,000	48.14	19.754	186.85
	5,000	41.85	16.012	174.23

Table C-3. Distributive effects of an emission charge with an exemption

Policy instrument parameters				Gross private cost						
				Annualized cost (10^6 dollars/year)						
						Variable cost				
Charge rate (cents/kg)	Exemption level (10^3 kg)	Reductions in sulfur emissions (percent)	Net private cost (10^6 dollars/year)	Total	Charge payments	Fuel cost premium	Abatement equipment operating cost	Credit for sulfur sales	Fixed Cost	Capital outlays for abatement equipment (10^6 dollars)
				St. Louis AQCR						
20	0	23.36	26.597	54.703	45.616	-2.628	6.863	0.229	5.081	31.805
	1,000	22.88	21.947	44.817	35.904	-2.763	6.842	0.221	5.055	31.644
	2,000	22.70	19.465	39.537	30.733	-2.873	6.842	0.221	5.055	31.644
	3,000	22.70	17.829	36.055	27.252	-2.873	6.842	0.221	5.055	31.644
	4,000	21.18	16.492	33.232	24.663	-3.027	6.780	0.181	4.997	31.276
	5,000	9.08	15.422	32.559	29.532	2.324	0.202	0.181	0.681	4.265
40	0	77.75	39.227	73.166	26.481	-11.871	31.086	0.238	27.708	173.431
	1,000	75.46	30.493	54.705	9.894	-12.784	30.441	0.221	27.376	171.353
	2,000	69.50	26.312	46.624	6.261	-13.346	28.744	0.221	25.186	157.646
	3,000	68.19	24.141	41.918	2.712	-15.266	29.275	0.221	25.418	159.097
	4,000	65.62	22.803	38.818	0.923	-19.095	31.075	0.181	26.096	163.345
	5,000	55.95	21.910	39.509	7.990	-11.391	23.964	0.181	19.126	119.718
60	0	84.58	44.550	83.021	27.526	-10.377	34.454	0.245	31.663	198.186
	1,000	77.73	32.473	58.904	10.823	-10.082	30.970	0.221	27.415	171.599
	2,000	74.40	27.255	47.465	3.399	-16.089	32.057	0.221	28.319	177.258
	3,000	69.39	24.603	42.900	1.928	-13.499	29.275	0.221	25.418	159.097
	4,000	65.94	23.011	39.262	0.885	-18.614	31.075	0.181	26.096	163.345
	5,000	65.11	22.090	37.301	0.000	-19.690	31.075	0.181	26.096	163.345
				Cleveland AQCR						
20	0	46.99	17.799	37.836	23.280	14.437	0.096	0.073	0.096	0.604
	1,000	39.68	12.799	27.204	14.860	12.254	0.082	0.063	0.072	0.450
	2,000	36.69	10.776	22.900	11.510	11.300	0.082	0.063	0.072	0.450
	3,000	33.12	9.230	19.612	9.457	10.064	0.082	0.063	0.072	0.450
	4,000	30.39	7.929	16.843	7.521	9.232	0.082	0.063	0.072	0.450
	5,000	28.07	6.913	14.681	6.089	8.501	0.082	0.063	0.072	0.450
40	0	77.98	26.031	53.581	19.341	22.971	6.486	0.073	4.857	30.400
	1,000	65.56	17.508	35.443	7.161	16.906	6.575	0.063	4.864	30.445
	2,000	58.24	14.108	28.772	4.180	16.525	4.781	0.063	3.349	20.965
	3,000	52.57	11.855	23.898	2.323	12.623	5.451	0.063	3.565	22.312
	4,000	47.30	10.077	20.116	0.984	10.180	5.451	0.063	3.565	22.312
	5,000	41.85	8.718	17.224	1.212	7.060	5.451	0.063	3.565	22.312
60	0	86.09	29.595	59.507	18.322	21.196	10.752	0.077	9.314	58.301
	1,000	72.04	18.853	36.535	3.272	12.018	11.678	0.063	9.630	60.275
	2,000	61.56	14.910	29.916	2.704	15.836	6.575	0.063	4.864	30.445
	3,000	54.28	12.294	24.833	1.510	14.371	5.451	0.063	3.565	22.312
	4,000	48.14	10.239	20.461	0.707	10.801	5.451	0.063	3.565	22.312
	5,000	41.85	9.003	17.830	1.818	7.060	5.451	0.063	3.565	22.312

