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An Empirical Analysis of Economic Strategies for Controlling Air Pollution*

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In evaluating current environmental protection policy, economists often note that current regulations are more costly than necessary to meet environmental quality standards. While the *a priori* case is strong that current regulatory approaches are resulting in higher-than-necessary costs to attain environmental standards, there is relatively little empirical evidence to support this claim. The purpose of this paper is to supply some of the missing evidence by presenting the results of one study that assesses some of the potential savings associated with implementing economic, rather than command-and-control, regulatory approaches to abate one type of air pollution in one region of the country. Specifically, the paper examines the costs of meeting a prospective short-term standard for nitrogen dioxide under a range of alternative emissions control strategies for stationary sources of nitrogen oxide emissions in the Chicago Air Quality Control Region. The alternative strategies that are considered range from those that might result under current regulatory policy to those that economic policy approaches (such as emissions charges or marketable permits) are designed to implement. The analysis shows that the most efficient program of emissions controls may be more than an order of magnitude less costly than current regulatory strategies, and that economic approaches have additional advantages over more conventional regulatory approaches.

1. INTRODUCTION

In their evaluation of current environmental protection policy, economists have sometimes noted that current regulations are far more costly than strictly necessary to meet environmental quality standards.[2] This conclusion derives, in part, from the

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[1]A more detailed and technical presentation of the analysis may be found in [2]. In preparing that study, the authors benefited from the patient and constructive criticism from a number of people including David Tundermann, the Technical Monitor, as well as Allen Basala, Tayler Bingham, Alan Carlin, Alex Christofaro, Toby Clark, John Hoffman, Barbara Ingle, Skip Luken, Willard Smith, Paul Stolpman, and Larry White. The study was subsequently used by EPA together with additional work in [10]. The empirical work reported in the present paper reflects additions made by EPA in the Report to Congress; however, it should not be inferred that EPA necessarily endorses the conclusions expressed in the present paper. Any errors are, of course, the responsibility of the current authors. The opinions and conclusions expressed in this paper are not necessarily those of the organizations with which the authors are affiliated.

[2]See, for example, Kneese and Schultze [5].

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observation that regulations often fail to exploit opportunities for polluters to reduce costs while achieving required emissions standards.

The causes adduced for this failure are many. For example, the procedural requirements of current regulatory approaches result frequently in protracted seriatim (source-by-source) negotiations. The standards ensuing from this process are unlikely to reflect a careful balancing of abatement costs with abatement effectiveness. Additional impediments may be imposed politically by legislated environmental laws, especially in cases where little scientific support was available. As a result, sources may be required to adopt specific emissions standards based on proven (or potential) technologies and processes. This, in turn, leaves sources with little incentive to exceed mandated requirements.

While the *a priori* case is strong that current regulatory approaches are resulting in higher-than-necessary costs to attain environmental quality standards, there is relatively little empirical evidence to support this claim. One previous study undertaken by Atkinson and Lewis [3] employed data for the St. Louis Air Quality Control Region (AQCR) to look at alternative strategies to control particulate emissions from 27 major sources of air pollution. Using a somewhat simplified version of the methodology applied in this study, it was found that an air quality control strategy representative of those developed by states in preparing State Implementation Plans (SIPs) was six to ten times as costly as a strategy designed to achieve a prescribed ambient particulate standard at minimum cost.

The purpose of this paper is to supply further empirical evidence of how economic measures could be used to control stationary-source air pollution emissions. Specifically, the paper examines the cost of meeting a prospective "short-term" standard for nitrogen dioxide (NO_2) under a range of alternative emissions control strategies.[3] An "emissions control strategy" refers to any plan specifying emissions limitations to be achieved by the specific sources in a region. The alternative strategies that are considered range from those that might result under current regulatory policy to those that economic policy approaches are designed to implement. The results are strikingly similar to those of Atkinson and Lewis [3]: The most efficient program of emissions controls may be more than an order of magnitude less costly than controls corresponding to current regulatory strategies. Furthermore, economic approaches have several inherent advantages over more conventional regulatory approaches for implementation.

2. METHOD OF ANALYSIS

In proceeding with the analysis, the first question to be answered is: What effect does a control strategy have on ambient concentrations of NO_2? In addressing this question, it is taken as given that an acceptable plan must be effective in meeting and maintaining an ambient short-term, 1-hour standard for NO_2.[4] The second

[3] Short-term here refers to an air quality standard based on pollution concentrations averaged over a period of one hour. The EPA has been evaluating alternative short-term, 1-hour NO_2 standards in the range of 250 to 1000 $\mu g/m^3$ because of potential adverse health effects from corresponding exposures.

