

# The Empirical Properties of Two Classes of Designs for Transferable Discharge Permit Markets<sup>1</sup>

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Previous work by Atkinson and Lewis (*J. Environ. Econ. Manag.* 1, 237-250 (1974)) and Anderson *et al.* ("An Analysis of Alternative Policies for Attaining and Maintaining a Short-Term NO<sub>2</sub> Standard," MATHTECH, Inc., Princeton, N.J., 1979) has indicated the tremendous cost advantages to be achieved by moving from a policy based on emission standards to one based on marketable emission permits. As Tietenberg (*Land Econ.* 56, 391-416 (1980)) points out, however, neither of the major permit designs treated in the literature are optimal from all points of view. This has triggered a search for alternative permit designs, which, while they may not minimize compliance costs, have sufficient other virtues as to make them attractive on other grounds. The purpose of this paper is to examine, within the context of an empirical mathematical programming model, the air quality, emission, and cost consequences of two classes of the permit designs which can be implemented in the absence of information on control costs. This case study involves particulate control in St. Louis.

## I. INTRODUCTION

### *Background*

The U.S. Environmental Protection Agency (EPA) has embarked on a new regulatory approach to controlling air pollutant emissions through controlled trading of the right to pollute. The principal objective of these reforms is to reduce the rapidly increasing costs of pollution control. The two main existing manifestations of this approach are the "bubble" and "offset" policies.<sup>2</sup> The former allows an emitter to relax the control on one or more sources of a particular pollutant providing it secures an equivalent reduction of the same pollutant from some other nearby source. The latter allows new sources of pollution to enter a region where the standards are already exceeded provided that the new source procures sufficient reductions in emissions from existing sources (over and above their previous legally mandated reductions) to guarantee that the air quality will be improved as a result of the transaction. The EPA is also exploring the possibilities of introducing similar

<sup>1</sup>The authors wish to acknowledge the helpful comments received from Cliff Russell and two anonymous referees.

<sup>2</sup>See 44 FR 71780 (11 December 1979) and 40 CFR 51 Appendix S, originally presented in 44 FR 3274 (16 January 1979).

regulatory innovations in areas which are now cleaner than the standards, but which face the prospect of limited growth in the future.<sup>3</sup>

All of these regulatory initiatives involve restrictions on the trades which can take place. There is sympathy within EPA for eliminating some of the restrictions on these trades, providing the less restrictive trades involve no threat to air quality. The empirical question which is the focus of this paper is how the permits (which define the property right to be traded) and the permit markets (which govern the trading possibilities) can be defined so as to minimize the compliance costs of achieving air quality standards while imposing tolerable regulatory burdens on the state control authorities. By tolerable regulatory burdens we mean simply those which depend on information which the regulatory authority can reasonably be expected to have. Specifically, we examine systems which can be implemented without any information on control costs.

The theoretical characteristics of two marketable permit (MP) systems—the ambient permit and the emissions permit systems—are well known.<sup>4</sup> If the objective is to produce the desired air quality at  $N$  predetermined receptor locations at minimum cost, an ambient permit system involving spatially differentiated permits is appropriate. This system takes into account each source's emission diffusion characteristics, which map emissions to each specific receptor's air quality. If, on the other hand, the objective is to reduce the total amount of emissions in an area at minimum cost, the administratively simpler emissions permit system, relying on spatially undifferentiated permits, is appropriate.

Unfortunately, as the set of policy concerns is expanded beyond a singular focus on the cost of compliance neither MP system is dominant. Both the ambient permit and emissions permit systems have shortcomings associated with them. The chief problem with the ambient permit system is its administrative complexity. In order to ensure the cost-effective allocation of the control responsibility among emitters for the achievement of the ambient standards monitored at  $N$  receptor locations, the control authority would have to establish  $N$  separate permit markets for each pollutant.<sup>5</sup> Each emitter whose emissions had an appreciable effect on the air pollution level at more than one receptor would have to purchase multiple permits to legitimize a single source of emissions. Though this may be manageable it does create a certain interest in seeing whether administratively simpler permit designs could approximate the ambient permit system.

The ambient permit system also has one other potentially undesirable characteristic—while it controls ambient air quality at the receptor locations it may do so while allowing increases in total regional emissions. While total emissions are clearly of secondary importance in the Clean Air Act, strategies which allow large aggregate emission increases may not be allowed under the current Act.<sup>6</sup> It therefore becomes important to establish the degree to which the cost superiority of the ambient permit

<sup>3</sup>See the advanced notice of proposed rulemaking on the Set II pollutants for the prevention of significant deterioration in 45 FR 30088 (7 May 1980).