Appendix D: TABLES FOR AN EMISSION CHARGE WITH A SUBSIDY

Table D-1. Distributive effects of an emission charge with a subsidy

Policy instrument parameters		Reductions in sulfur emissions (percent)	Net private cost (10^3 dollars/year)	Gross private cost						
				Annualized cost (10^6 dollars/year)						
					Variable cost					
Charge rate (cents/kg)	Breakeven emission rate (10^3 kg)			Total	Net charge payments	Fuel cost premium	Abatement equipment operating cost	Credit for sulfur sales	Fixed cost	Capital outlay for abatement equipment (10^6 dollars)
				St. Louis AQCR						
4	50	4.56	5.376	$11.384	$10.821	$ 0.383	$ 0.173	$0.142	$ 0.148	$ 0.928
8	50	4.73	10.458	22.188	21.601	0.383	0.187	0.148	0.166	1.036
12	50	7.22	15.512	32.718	31.514	0.383	0.285	0.229	0.766	4.794
16	50	7.22	20.448	43.224	42.019	0.383	0.285	0.229	0.766	4.794
20	50	23.36	25.329	52.003	42.916	-2.628	6.863	0.229	5.081	31.805
24	50	34.85	29.264	58.889	43.293	-4.311	11.060	0.238	9.086	56.871
28	50	51.22	32.106	63.164	36.863	-4.292	16.973	0.238	13.857	86.738
32	50	58.94	34.308	66.171	34.784	-6.960	19.867	0.238	16.451	102.973
36	50	75.73	35.620	65.582	21.146	-8.631	21.888	0.238	18.368	114.972
40	50	77.75	36.690	67.767	21.082	-13.171	30.381	0.238	27.464	171.907
60	50	84.58	40.744	74.922	19.428	-11.871	31.086	0.238	27.708	173.431
80	50	87.87	43.247	79.724	18.090	-10.377	34.454	0.245	31.663	198.186
100	50	89.76	45.054	83.255	16.991	-6.085	34.889	0.245	33.075	207.030
200	50	92.60	50.682	95.185	17.027	-4.187	36.791	0.259	33.919	212.309
				Cleveland AQCR						
4	50	2.89	3.812	8.080	7.985	$ 0	$ 0.083	$0.069	$ 0.083	$ 0.517
8	50	4.01	7.549	16.027	15.775	0.133	0.096	0.073	0.096	0.604
12	50	18.27	11.153	23.692	19.901	3.672	0.096	0.073	0.096	0.604
16	50	26.70	14.116	29.996	23.576	6.300	0.096	0.073	0.096	0.604
20	50	46.99	16.522	35.116	20.559	14.437	0.096	0.073	0.096	0.604
24	50	46.99	18.453	39.228	24.671	14.438	0.096	0.073	0.096	0.604
28	50	57.00	20.081	42.691	22.632	19.940	0.095	0.073	0.096	0.604
32	50	68.46	21.495	44.480	17.807	18.577	4.794	0.073	3.374	21.119
36	50	68.51	22.539	46.692	19.997	18.525	4.838	0.073	3.405	21.314
40	50	77.98	23.475	48.143	13.902	22.971	6.406	0.073	4.857	30.400
60	50	86.09	25.760	51.349	10.164	20.352	8.500	0.073	6.653	41.646
80	50	89.51	26.974	53.188	7.544	21.196	10.752	0.077	9.314	58.301
100	50	92.30	27.502	53.663	3.304	22.034	12.374	0.077	11.313	70.815
200	50	94.93	27.298	52.874	-4.931	22.987	14.401	0.088	13.060	81.747

Table D-1 (continued). Distributive effects of an emission charge with a subsidy

Policy instrument parameters		Reductions in sulfur emissions	Net private cost	Gross private cost						
				Annualized cost (10^6 dollars/year)						
					Variable cost					
Charge rate (cents/kg)	Breakeven emission rate (10^3 kg)	(percent)	(10^3 dollars/year)	Total	Net charge payments	Fuel cost premium	Abatement equipment operating cost	Credit for sulfur sales	Fixed cost	Capital outlays for abatement equipment (10^6 dollars)
				St. Louis AQCR						
4	100	4.56	5.122	$10.844	$ 10.282	$ 0.383	$ 0.173	$0.142	$ 0.148	$ 0.928
8	100	4.73	9.950	21.108	20.521	0.383	0.187	0.148	0.166	1.036
12	100	7.22	14.751	31.099	29.984	0.383	0.285	0.229	0.766	4.794
16	100	7.22	19.434	41.064	39.860	0.383	0.285	0.229	0.766	4.794
20	100	23.36	24.060	49.303	40.216	-2.628	6.863	0.229	5.081	31.805
24	100	34.85	27.742	55.650	40.053	-4.311	11.060	0.238	9.086	56.871
28	100	51.22	30.330	59.385	33.084	-4.292	16.973	0.238	13.857	86.738
32	100	58.94	32.278	61.852	30.466	-6.960	19.867	0.238	16.451	102.973
36	100	75.73	33.336	60.724	16.288	-8.631	21.888	0.238	18.368	114.972
40	100	77.75	34.152	62.369	15.684	-13.171	30.381	0.238	27.464	171.907
60	100	84.58	36.937	66.824	11.330	-11.871	31.086	0.238	27.708	173.431
80	100	87.87	38.172	68.926	7.292	-10.377	34.454	0.245	31.663	198.186
100	100	89.76	38.710	69.759	3.495	-6.085	34.889	0.245	33.075	207.030
200	100	92.60	37.995	68.191	-9.968	-4.187	36.791	0.259	33.919	212.309
				Cleveland AQCR						
4	100	2.89	3.556	7.536	7.441	$ 0*	$ 0.083	$0.069	$ 0.083	$ 0.517
8	100	4.01	7.038	14.939	14.687	0.133	0.096	0.073	0.096	0.604
12	100	18.27	10.386	22.061	18.270	3.672	0.096	0.073	0.096	0.604
16	100	26.70	13.093	27.820	21.401	6.300	0.096	0.073	0.096	0.604
20	100	46.99	15.244	32.396	17.840	14.437	0.096	0.073	0.096	0.604
24	100	46.99	16.919	35.965	21.408	14.438	0.096	0.073	0.096	0.604
28	100	57.00	18.292	38.884	18.825	19.940	0.095	0.073	0.096	0.604
32	100	68.46	19.449	40.130	13.457	18.577	4.794	0.073	3.374	21.119
36	100	68.51	20.239	41.797	15.102	18.525	4.858	0.073	3.405	21.314
40	100	77.98	20.919	42.704	8.463	22.971	6.486	0.073	4.857	30.400
60	100	86.09	21.926	43.190	2.006	20.352	8.500	0.073	6.653	41.646
80	100	89.51	21.861	42.311	-3.334	21.196	10.752	0.077	9.314	58.301
100	100	92.30	21.111	40.066	-10.294	22.034	12.374	0.077	11.313	70.815
200	100	94.93	14.517	25.681	-32.125	22.987	14.401	0.088	13.060	81.747