[4] It should be noted that the results of this analysis will differ according to the standard that is finally set (see below). Furthermore, if the environmental objective was maintenance and attainment of a *long-term* standard based on annual average concentrations, the conclusions would be expected to change because elevated concentrations of NO_2 during short averaging periods occur only sporadically.

question to be addressed is: What effect does the choice of strategy have on the costs of controlling nitrogen oxides? In answering this question, primary emphasis is on the costs incurred by polluters to control their emissions; however, consideration is also given to the costs incurred by polluters to administer their programs and to monitor their emissions as well as costs incurred by the public sector to administer, monitor, and enforce programs.

The Analytical Model

The starting point of the analysis of plans for the control of stationary-source emissions of nitrogen oxides is an examination of alternative emissions control strategies and their effects on the control expenditures necessary to achieve a specified ambient short-term, 1-hour NO_2 standard. Basically, the approach used for this exercise involves the application of a mathematical programming model to the problem.

The specific type of mathematical programming model adopted for the analysis was an integer programming model. This model is basically a variation of what is known in operations research as the Knapsack Problem.[5]

The basic elements of the programming model are as follows:

- Emissions—$E_{i_k} \geqslant 0$ representing nitrogen oxide emissions of the i^{th} source using control technology level k.
- Cost functions—$C_{i_k}(E_{i_k}) \geqslant 0$ representing the costs of controlling emissions at the i^{th} source using control technology level k.

Given these elements, the model estimates the total technological costs of emissions controls across all N_s sources:

$$\sum_{i=1}^{N_s} C_{i_k}(E_{i_k})$$

and the corresponding 1-hour ambient concentrations of NO_2 at each of N_r receptors:

$$\sum_{i=1}^{N_s} d_{i_k j} E_{i_k} \quad j = 1, \ldots, N_r,$$

where $d_{i_k j}$ is the contribution of the i^{th} source (with control technology level k in place) of nitrogen oxide emissions to concentrations of NO_2 at the j^{th} receptor.

Using this notation, the least cost optimization problem can be characterized as:

$$\text{minimize} \sum_{i=1}^{N_s} C_{i_k}(E_{i_k})$$

$$\text{subject to} \sum_{i=1}^{N_s} d_{i_k j} E_{i_k} \leqslant Q \quad j = 1, \ldots, N_r,$$

[5]See, for example, Senju and Toyoda [7], Toyoda [8], and Zanakis [12].

where $Q \geqslant 0$ represents the short-term NO_2 air quality standard that must be met at each of N_r receptors.

For each strategy analyzed, the model simultaneously produces two types of estimates. It computes the total costs of emissions control of nitrogen oxides for all sources on an annual basis. This provides a means for comparing strategies on the basis of these costs. At the same time, it calculates the 1-hour ambient NO_2 concentrations that would result at each receptor. This provides a means for comparing the strategies on the basis of effectiveness in reducing pollution.

The Data

The analysis was performed using data characterizing the Chicago Air Quality Control Region (AQCR) which represents an area approximately 150 by 80 kilometers and includes the following counties: Cook, Lake, Dupage, McHenry, Kane, and Will. Chicago was selected not only because data were available, but also because peak 1-hour NO_2 levels in Chicago were among the highest concentrations observed in any urban area of the United States [9, pp. 22–27].

Because only four continuous monitors of nitrogen oxides existed at the time of the study in the Chicago AQCR, it was necessary to develop an air quality assessment model to evaluate further the extent of the short-term NO_2 problem in the region. For this purpose, a multiple point- and area-source model known as RAM was used.[6] To implement, the model requires data on point sources, area sources, mobile sources, and meteorological conditions.

Point-source information for the Chicago AQCR was obtained and augmented with data from EPA's National Emissions Data System (NEDS) point-source subfile and from the Illinois EPA.[7] For each point source, data included: location, level of nitrogen oxide emissions and associated activity (capacity of unit, hours of operation per year), and characteristics of emissions point (stack height and diameter, exhaust gas temperature and volume). When required data were unavailable, default values typical of normal operating practice were used. Area-source data on small stationary sources emitting less than 10 pounds per hour of nitrogen oxides and mobile-source data primarily on automobiles were apportioned to 634 five-kilometer-square grid cells and entered into the area-source subroutine of RAM. Meteorological data on wind direction, wind speed, stability class, and mixing height were obtained from the National Weather Service and covered stations located in Greenbay, Peoria, Flint, and Dayton.