<sup>4</sup>See Tietenberg (1980).

<sup>5</sup>It may be that at a particular point in time fewer than  $N$  are needed because air quality at some receptors will be below the legal threshold. Nonetheless to guarantee that the ambient standards are met at all receptors for all points in time all  $N$  permit markets need to be activated.

<sup>6</sup>See, for example, the "reasonable further progress" requirement which is defined in terms of aggregate emission reductions rather than improvements in air quality. 42 USC 7501(1) and 42 USC 7503.

system is due to the fact that it allows more of the pollutant to be emitted. Empirical estimates of the importance of this issue are presented in Section IV.

The emissions permit system is generally not a particularly close substitute for an ambient permit system due to the fact that aggregate emissions (the variable being controlled) is not uniquely related to the ambient air quality targets specified in the Clean Air Act.<sup>7</sup> First in order to insure the ambient standards are met, the aggregate level of allowable emissions has to be reduced sufficiently to ensure that the air quality at the most polluted receptor location meets the standard. This results in substantial over-control of the more distant sources, thus increasing the cost of compliance to achieve specified air quality levels. Work by Atkinson and Lewis (1974) on particulate control in St. Louis and Anderson *et al.* (1979) on nitrogen oxide control in Chicago indicates that the increase in compliance cost from using an emission permit system to achieve the ambient standards can be substantial.

The second reason why an emission permit is not a close substitute for an ambient permit is that even if the control authority can find a feasible initial permit allocation there is nothing to guarantee that it will remain feasible over time. A feasible permit allocation is defined as one which results in a geographic allocation of emissions which satisfies the ambient standards. Suppose that a feasible allocation currently exists and that a new source enters the area. The emissions permit system, if enforced, will guarantee that the total level of emissions in the area will be the same before and after the entry of the new source. This source will have purchased a sufficient number of permits from existing sources (necessitating emission reductions by them) to offset its own increase in emissions to the area. If the permits, however, are purchased from emitters in relatively clean parts of the region and used in relatively polluted parts of the region the result will trigger a violation of the ambient standard in a region which was formerly in compliance. The emission permit system is, by itself, powerless to prevent these "hot spots" from emerging.

The fact that neither of these permit systems is optimal from all points of view has triggered a search for alternative permit designs which, while they may not be optimal, may represent a reasonable, pragmatic compromise. The search is for a permit design with low compliance cost as well as low administrative and enforcement cost which provides reasonable assurance that "hot spots" will not arise over time.

### *An Overview of the Paper*

The purpose of this paper is to examine, within the context of an empirical mathematical programming model, the air quality, emission, and cost consequences of a variety of these limited information permit designs. They are limited information in the sense that the control authority can implement them without any information on the costs of control faced by emitters. The focus on limited information designs is dictated by the pragmatic realization that control authorities rarely have this information.

The next section of the paper introduces the types of permit designs considered and formulates the programming models which simulate their effects on control cost,

<sup>7</sup>It can be a good substitute when the location of the emission source is of no consequence. This would be the case, for example, with pollutants which rapidly become uniformly mixed in the atmosphere or with global pollutants (e.g., fluorocarbons).

aggregate emissions, and air quality. Section III presents the data employed to operationalize these programming models. Section IV summarizes the main empirical results and Section V draws some conclusions and speculates on their generality for other geographic areas, other pollutants, and other periods of time.

## II. MODELS OF MARKETABLE DISCHARGE PERMIT SYSTEMS

The types of marketable permit (MP) designs considered in this paper are modifications of the two basic permit types discussed above—ambient permits and emission permits. The modification of the ambient permit design involves the use of a single ambient permit market tied to the receptor with the worse air quality. This reduces the administrative complexity of the full ambient permit market, but, of course, it does so at some loss of control over air quality measured at the other receptor locations and increased compliance costs for meeting the air quality standards at all receptor locations. The empirical question is how severe these impacts are.

The various modifications of the emissions permit design involve restricting the trading areas of the permits, using trading zones, to reduce the “hot spot” problem. Restrictions on trading areas, however, have three undesirable effects: (1) they raise compliance cost by eliminating some cost reducing trading possibilities, (2) they make the final outcome sensitive to the initial allocation of permits of the control authority (since the initial allocation determines the aggregate amount of emissions allowed in each zone), and (3) they reduce the number of buyers and sellers which increases the potential for noncompetitive behavior. In light of the second effect a complete specification of the various modified emission permit designs must include some rules for initially allocating the permits to the trading zones.