Table D-1 (continued). Distributive effects of an emission charge with a subsidy

Policy instrument parameters		Reductions in sulfur emissions (percent)	Net private cost (10^3 dollars/year)	Gross private cost						
				Annualized cost (10^6 dollars/year)						
					Variable cost					
Charge rate (cents/kg)	Breakeven emission rate (10^3 kg)			Total	Net charge payments	Fuel cost premium	Abatement equipment operating cost	Credit for sulfur sales	Fixed cost	Capital outlays for abatement equipment (10^6 dollars)
				St. Louis AQCR						
4	150	4.56	4.869	$10.304	$ 9.742	$ 0.383	$ 0.173	$0.142	$ 0.148	$ 0.928
8	150	4.73	9.443	20.028	19.441	0.383	0.187	0.148	0.166	1.036
12	150	7.22	13.990	29.479	28.275	0.383	0.285	0.229	0.766	4.794
16	150	7.22	18.418	38.905	37.700	0.383	0.285	0.229	0.766	4.794
20	150	23.36	22.791	46.604	37.517	-2.628	6.863	0.229	5.081	31.805
24	150	34.85	26.220	52.411	36.814	-4.311	11.060	0.238	9.086	56.871
28	150	51.22	28.554	55.606	29.305	-4.292	16.973	0.238	13.857	86.738
32	150	58.94	30.248	27.532	26.146	-6.960	19.867	0.238	16.451	102.973
36	150	75.73	31.053	55.865	11.429	-8.631	21.888	0.238	18.368	114.972
40	150	77.75	31.615	56.970	10.285	-13.171	30.381	0.238	27.464	171.907
60	150	84.58	33.131	58.726	3.231	-11.871	31.086	0.238	27.708	173.431
80	150	87.87	33.096	58.128	-3.506	-10.377	34.454	0.245	31.663	198.186
100	150	89.76	32.366	56.261	-10.003	-6.085	34.889	0.245	33.075	207.030
200	150	92.60	25.308	41.196	-36.962	-4.187	36.791	0.259	33.919	212.309
				Cleveland AQCR						
4	150	2.89	3.301	6.992	6.897	$ 0	$ 0.083	$0.069	$ 0.083	$ 0.517
8	150	4.01	6.527	13.851	13.599	0.133	0.096	0.073	0.096	0.604
12	150	18.27	9.619	20.429	16.638	3.672	0.096	0.073	0.096	0.604
16	150	26.70	12.071	25.645	19.226	6.300	0.096	0.073	0.096	0.604
20	150	46.99	13.966	29.678	15.121	14.437	0.096	0.073	0.096	0.604
24	150	46.99	15.387	32.702	18.145	14.438	0.096	0.073	0.096	0.604
28	150	57.00	16.502	35.078	15.019	19.940	0.095	0.073	0.096	0.604
32	150	68.46	17.404	35.779	9.106	18.577	4.794	0.073	3.374	21.119
36	150	68.51	17.938	36.903	10.208	18.525	4.838	0.073	3.405	21.314
40	150	77.98	18.362	37.265	3.024	22.971	6.486	0.073	4.857	30.400
60	150	86.09	18.091	35.032	-6.153	20.352	8.500	0.073	6.653	41.646
80	150	89.51	16.748	31.433	-14.212	21.196	10.752	0.077	9.314	58.301
100	150	92.30	14,720	26.469	-23.891	22.034	12.374	0.077	11.313	70.815
200	150	94.93	1.736	-1.514	-59.320	22.987	14.401	0.088	13,060	81.747