In addition to the above information, receptor locations were selected to "monitor" the impact of nitrogen oxide emissions across the Chicago AQCR. Their locations were difficult to determine because the pollution concentration at any point is a complex function of meteorological parameters, source locations and

[6]RAM is an EPA-approved, Gaussian steady-state model capable of predicting short-term ambient concentrations of relatively stable pollutants from multiple point and area sources. Since NO_2 is primarily a secondary pollutant formed by oxidation of nitric oxide (NO), a dynamic model of NO_2 formation was developed and used in conjunction with RAM to predict nitrogen oxide concentrations at receptors due to point sources and to translate them into NO_2 concentrations.

[7]Specifically, 472 point sources in 1975 were "updated" to 534 sources in 1984. "Point source" here is equivalent to a source classification code (SCC) source. Thus, several "point sources" may be found in a given plant. Since EPA deemed 1984 as the earliest possible date for implementing a short-term NO_x control strategy, EPA "updated" the 1975 source inventory to represent 1984 conditions; see [10, p. A2].

emissions, source overlaps, and so on. Several preliminary analyses revealed the presence of two distinct types of point sources: (1) large plants with tall stacks such as power plants, and (2) plants with a large number of smaller sources with short stacks such as steel mills and refineries. It was found that the diffusion characteristics of emissions from the second category were similar to those of area sources and that together these sources were the dominant cause of high short-term NO_2 concentrations in Chicago. Thus, for the final analyses, 200 high-impact receptors selected by RAM, along with approximately 400 other receptors "blanketing" the region were used.

Finally, information on specific nitrogen oxide control technologies and their associated costs was needed. EPA has identified roughly three hundred separate source categories that emit nitrogen oxides. Nine such categories were sufficient to characterize the important point sources in the Chicago AQCR. These were:

1. Utility Coal-fired Boilers
2. Utility Oil- and Gas-fired Boilers
3. Industrial Coal-fired Boilers
4. Industrial Oil- and Gas-fired Boilers
5. Gas Turbines
6. Large Internal Combustion Engines
7. Industrial Process Units
8. Nitric Acid Plants
9. Municipal Incinerators

For purposes of the analysis that follows, the control technologies applicable to these sources can be categorized in terms of *combinations* of the following techniques: combustion process modification, fuel modification, removal of nitrogen oxides from stack gases (flue gas treatment), and alternative combustion processes. The costs of implementing these controls as well as their effectiveness in terms of reducing emissions of nitrogen oxides were estimated by using data from a number of sources. Information on source size was used to estimate capital costs, while information on source utilization (annual hours of operation) was used to estimate operating and maintenance costs.[8] It is important to note that most of these data were based on engineering analyses of hypothetical plants with only limited "field" experience; hence, the actual cost-effectiveness of these control technologies could vary by a wide margin when applied to individual sources.

3. COMPARING CONTROL STRATEGIES

The relative efficiency (measured in terms of annual emissions control costs) and effectiveness (measured in terms of resulting ambient concentrations) of four basic emissions control strategies were compared. The strategies were:

1. No Control Baseline—which considers only those emissions controls already in place.

[8] The interested reader is referred to chapter 2 of [2] for further details.

TABLE 1
Analysis of Alternative Emissions Control Strategies for Chicago

Strategy	Number of sources controlled	Number of receptors in violation of 250 $\mu g/m^3$ standard	Areawide point-source emission rate reductions (percent)	Annual control costs (millions of dollars)
No Control Baseline	0	36	0	0
SIP (State Implementation Plan)	472	0	21	130
Least Cost	100	0	3	9
Source Category Emissions Controls	472	0	18	66

2. SIP (State Implementation Plan)—which requires similar categories of major polluting sources to meet specific technology-based uniform levels of emissions control.

3. Least Cost—which establishes emissions limits by source based on each source's control costs and impact on ambient air quality.

4. Source Category Emissions Controls—which establishes uniform emissions limits for each source *category* consistent with the air quality objective.

The results of the comparison of these strategies are reported in Table 1.