In general, these various permit markets may be simulated by solving the primal and dual constrained cost-minimization programming problems which describe these systems. The validity of this simulation is compromised to the extent that the following assumptions fail to hold in reality:

- (1) Plants choose the least-costly combination of control devices and MPs;
- (2) Firms are on long-run cost functions as described by the programming problem objective function;
- (3) Buyers and sellers of permits are sufficiently numerous within each zone so that permit prices are independent of individual actions; and
- (4) Plant production and consumption functions are independent.

In the primal problem control costs are minimized subject to a set of linear constraints. Solution of the primal problem yields the cost-minimizing level of control to be undertaken by each firm. Subtraction of these values from uncontrolled emission levels yields the volume of permits which each plant must purchase. The dual variables associated with the permit constraints represent the permit prices.

### *The Ambient Permit System*

The first benchmark case is provided by a model of the ambient permit (AP) system. It serves to define the minimum compliance cost for meeting the ambient

standards as well as to provide an empirical basis for subsequent discussions of some problems with the ambient permit approach.

Assuming that cost functions are highly nonlinear and convex for all sources, we approximate the AP cost-minimization problem with a quadratic program:

$$\text{minimize} \quad z = \sum_j c_j x_j + \sum_j d_j x_j^2 \quad (1)$$

$$\text{subject to} \quad \sum_j a_{ij} x_j \geq b_i, \quad i = 1, \dots, m, \quad (2)$$

$$x_j \geq 0, \quad j = 1, \dots, n, \quad (3)$$

where:

$b_i$  = the reduction in particulate concentration required to achieve the standard at the  $i$ th receptor ( $i = 1, \dots, m$ ),

$c_j, d_j$  = coefficients representing the cost of control per day for the  $j$ th source ( $j = 1, \dots, h$ ),

$x_j$  = the number of tons to be removed per day by the  $j$ th source,

$a_{ij}$  = the transfer coefficient which relates all emissions from the  $j$ th source to air quality at the  $i$ th receptor.

This formulation indicates that we assume, as have other studies, the independence of individual source control and the absence of possible synergistic effects in our transfer coefficients.

The objective function to be minimized in Eq. (1) and the constraints in equation set (3) remain the same for all permit strategies. Only the constraint inequality in (2) changes. For the AP system, (2) guarantees that reductions in ambient concentrations will be at least sufficient to meet the standard at receptor  $i$ .

Ambient air quality standard  $q$  implies a unique  $b_i^q$  ( $q = 1, \dots, t$ ) at each receptor. The volume of permits to be issued at receptor  $i$  for standard  $q$  consistent with the solution to cost-minimizing problem in Eqs. (1)–(3) is then determined as

$$p_i^q = u_i - b_i^q, \quad i = 1, \dots, m, \quad (4)$$

where:

$u_i$  = uncontrolled air quality at receptor  $i$

and

$b_i^q$  = required improvement in air quality at receptor  $i$  for standard  $q$ .

The volume of permits to be issued for the other MP strategies are also calculated using Eq. (4).

Assuming an initial distribution of permits, free permit trading is allowed within zonal boundaries, in this case the boundaries of the region. Each source must calculate its uncontrolled emissions, map them into air quality degradation at each receptor  $i$  using an agreed-upon diffusion model, and then purchase sufficient ambient permits at each receptor to cover this degradation. The permit price at receptor  $i$  equals the dual shadow value for constraint  $i$  in Eq. (2). Each source

purchases permits only if the expenditure on ambient permits at all receptors required due to an increment of emissions is less than its relevant marginal cost of control, i.e., if the dual constraint corresponding to Eq. (2) fails to hold with equality.

### *The Emission Permit System*

The Emission Permit (EP) system quadratic programming problem is written as:

$$\begin{array}{ll} \text{minimize} & z \\ \text{subject to} & \sum_j x_j \geq d \end{array} \quad (5)$$

and the constraints in equation set (3), where the scalar,  $d$ , is the aggregate amount of regional emissions which must be removed.