Table D-1 (continued). Distributive effects of an emission charge with a subsidy

Policy instrument parameters		Reductions in sulfur emissions (percent)	Net private cost (10^3 dollars/year)	Gross private cost						
				Annualized cost (10^6 dollars/year)						
					Variable cost					
Charge rate (cents/kg)	Breakeven emission rate (10^3 kg)			Total	Net charge payments	Fuel cost premium	Abatement equipment operating cost	Credit for sulfur sales	Fixed cost	Capital outlays for abatement equipment (10^6 dollars)
				St. Louis AQCR						
4	200	4.56	4.615	$ 9.764	$ 9.202	$ 0.383	$ 0.173	$0.142	$ 0.148	$ 0.928
8	200	4.73	8.935	18.949	18.362	0.383	0.187	0.148	0.166	1.036
12	200	7.22	13.228	27.860	26.655	0.383	0.285	0.229	0.766	4.794
16	200	7.22	17.403	36.745	35.541	0.383	0.285	0.229	0.766	4.794
20	200	23.36	21.522	43.905	34.818	-2.628	6.863	0.229	5.081	31.805
24	200	34.85	24.697	49.171	33.574	-4.311	11.060	0.238	9.086	56.871
28	200	51.22	26.778	51.826	25.525	-4.292	16.973	0.238	13.857	86.738
32	200	58.94	28.218	53.213	21.827	-6.960	19.867	0.238	16.451	102.973
36	200	75.73	28.769	51.006	6.570	-8.631	21.888	0.238	18.368	114.972
40	200	77.75	29.077	51.571	4.886	-13.171	30.381	0.238	27.464	171.907
60	200	84.58	29.324	50.628	-4.867	-11.871	31.086	0.238	27.708	173.431
80	200	87.87	29.021	47.330	-14.304	-10.377	34.454	0.245	31.663	198.186
100	200	89.76	26.022	42.764	-23.500	-6.085	34.889	0.245	33.075	207.030
200	200	92.60	12.620	14.202	-63.956	-4.187	36.791	0.259	33.919	212.309
				Cleveland AQCR						
4	200	2.89	3.045	6.448	6.354	$ 0	$ 0.083	$0.069	$ 0.083	$ 0.517
8	200	4.01	6.016	12.764	12.511	0.133	0.096	0.073	0.096	0.604
12	200	18.27	8.852	18.798	15.007	3.672	0.096	0.073	0.096	0.604
16	200	26.70	11.048	23.469	17.050	6.300	0.096	0.073	0.096	0.604
20	200	46.99	12.688	26.959	12.402	14.437	0.096	0.073	0.096	0.604
24	200	46.99	13.853	29.438	14.881	14.438	0.096	0.073	0.096	0.604
28	200	57.00	14.714	31.270	11.211	19.940	0.095	0.073	0.096	0.604
32	200	68.46	15.360	31.437	4.755	18.577	4.794	0.073	3.374	21.119
36	200	68.51	15.638	32.008	5.313	18.525	4.838	0.073	3.405	21.314
40	200	77.98	15.806	31.826	-2.415	22.971	6.486	0.073	4.857	30.400
60	200	86.09	14.257	26.873	-14.311	20.352	8.500	0.073	6.653	41.646
80	200	89.51	11.636	20.555	-25.089	21.196	10.752	0.077	9.314	58.301
100	200	92.30	8.330	12.872	-37.488	22.034	12.374	0.077	11.313	70.815
200	200	94.93	-11.045	-28.709	-86.514	22.987	14.401	0.088	13.060	81.747

Appendix E: TABLES FOR A HYBRID PROGRAM

Table E-1. Sulfur emission estimated under hybrid programs

Policy instrument parameters				
Charge rate (cents/kg)	Constraint (proportion of emission standards)	Sulfur emissions after abatement (10^6 kg/year)	Reductions in sulfur emissions (10^6 kg)	Reductions in sulfur emissions (percent)
		St. Louis AQCR		
0	1.00	134.590	163.066	54.78
4	1.00	134.180	163.476	54.92
8	1.00	133.993	163.663	54.98
12	1.00	133.982	163.674	54.99
16	1.00	133.982	163.674	54.99
20	1.00	133.869	163.787	55.03
24	1.00	99.705	197.951	66.50
28	1.00	99.683	197.973	66.51
32	1.00	70.541	227.115	76.30
36	1.00	44.990	252.666	84.89
40	1.00	42.423	255.233	85.75
60	1.00	35.885	261.771	87.94
80	1.00	89.866	267.490	89.87
100	1.00	27.831	269.825	90.65
200	1.00	19.829	277.827	93.34
		Cleveland AQCR		
0	1.00	47.225	172.397	78.50
4	1.00	47.522	172.100	78.36
8	1.00	47.208	172.415	78.51
12	1.00	47.208	172.415	78.51
16	1.00	47.208	172.415	78.51
20	1.00	40.198	179.424	81.70
24	1.00	40.198	179.424	81.70
28	1.00	40.198	179.424	81.70
32	1.00	37.297	182.326	83.02
36	1.00	37.283	182.340	83.02
40	1.00	33.813	185.809	84.60
60	1.00	27.849	191.774	87.32
80	1.00	20.384	199.239	90.72
100	1.00	15.308	204.315	93.03
200	1.00	9.592	210.031	95.63