No Control Baseline

To analyze this case, the model was run under the assumption that no *new* emissions controls were put in place. That is, the 1975 source inventory characteristics updated to 1984 conditions (see Fn. 7) were adopted.[9] As can be seen from Table 1, 36 of the receptor locations used in the final analysis indicated potential violations of a 250 $\mu g/m^3$ short-term, 1-hour NO_2 standard. Since no new emissions controls were added it was assumed that no further reduction in nitrogen oxides emissions would take place and no additional costs would be borne under this strategy.

SIP (State Implementation Plan)

This strategy, which simulates the "traditional" approach to pollution control,[10] applies the highest level of emissions control to *all* sources in the three source

[9]Presumably, these characteristics account for any existing pollution controls required to ensure attainment of the current *annual* standard for ambient concentrations of NO_2.

[10]If EPA promulgates a short-term NO_2 standard, many existing State Implementation Plans (SIPs) would have to be revised. Such revisions would involve state regulations prescribing emissions limitations for specific source categories and timetables for compliance. Under the Clean Air Act, states are allowed nine months after a standard is issued to develop their plans, which must demonstrate attainment within three years. Until the area attains the standard, the applicable emissions regulation for an existing source is termed Reasonably Available Control Technology (RACT) and for a new source it is termed Lowest Achievable Emissions Rate (LAER) achieved in practice for that source category, or the most stringent emissions limitation contained in any SIP (whichever is more stringent).

categories that were the major stationary-source polluters in Chicago. The three source categories were: industrial coal-fired boilers, industrial oil- and gas-fired boilers, and industrial process units. Table 1 indicates that for this simulation, controls were placed on 472 sources in these categories, and that these controls were sufficient to attain the ambient standard at all receptor locations. It can also be seen that areawide point-source emissions rates would be reduced by 21% under this strategy. The incremental costs associated with implementing SIP (over and above the No Control Baseline) were estimated to be $130 million per year.

Least Cost

The Least Cost strategy was found by using the programming model described in Section 2 to find a set of emissions controls that simultaneously minimize control costs and meet the short-term 1-hour NO_2 standard at all receptor locations. By definition, under the Least Cost strategy, no receptors would be in violation of the 250 $\mu g/m^3$ standard. Furthermore, as seen in Table 1, only 100 of the point sources would require emissions controls *over and above* those controls associated with the No Control Baseline. These emitters were all from the three most polluting source categories noted above: industrial coal-fired boilers, industrial oil- and gas-fired boilers, and industrial process units.[11] It is also interesting to note that a reduction of only 3% in the areawide emissions rates would be sufficient to attain the short-term standard at all receptor locations. Finally, it can be seen that the annual costs associated with the Least Cost strategy were estimated to be only $9 million more than the No Control Baseline.

Source Category Emissions Controls

This strategy requires the application of a uniform set of emissions controls across all sources in a particular source category. As such, it circumvents the need for the source-by-source emissions limitations necessary to implement the Least Cost option and represents a relatively sophisticated use of current regulatory planning methods. The emissions control level specified for a given source category was that control level—for example, dry selective catalytic reduction (flue gas treatment)—required to ensure that no emitter in the class would violate the short-term, 1-hour ambient standard at any receptor.[12] Again, the three source categories requiring controls were: industrial coal-fired boilers, industrial oil- and gas-fired boilers, and industrial process units. As defined, under this strategy all receptors would be in compliance with the short-term, 1-hour NO_2 standard. The reduction in areawide emissions rates was estimated to be 18% and the total control costs were estimated to be $66 million annually over and above the No Control Baseline (see Table 1).

[11] It should be stressed that this does not mean that other sources were not *contributing* to violations of the short-term, 1-hour standard, only that it was not cost-effective to control those sources.

[12] Note, this differs from the SIP strategy in that it does not require that the most stringent control level be applied to each source category in question.

Summary of Findings

The preceding analyses demonstrate that abatement strategies designed to exploit differences in sources' emissions control costs as well as associated meteorological-dispersion characteristics are significantly less costly than those that do not account for such factors. For example, the results for Chicago indicate that a Least Cost strategy is less than one-tenth as costly as a strategy that reflects a more traditional regulatory approach (SIP) and less than one-seventh as costly as a strategy that represents a relatively sophisticated version of current regulatory approaches (Source Category Emissions Controls). In absolute terms, a policy that would lead to the adoption of a scenario approximating the Least Cost strategy to meet a short-term, 1-hour NO_2 standard could save more than $100 million annually in technological control costs in the Chicago Air Quality Control Region alone.