To operationalize this model a value for  $d$  is needed which is *ex ante* feasible. Following the procedure utilized by many states to justify the adequacy of their SIPs, we use a rollback model. The rollback model is based on a linear relationship between regional emissions and air quality. A given percentage improvement in air quality at the receptor with the worse regional air quality is assumed to require the same percentage reduction in emissions. Thus

$$d^q/\text{RE} = (B_{\max} - B^q)/(B_{\max} - B_{\text{back}}), \quad q = 1, \dots, t, \quad (6)$$

where:

RE = total regional emissions,

$B_{\max}$  = existing pollution concentration at the receptor having the highest measured or estimated concentration in the region,

$B^q$  = air quality standard  $q$ ,

and

$B_{\text{back}}$  = background pollution concentration.

Equation (6) may be easily solved for  $d^q$ . Equation (6) will be completely accurate (i.e., result in *ex post* feasibility) only under the extreme condition that individual source emissions are nonsynergistic and that all sources have the same linear transfer coefficient. We use it here to approximate current regulatory behavior and to derive empirically an estimate of the precision of this behavior.

As with the AP strategy, permit trading is allowed throughout the entire region. However, with the EP system, permits are purchased by sources strictly for emission discharge rather than air quality degradation. Emission permits trade at a uniform price equal to the shadow value corresponding to Eq. (5). Thus, the EP problem requires that sources trade permits to minimize total control costs subject to the constraint in Eq. (5) on total emission removal.

For this emission permit system and for the various modifications which follow, *ex post* air quality levels will, in general, differ from *ex ante* levels. Although the control authority theoretically could iteratively adjust the number of permits in

circulation to achieve desired air quality after the initial installation of control devices and purchase of permits, such a policy appears unlikely to be followed because of the uncertainty it would induce. Therefore, for the purpose of this paper, in order to simulate what we consider to be the most likely alternatives we do not iterate.

### *The Highest Ambient Permit System*

The highest ambient permit (HAP) system defines a single market in ambient permits. The permits in this market are defined in terms of the most polluted receptor location. The HAP system separable linear programming problem may be written as:

$$\begin{array}{ll} \text{minimize} & z \\ \text{subject to} & \sum_j a_j^* x_j \geq b^* \end{array} \quad (7)$$

and the constraints in equation set (3), where:

$b^*$  = the greatest required reduction in pollution concentration among the  $i$  receptors,

and

$a_j^*$  = the transfer coefficients relating emissions from source  $j$  to ambient concentrations at the receptor with the greatest required reduction in pollution concentration.

Equation (7) represents the permit market constraint. The major difference between the HAP and the AP systems is reflected in this equation. While both systems allow trading of permits within the entire region to minimize total control costs, for the HAP system  $b^*$  is a scalar (reflecting the single permit market) while for the AP system it is a vector (reflecting the many permits involved).

### *Modified Emission Permit Systems*

Three types of multiple-zone modified emission permit systems are simulated, all of which may be considered as generalizations of the emission density zoning systems examined recently by the EPA.<sup>8</sup> The multiple-zone systems include the Zonal Discharge Permit–State Implementation Plan (ZDP–SIP) system, the Zonal Discharge Permit–Rollback (ZDP–R) system, and the Uniform Zone Discharge Permit (UZDP) system. For all three systems trading within the zones is permitted while trading across zonal boundaries is not. Thus, greater control over “hot spots”

<sup>8</sup>See Kron *et al.* (1978). Emission density zoning systems as proposed by Kron (EPA) are simply a specialization of the general zonal emission permit model, Eq. (8). Typically, emission discharge is maximized subject to air quality restrictions. However, since no allowance is made for least-cost trading of permits within zones, these systems should be far less cost-effective than any of the zonal systems examined in this paper which allow permit trading.

is obtained but at some (to be determined) higher cost of compliance. For all three of these systems *ex ante* and *ex post* air quality will diverge.

The same quadratic programming problem describes the three multizonal MEP systems:

$$\begin{aligned} & \text{minimize} && z \\ & \text{subject to} && \sum_j e_{jw} x_j \geq d_w, \quad w = 1, \dots, r, \end{aligned} \quad (8)$$

and the constraints in equation set (3), where:

$d_w$  = the aggregate required emission reduction in zone  $w$ ,

and

$e_{jw}$  = 1 if source  $j$  is in zone  $w$  and 0 otherwise.

The three multizonal emission permit systems differ in either: (1) the calculation of zonal emission reduction,  $d_w$ , or (2) the mapping of sources to zones, as specified by the  $e_{jw}$ . Free trades are permitted within zones, but not among zones. The permit prices will generally vary among zones and are given by the dual variables associated with (8).