Table E-1 (continued). Sulfur emission estimated under hybrid programs

Policy instrument parameters				
Charge rate (cents/kg)	Constraint (proportion of emission standards)	Sulfur emissions after abatement (10^6 kg/year)	Reductions in sulfur emissions (10^6 kg)	Reductions in sulfur emissions (percent)
		St. Louis AQCR		
0	.8	155.683	141.973	47.70
4	.8	155.274	142.382	47.84
8	.8	153.016	144.640	48.59
12	.8	150.128	147.528	49.56
16	.8	150.128	147.528	49.56
20	.8	150.128	147.528	49.56
24	.8	123.808	173.848	58.41
28	.8	111.443	186.213	62.56
32	.8	98.292	199.364	66.98
36	.8	51.705	245.951	82.63
40	.8	50.009	247.647	83.20
60	.8	39.380	258.276	86.77
80	.8	32.231	265.425	89.17
100	.8	28.307	269.349	90.49
200	.8	19.829	277.827	93.34
		Cleveland AQCR		
0	.8	58.308	161.315	73.45
4	.8	58.623	161.000	73.31
8	.8	58.308	161.315	73.45
12	.8	58.308	161.315	73.45
16	.8	58.308	161.315	73.45
20	.8	58.308	161.315	73.45
24	.8	58.282	161.341	73.46
28	.8	49.092	170.531	77.65
32	.8	49.084	170.539	77.65
36	.8	45.271	174.351	79.39
40	.8	45.265	174.358	79.39
60	.8	27.903	191.720	87.30
80	.8	20.438	199.185	90.69
100	.8	15.334	204.289	93.02
200	.8	9.592	210.031	95.63

Table E-1 (continued). Sulfur emission estimated under hybrid programs

Policy instrument parameters				
Charge rate (cents/kg)	Constraint (proportion of emission standards)	Sulfur emissions after abatement (10^6 kg/year)	Reductions in sulfur emissions (10^6 kg)	Reductions in sulfur emissions (percent)
		St. Louis AQCR		
0	.6	221.847	75.809	25.47
4	.6	221.848	75.808	25.47
8	.6	221.847	75.809	25.47
12	.6	221.847	75.809	25.47
16	.6	200.225	97.431	32.73
20	.6	200.225	97.431	32.73
24	.6	154.984	142.672	47.93
28	.6	126.567	171.089	57.48
32	.6	109.575	188.081	63.19
36	.6	62.984	234.672	78.84
40	.6	60.061	237.595	79.82
60	.6	42.492	255.164	85.73
80	.6	32.738	264.918	89.00
100	.6	28.307	269.349	90.49
200	.6	19.829	277.827	93.34
		Cleveland AQCR		
0	.6	79.585	140.038	63.76
4	.6	79.900	139.723	63.62
8	.6	79.585	140.038	63.76
12	.6	79.585	140.038	63.76
16	.6	79.585	140.038	63.76
20	.6	79.585	140.038	63.76
24	.6	79.584	140.039	63.76
28	.6	79.581	140.042	63.77
32	.6	66.185	153.438	69.86
36	.6	66.092	153.531	69.91
40	.6	45.311	174.312	79.37
60	.6	27.949	191.674	87.27
80	.6	20.454	199.169	90.69
100	.6	15.334	204.289	93.02
200	.6	9.592	210.031	95.63

Table E-2. Allocative effects of hybrid programs

Policy instrument parameters		Reductions in sulfur emissions (percent)	Resource costs	
Charge rate (cents/kg)	Constraint (proportion of emission standards)		Total cost of abatement (10^6 dollars year)	Average cost of abatement (dollars/10^3 kg of reductions in sulfur emissions)
		St. Louis AQCR		
0	1.00	54.78	49.521	303.69
4	1.00	54.92	49.606	303.45
8	1.00	54.98	49.629	303.24
12	1.00	54.99	49.630	303.22
16	1.00	54.99	49.630	303.22
20	1.00	55.03	49.616	302.93
24	1.00	66.50	54.808	276.88
28	1.00	66.51	54.814	276.88
32	1.00	76.30	61.230	269.60
36	1.00	84.89	67.092	265.54
40	1.00	85.75	67.747	265.43
60	1.00	87.94	70.355	268.77
80	1.00	89.87	73.924	276.36
100	1.00	90.65	75.979	281.59
200	1.00	93.34	87.302	314.23
		Cleveland AQCR		
0	1.00	78.50	45.750	265.38
4	1.00	78.36	45.498	264.37
8	1.00	78.51	45.732	265.25
12	1.00	78.51	45.732	265.25
16	1.00	78.51	45.732	265.25
20	1.00	81.70	45.891	255.77
24	1.00	81.70	45.891	255.77
28	1.00	81.70	45.891	255.77
32	1.00	83.02	46.251	253.67
36	1.00	83.02	46.256	253.68
40	1.00	84.60	46.905	252.49
60	1.00	87.32	48.768	254.30
80	1.00	90.72	53.197	267.00
100	1.00	93.03	56.904	278.51
200	1.00	95.63	64.286	306.08