4. IMPLEMENTATION: POLICY INSTRUMENTS AND RELATED ISSUES

It would be premature to conclude that the less costly strategies described would necessarily be superior *in practice* to more traditional regulatory approaches. This follows from the fact that the policy instruments needed to implement the less costly strategies may be unavailable because of legal or political constraints, or may be so costly to administer as to offset the potential savings in emissions control costs. One category of policy instruments—emissions charges—can be examined briefly to shed more light on these issues.[13] In doing so, alternative emissions charge plans will first be described. This will be followed by an examination of informational requirements, their associated costs, and some legal considerations.

Alternative Emissions Charge Plans

The results of a mathematical programming analysis of the type discussed above can be used to formulate emissions charge schemes. In particular, charges were set at the minimum amounts required to ensure that the ambient standard would be achieved at all receptors when the sources acted in their economic self-interest to minimize the sum of annual control costs plus charge payments. It should be noted that the charges were applied to emissions *rates* rather than simply to emissions. This is necessary because a charge scheme based on total emissions would not ensure attainment of a 1-hour standard since sources could reduce their charge liabilities simply by reducing their hours of operation without reducing their *rate* of emissions. The resulting source-by-source charge levels (and the associated annual liabilities for charge payments) were found to vary considerably by source. Total annual liabilities for the charge payments amounted to $4 million or almost 50% of the total control expenditures estimated under the Least Cost option.

[13] No explicit consideration is given here to a system of marketable emissions permits for implementing efficient control strategies. However, such policy instruments were analyzed in [2, Chapter 7] and in [10], and were shown to have many favorable attributes and in some ways were thought to be easier to implement and superior to emissions charge systems.

TABLE 2

Effects of Alternative Charge Systems for Chicago

Plan	Number of sources controlled	Areawide point-source emissions rate reductions (percent)	Annual control costs (millions of dollars)	Annual charge payments (millions of dollars)	Annual control costs + charge payments (millions of dollars)
Least cost (source-by-source) charge levels (see text)	100	3	9	4	13
Uniform charge levels ($15,800 per year per pound per hour)	534	84	305	414	719
Source category charge levels[a]	472	18	66	89	155

[a]Industrial coal-fired boilers = $15,800 per year per pound per hour; industrial oil- and gas-fired boilers = $15,300 per year per pound per hour; and industrial process units = $3500 per year per pound per hour.

The marked differences in charge levels and liabilities together with the preceding comparison of control strategies reaffirm that a system based on uniform treatment of sources or even uniform treatment by source classification is not consistent with the implementation of an efficient control program. Nevertheless, it is recognized that there may be practical difficulties in implementing a system in which "seemingly similar" sources are treated differently.[14]

In order to more fully explore the "excess" control costs associated with establishing more uniform charge systems, two alternative schemes were examined. Under the first system, denoted the Uniform Charge plan, a single charge level was levied on all sources. The magnitude of the charge was set at the lowest amount that would ensure compliance with the short-term, 1-hour NO_2 standard at all receptors. That amount was equal to $15,800 per year (per pound of nitrogen oxides per hour).

Under the second system, designated the Source Category Charge plan, three different charge rates were set, one for each of the three source classes that were controlled under the Least Cost strategy.[15] The magnitudes of these charges were set equal to the highest *average* annual control costs (per pound of nitrogen oxides per hour) in each source category under the Least Cost option. The resulting charge levels were $15,800 per year (per pound of nitrogen oxides per hour) for industrial coal-fired boilers, $15,300 for industrial oil- and gas-fired boilers, and $13,500 for industrial process units.

Table 2 presents the results of implementing these alternative schemes together with the basic results from the Least Cost Charge plan (described above). As can be seen, the Uniform Charge plan is associated with estimated nitrogen oxide emissions

[14]For example, it is quite conceivable that the Least Cost strategy would require two plants producing competing brands of the same product to meet substantially different emissions limitations because their locations (and impacts on ambient air quality) differed.