Table E-2 (continued). Allocative effects of hybrid programs

Policy instrument parameters		Reductions in sulfur emissions (percent)	Resource costs	
Charge rate (cents/kg)	Constraint (proportion of emission standards)		Total cost of abatement (10^6 dollars/year)	Average cost of abatement (dollars/10^3 kg of reductions in sulfur emissions)
		St. Louis AQCR		
0	.8	47.70	42.388	298.56
4	.8	47.84	42.473	298.30
8	.8	48.59	42.292	292.39
12	.8	49.56	42.183	285.93
16	.8	49.56	42.183	285.93
20	.8	49.56	42.183	285.93
24	.8	58.41	46.690	268.57
28	.8	62.56	48.892	262.56
32	.8	66.98	51.711	259.38
36	.8	82.63	63.635	258.73
40	.8	83.20	64.263	259.49
60	.8	86.77	67.973	263.18
80	.8	89.17	72.254	272.22
100	.8	90.49	75.417	280.00
200	.8	93.34	87.302	314.23
		Cleveland AQCR		
0	.8	73.45	39.803	246.74
4	.8	73.31	39.568	245.77
8	.8	73.45	39.803	246.74
12	.8	73.45	39.803	246.74
16	.8	73.45	39.803	246.74
20	.8	73.45	39.803	246.74
24	.8	73.46	39.800	246.69
28	.8	77.65	41.126	241.17
32	.8	77.65	41.126	241.15
36	.8	79.39	41.944	240.57
40	.8	79.39	41.946	240.57
60	.8	87.30	48.704	254.04
80	.8	90.69	53.133	266.75
100	.8	93.02	56.964	278.84
200	.8	95.63	64.286	306.08

Table E-2 (continued). Allocative effects of hybrid programs

Policy instrument parameter		Reductions in sulfur emissions (percent)	Resource costs	
Charge rate (cents/kg)	Constraint (proportion of emission standards)		Total cost of abatement (10^6 dollars/year)	Average cost of abatement (dollars/10^3 kg of reductions in sulfur emissions)
		St. Louis AQCR		
0	.6	25.47	26.350	347.59
4	.6	25.47	26.341	347.47
8	.6	25.47	26.350	347.59
12	.6	25.47	26.350	347.59
16	.6	32.73	27.450	281.74
20	.6	32.73	27.450	281.74
24	.6	47.93	35.496	248.80
28	.6	57.48	41.647	243.42
32	.6	63.19	45.252	240.60
36	.6	78.84	57.164	243.59
40	.6	79.82	58.190	244.91
60	.6	85.73	65.662	257.33
80	.6	89.00	71.793	271.00
100	.6	90.49	75.417	279.99
200	.6	93.34	87.302	314.23
		Cleveland AQCR		
0	.6	63.76	31.358	223.93
4	.6	63.62	31.123	222.75
8	.6	63.76	31.358	223.93
12	.6	63.76	31.358	223.93
16	.6	63.76	31.358	223.93
20	.6	63.76	31.358	223.93
24	.6	63.76	31.358	223.93
28	.6	63.77	31.359	223.93
32	.6	69.86	34.351	223.88
36	.6	69.91	34.371	223.87
40	.6	79.37	41.910	240.43
60	.6	87.27	48.667	253.91
80	.6	90.69	53.118	266.70
100	.6	93.02	56.964	278.84
200	.6	95.63	64.286	306.08