[15]The reader will note similarities between the Source Category Charge plan and the Source Category Emissions Control strategy discussed above.

rate reductions of more than 80% below the levels corresponding to the Least Cost Charge plan, but estimated annual emissions control costs exceed the costs under the Least Cost Charge plan by almost $300 million; annual charge payments are $410 million greater. Under the Source Category Charge plan, emissions rates are reduced by approximately 15% below the levels corresponding to the Least Cost Charge plan but estimated annual emissions control costs are about $57 million greater than those associated with the Least Cost Charge plan and annual charge payments are about $85 million greater. Thus, while the more uniform plans do reduce nitrogen oxide emissions rates substantially below emissions rates under the Least Cost Charge plan, these reductions are exceedingly costly and represent overcontrol in that all figures are based on minimum charge levels necessary to ensure attainment of the short-term, 1-hour NO_2 standard. At the same time, the Least Cost Charge plan appears to impose the smallest *overall* burden on sources (and ultimately society).

Informational Requirements, Associated Costs, and Legal Considerations

As alluded to above, it is sometimes suggested that despite possible Control cost savings associated with economic approaches to pollution control, implementation costs of such approaches would more than offset the potential savings. Therefore, it is useful to explore the feasibility and costs of implementing these approaches.

The Appendix details estimates for the range of administration, monitoring, and enforcement (AME) activities required to implement a regulatory system and a charge system in Chicago. There it is shown that the costs directly attributable to the administration, monitoring, and enforcement of a charge system to control stationary sources of nitrogen oxide emissions are of the same order of magnitude as the costs associated with implementing an effective regulatory policy.[16] The main reason for this is that effective regulation is likely to involve more investigation, negotiation, and litigation than would an equally effective incentive system. At the same time, it is recognized that existing legislation may need to be amended explicitly to allow implementation of such incentive systems. Nevertheless, it does not appear that legal considerations pose serious barriers to the implementation of economic approaches to pollution control such as emissions charge systems. While such approaches and the requisite supporting legislation represent a somewhat new regulatory framework and, as such, have not been fully tested in the courts, a thorough examination of the possible legal bases for implementing these types of economic inventive systems led one study to the conclusion that "[m]any different sources of government power could be invoked to legitimatize the legislature's imposition of charge plans,..." [1, p. 144].

5. CONCLUSIONS

The quantitative analysis of emissions control strategies for Chicago shows that approaches designed to account for differences in sources' incremental costs of

[16] While the cost estimates forming the basis for this conclusion are, at best, approximate, it is unlikely that further refinement would change the qualitative results.

controls and incremental contributions to ambient pollution concentrations can achieve a short-term ambient NO_2 standard at significantly lower costs than strategies that do not account for these differences. While acknowledging some of the practical difficulties in implementing such strategies as well as legal and political considerations, these problems do not appear to be insurmountable.

The analysis also suggests that emissions charge plans can provide profit-and-loss incentives to firms sufficient to induce the degree of emissions controls required to attain the short-term NO_2 standard in an economically efficient manner. Furthermore, a charge system provides an effective stimulus to the development and application of new emissions control technology. This, too, is an important practical advantage of the emissions charge approach. It is especially apparent if one recognizes that in the simulation study of Chicago, the emissions control technologies required to meet a short-term, 1-hour NO_2 standard of 250 $\mu g/m^3$ were technologies that are only *projected* to become available (at the earliest) between 1981 and 1985. Clearly, efficient and effective environmental policy must provide incentives for technological development, and economic approaches—in the form of emissions charges or marketable emissions permits—do exactly this. Taken as a whole, then, the magnitude of the potential cost savings associated with simulating such a system in only one region, together with the attributes just noted, appear to provide adequate justification for further experimentation and analysis of economic approaches to control environmental pollution.

APPENDIX: ADMINISTRATION, MONITORING, AND ENFORCEMENT ESTIMATES FOR THE CHICAGO AQCR

To effectively implement the economic strategies described above, the regulatory authority must know sources' emissions rates, the impact of these emissions on ambient air quality, the effects of abatement controls on emissions, and the costs of these controls.[17] One of the most important aspects concerning these informational requirements is the ability of existing monitoring techniques to provide adequate and reliable data. It appears that technically adequate nitrogen oxide emissions monitoring systems are currently available at a cost that is considerably smaller than the total costs of abatement associated with meeting a short-term, 1-hour NO_2 standard of 250 $\mu g/m^3$.[18] This is true even under the Least Cost emissions control strategy in which the average annual control cost per controlled source is approximately $90,000 ($9 million divided by 100; see Table 1). Under the conservative assumption that each controlled source would require a separate monitoring system,[19] annual monitoring costs were estimated to be on the order of $25,000 per source.