Table E-3. Distributive effects of hybrid programs

Policy instrument parameters				Gross private costs						
				Annualized costs (10^6 dollars/year)						
					Variable costs					
Charge rate (cents per kilogram)	Constant (proportion of emission standards)	Reductions in sulfur emissions (percent)	Net private cost (10^6 dollars/year)	Total	Charge payments	Fuel cost Premium	Abatement equipment operating cost	Credit for sulfur sales	Fixed cost	Capital outlays for abatement equipment (10^6 dollars)
				St. Louis AQCR						
0	1.00	54.78	25.160	49.521	0.0	15.308	23.700	0.283	10.795	67.572
4	1.00	54.92	27.680	54.972	5.366	16.166	23.166	0.283	10.557	66.078
8	1.00	54.98	30.207	60.346	10.717	16.295	23.052	0.283	10.564	66.121
12	1.00	54.99	32.726	65.705	16.075	16.301	23.048	0.283	10.564	66.121
16	1.00	54.99	35.244	71.062	21.432	16.301	23.048	0.283	10.564	66.121
20	1.00	55.03	37.761	76.384	26.768	15.946	23.296	0.283	10.657	66.705
24	1.00	66.50	39.905	78.732	23.924	8.370	30.111	0.283	16.611	103.972
28	1.00	66.51	41.779	82.719	27.905	8.385	30.101	0.283	16.611	103.972
32	1.00	76.30	43.429	83.799	22.568	1.729	36.631	0.283	23.153	144.923
36	1.00	84.89	44.448	83.286	16.194	-6.063	43.067	0.283	30.371	190.101
40	1.00	85.75	45.284	84.713	16.966	-7.558	44.274	0.283	31.314	196.003
60	1.00	87.94	48.995	91.882	21.527	-8.858	46.228	0.283	33.269	208.240
80	1.00	89.87	52.036	96.052	24.128	-5.924	46.059	0.283	34.072	213.271
100	1.00	90.65	54.756	103.805	27.825	-3.615	45.711	0.283	34.166	213.858
200	1.00	93.34	65.657	126.952	39.650	10.235	43.059	0.283	34.290	214.632
				Cleveland AQCR						
0	1.00	78.50	21.617	45.750	0.0	37.906	7.291	0.106	0.660	4.129
4	1.00	78.36	22.370	47.398	1.901	37.752	7.312	0.102	0.536	3.355
8	1.00	78.51	23.392	49.508	3.776	37.752	7.378	0.106	0.708	4.433
12	1.00	78.51	24.279	51.396	5.664	37.752	7.378	0.106	0.708	4.433
16	1.00	78.51	25.167	53.284	7.552	37.752	7.378	0.106	0.708	4.433
20	1.00	81.70	26.042	53.929	8.038	29.935	12.076	0.106	3.986	24.949
24	1.00	81.70	26.798	55.537	9.646	29.935	12.076	0.106	3.986	24.949
28	1.00	81.70	27.553	57.145	11.254	29.935	12.076	0.106	3.986	24.949
32	1.00	83.02	28.287	58.184	11.933	27.330	13.638	0.106	5.389	33.730
36	1.00	83.02	28.988	59.676	13.420	27.338	13.635	0.106	5.389	33.730
40	1.00	84.60	29.656	60.428	13.523	24.178	15.648	0.106	7.185	44.975
60	1.00	87.32	32.469	65.475	16.707	21.297	17.865	0.106	9.712	60.791
80	1.00	90.72	34.710	69.502	16.304	22.114	19.484	0.106	11.706	73.269
100	1.00	93.03	36.266	72.209	15.305	23.051	20.629	0.105	13.330	83.435
200	1.00	95.63	41.724	83.465	19.179	29.576	20.529	0.105	14.287	89.426

Table E-3 (continued). Distributive effects of hybrid programs

Policy instrument parameters				Gross private costs						
				Annualized costs (10^6 dollars/year)						
					Variable costs					
Charge rate (cents per kilogram)	Constant (proportion of emission standards)	Reductions in sulfur emissions (percent)	Net private cost (10^6 dollars/year)	Total	Charge payments	Fuel cost premium	Abatement equipment operating cost	Credit for sulfur sales	Fixed cost	Capital outlays for abatement equipment (10^6 dollars)
St. Louis AQCR										
0	.8	47.70	21.430	42.388	0.0	13.272	20.764	0.283	8.635	54.048
04	.8	47.84	24.347	48.682	6.210	14.130	20.229	0.283	8.396	52.555
08	.8	48.59	27.265	54.531	12.239	11.852	21.353	0.283	9.369	58.645
12	.8	49.56	30.136	60.195	18.011	8.855	23.048	0.283	10.564	66.121
16	.8	49.56	32.958	66.199	24.015	8.855	23.048	0.283	10.564	66.121
20	.8	49.56	35.780	72.202	30.019	8.855	23.048	0.283	10.564	66.121
24	.8	58.41	38.429	76.397	29.708	5.294	27.233	0.283	14.445	90.414
28	.8	62.56	40.527	80.090	31.197	2.805	29.853	0.283	16.517	103.39
32	.8	66.98	42.422	83.158	31.447	0.136	32.746	0.283	19.111	119.623
36	.8	82.63	43.575	82.245	18.610	-5.321	41.070	0.283	28.168	176.313
40	.8	83.20	44.539	84.262	19.999	-5.006	41.290	0.283	28.261	176.897
60	.8	86.77	48.631	91.596	23.623	-8.066	44.368	0.283	31.954	200.009
80	.8	89.17	51.903	98.034	25.780	-5.624	44.799	0.283	33.361	208.817
100	.8	90.49	54.717	103.719	28.301	-4.187	45.714	0.283	34.173	213.901
200	.8	93.34	65.657	126.952	39.650	10.235	43.059	0.283	34.290	214.632
Cleveland AQCR										
0	.8	73.45	18.817	39.803	0.0	32.037	7.243	0.106	0.628	3.934
4	.8	73.31	19.779	41.913	2.344	32.037	7.178	0.102	0.456	2.856
8	.8	73.45	21.009	44.467	4.664	32.037	7.243	0.106	0.628	3.934
12	.8	73.45	22.104	46.798	6.996	32.037	7.243	0.106	0.628	3.934
16	.8	73.45	23.200	49.130	9.328	32.037	7.243	0.106	0.628	3.934
20	.8	73.45	24.296	51.462	11.660	32.037	7.243	0.106	0.628	3.934
24	.8	73.46	25.392	53.785	13.985	31.974	7.280	0.105	0.652	4.080
28	.8	77.65	26.475	54.870	13.743	25.325	11.978	0.106	3.929	24.595
32	.8	77.65	27.397	56.830	15.704	25.305	11.989	0.106	3.937	24.644
36	.8	79.39	28.313	58.239	16.295	23.026	13.635	0.106	5.389	33.730
40	.8	79.39	29.164	60.048	18.102	23.029	13.634	0.106	5.389	33.730
60	.8	87.30	32.454	65.443	16.739	21.232	17.865	0.106	9.712	60.791
80	.8	90.69	34.700	69.480	16.347	22.049	19.484	0.106	11.706	73.269
100	.8	93.02	36.322	72.295	15.331	22.987	20.663	0.106	13.420	84.002
200	.8	95.63	41.724	83.465	19.179	29.576	20.529	0.105	14.287	89.426

Table E-3 (continued). Distributive effects of hybrid programs

Policy instrument parameters				Gross private costs						
				Annualized costs (10^6 dollars/year)						
					Variable costs					
Charge rate (cents per kilogram)	Constant (proportion of emission standards)	Reductions in sulfur emissions (percent)	Net private cost (10^6 dollars/year)	Total	Charge payments	Fuel cost premium	Abatement equipment operating cost	Credit for sulfur sales	Fixed cost	Capital outlays for abatement equipment (10^6 dollars)
				St. Louis AQCR						
0	.6	25.47	12.621	26.350	0.0	15.003	10.280	0.283	1.350	8.450
4	.6	25.47	16.785	35.213	8.872	15.003	10.277	0.283	1.343	8.407
8	.6	25.47	20.960	44.094	17.744	15.003	10.280	0.283	1.350	8.450
12	.6	25.47	25.130	52.966	26.616	15.003	10.280	0.283	1.350	8.450
16	.6	32.73	28.944	59.479	32.029	5.209	16.858	0.283	5.665	35.461
20	.6	32.73	32.708	67.487	40.037	5.209	16.858	0.283	5.665	35.461
24	.6	47.93	36.300	72.684	37.188	-0.795	24.328	0.283	12.245	76.646
28	.6	57.48	38.896	77.078	35.431	-1.433	28.078	0.283	15.284	95.668
32	.6	63.19	41.033	80.309	35.057	-5.165	31.872	0.283	18.828	117.854
36	.6	78.84	42.399	79.834	22.670	-10.843	40.366	0.283	27.924	174.789
40	.6	79.82	43.558	82.209	24.020	-10.766	41.070	0.283	28.168	176.313
60	.6	85.73	48.423	91.152	25.490	-10.377	44.368	0.283	31.954	200.009
80	.6	89.00	51.877	97.978	26.185	-6.085	44.799	0.283	33.361	208.817
100	.6	90.49	54.717	103.719	28.301	-4.187	45.714	0.283	34.173	213.901
200	.6	93.34	65.657	126.952	39.650	10.235	43.059	0.283	34.290	214.632
				Cleveland						
0	.6	63.76	14.848	31.358	0.0	23.592	7.244	0.106	0.628	3.934
4	.6	63.62	16.210	34.319	3.195	23.592	7.178	0.102	0.452	2.856
8	.6	63.76	17.840	37.724	6.366	23.592	7.244	0.106	0.628	3.934
12	.6	63.76	19.336	40.906	9.548	23.592	7.244	0.106	0.628	3.934
16	.6	63.76	20.831	44.089	12.731	23.592	7.244	0.106	0.628	3.934
20	.6	63.76	22.327	47.272	15.914	23.592	7.244	0.106	0.628	3.934
24	.6	63.76	23.823	50.454	19.096	23.592	7.244	0.106	0.628	3.934
28	.6	63.77	25.319	53.637	22.277	23.593	7.243	0.106	0.628	3.934
32	.6	69.86	26.779	55.525	21.174	18.609	11.942	0.106	3.906	24.449
36	.6	69.91	28.022	58.158	23.788	18.553	11.986	0.106	3.937	24.644
40	.6	79.37	29.155	60.030	18.120	22.993	13.634	0.106	5.389	33.730
60	.6	87.27	32.450	65.434	16.766	21.196	17.865	0.106	9.712	60.791
80	.6	90.69	34.699	69.479	16.360	22.034	19.484	0.106	11.706	73.269
100	.6	93.02	36.322	72.295	15.331	22.987	20.663	0.106	13.420	84.002
200	.6	95.63	41.724	83.465	19.179	29.576	20.529	0.105	14.287	89.426

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