It was also noted that under any policy approach to pollution control, sources will bear the burden of some costs of monitoring and reporting their emissions. Thus, one would not expect the costs of these activities to differ very much between a

[17] While it has been discussed in the theoretical literature that a regulatory agency could achieve air quality objectives under a "standard-and-charges" program without knowledge of sources' control costs by adjusting charge rates until the desired objectives were achieved (see, for example, [4, p. 144]), in practice, the rigidities imposed by economic, political, and legal constraints make this seem unlikely.

[18] For details see [2], especially Section 2.5.

[19] The assumption is conservative in that many sources are co-located and could therefore share some or all parts of the monitoring system.

TABLE 3
Administration, Monitoring, and Enforcement Estimates for the Chicago AQCR

	Regulatory system		Charge system	
Activity	Person-years	thousands of dollars[a]	Person-years	thousands of dollars
Initial (one-time) efforts:				
Dispersion modelling	0.24	5	0.24	5
Determining emissions control cost functions	—	—	0.32	6
Equipment expenditures	—	150	—	150
Total	0.24	155	0.56	161
Recurring (annual) efforts:				
Administration	26 to 30	376 to 445	29 to 37	370 to 489
Monitoring	9 to 15	104 to 207	8 to 15	108 to 207
Enforcement	27 to 110	441 to 1950	19 to 44	280 to 631
Total	62 to 155	921 to 2602	56 to 96	758 to 1327

[a] All expenditures in 1978 dollars. Salary information was obtained from [11, p. 40]; estimates do not include overhead and fringe benefits.

regulatory approach and one based on an economic approach such as an emissions charge plan. The main difference would be related to some additional accounting and record-keeping activities necessary under a charge system. Following an examination of alternatives for carrying out these activities, it was concluded that they could be relatively easily and inexpensively integrated into the hardware and software associated with emissions monitoring systems that would be required under conventional regulatory approaches. Specifically, the incremental annual cost was estimated to be on the order of, at most, \$2500 per source.[20]

Table 3 details the complete personnel and cost estimates for the range of administration, monitoring, and enforcement (AME) activities required to implement a regulatory system and a charge system in Chicago. Note that there are essentially two stages of effort. Initially, estimates of transfer coefficients (the $d_{i_k j}$ described on p. 114), background concentrations of pollutants, and (in the case of a charge system) engineering-based emissions control cost functions would be derived. Subsequently, there would be less intense, on-going efforts to improve this information as well as the recurring costs associated with operating the systems.

These estimates were derived by using the format developed in an EPA "manpower planning model" [6]. However, since the model focuses only on state and local agencies, it was necessary to include supplementary information on Federal involvement.[21] Specifically, it was found that in the Chicago AQCR, a major portion of Federal activity involves case development; that is, bargaining and negotiating with sources on acceptable compliance schedules. Since sources can realize substantial economic benefits from delaying compliance, they often challenge agency-desired

[20] Details on system configurations and estimated development and system costs can be found in Section 6.8 of [2].

[21] Much of this information was obtained through conversations and correspondence with Tom Donaldson, USEPA, Control Program Section, Research Triangle Park; Ron Shafer, USEPA, Washington, D.C.; Pat Reape, Enforcement Division, USEPA, Region V; Wayne Jones, Division of Air Pollution Control, Illinois EPA; and Mr. Kason of the Department of Environmental Control, City of Chicago.

control techniques or the time frame for compliance. Thus, the agency must have resources available for intensive negotiating sessions as well as for courtroom appearances in formal legal proceedings. It was estimated that such activities could require between 7 and 45 person-years at a cost of between $100,000 and $700,000 annually.[22] The estimated range of total AME costs under a regulatory system were $900,000 to $2.6 million annually, with personnel effort ranging between 62 and 155 person-years.

The specific charge system used in the development of corresponding AME costs estimates was based on the Least Cost Charge plan discussed above. Again, calculations were made using the framework in the EPA manpower planning model. Table 3 indicates that a Least Cost emissions charge program could be implemented in the Chicago AQCR with AME costs running between $750,000 and $1.3 million annually and with personnel effort ranging between 56 and 96 person-years.[23]

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[22] These figures are incorporated in the category of recurring annual enforcement costs of the regulatory system.

[23] It should be noted that these numbers do not reflect Federal-level case development activities, since it is assumed that no compliance schedules are required under a charge system.