The ZDP-SIP and ZDP-R systems both allow the use of nonuniform zones (the exact configuration is discussed in the next section) and differ only in the initial allocation of permits among these zones. The ZDP-SIP system determines zonal permits as the sum of SIP allowable emission rates within each zone. The ZDP-R system employs the rollback calculation, Eq. (6), to determine allowable emissions within each zone, where  $B_{\max}$  in each zone is generally the air quality of the highest concentration receptor in that zone. The UZDP system employs grids of generally uniform size and determines zonal permit volumes using the rollback model.<sup>9</sup>

### III. DATA: THE ST. LOUIS CASE STUDY

The data employed in this study comprise the 27 largest point sources of particulate emissions in the St. Louis Air Quality Control Region (AQCR), accounting for approximately 80% of total particulate emissions.

<sup>9</sup>Transfer coefficients, whose utilization in the AP strategy is a major source of control cost reduction, generally cannot be employed to allocate regional control burdens to zones or to allocate zonal control burdens to individual sources. Infeasible fractions of total regional emission reductions can be easily allocated to zones (i.e., required zonal reductions exceed uncontrolled zonal emission levels). This could easily occur, for example, if the fraction of regional emissions to be removed within each zone were determined by the relative impact of zonal emissions on the highest-concentration receptor in the entire region.

In addition, substantial infeasibilities in intrazonal permit trading can be created by the use of transfer coefficients to assign individual source control burdens. If, for example, the permits within each zone are purchased by each source for degradation of air quality at the highest-concentration receptor within each zone, infeasible solutions (i.e., required air quality improvements are not met even though all sources control all emissions) can easily result since interzonal pollution flows are not considered in assigning control responsibility.

### *Control Cost Data*

Source-receptor transfer coefficients, employed in the AP and HAP constraint equations and utilized in the diffusion model to map source emissions into air quality for the other strategies, are derived using a Gaussian diffusion model developed by Martin and Tikvart (1968). The meteorological input data required for the model are pollution dispersion characteristics which include location, stack height, average mixing height, stack exit conditions, stability wind rose (speed, direction, and stability class), and pollutant decay rates.<sup>10</sup> The output consists of a matrix which gives the contribution of each of  $n$  sources to the predicted annual arithmetic average pollutant ground-level concentrations at each of  $m$  receptors. Transfer coefficients, with units of  $\mu\text{g}/\text{m}^3/\text{ton}/\text{day}$ , are obtained by dividing the concentration at the  $i$ th receptor due to the  $j$ th source by the number of tons emitted by the  $j$ th source.

Based on Standard Industrial Classification code and source type, all area sources were excluded from the present analysis and all mobile sources and any other sources too small or too numerous to categorize as point sources were treated as part of the background. Thus, this study examines only major point sources, which comprise three basic categories: stationary fuel combustion plants (primarily industrial and steam-electric power-plant boilers), industrial process sources, and solid-waste disposal sources (incineration and open burning).

Prior to developing control cost data, the applicability of control measures to each source was considered. In order to determine the compatibility of control devices with each source, consideration must be given to the temperature and volume of the effluent gas stream, type and efficiency of existing pollution controls, fuel usage requirements, and the maximum process rate. A number of measures were examined: wet scrubbers, mechanical collectors, electrostatic precipitators, mist eliminators, fabric filters, afterburners, and fuel substitution.

The costs of each device (in 1969 dollars) are obtained from the Control Technique Documents prepared by EPA (1969) and are the same for each control strategy. The total annual cost includes annualized capital and installation cost (based on a rate of interest and rated life of the device), as well as annual operating and maintenance costs.<sup>11</sup>

The industrial classifications for 27 plants considered in the St. Louis region are listed in Table I. The emission rate and control cost data may be found in Atkinson and Lewis (1974). The approximate location of each source and the nine receptors for which air quality predictions are made are shown in Fig. 1. The same control information and source-receptor pattern were used for the cost comparisons of all strategies.

### *The SIP Strategy*

In accordance with the Clean Air Act of 1970, each state has submitted to the Federal Government an SIP which describes its basic air pollution control strategy

<sup>10</sup>For a more complete discussion see TRW Systems Group (1970).

<sup>11</sup>Discussions with engineers at EPA indicate that while capital and operating costs of particulate control devices have risen substantially, total costs for each control device have risen by the same factor. Thus, all calculations are carried out in 1969 dollars. While EPA is in the process of developing new cost estimates, these are not yet available.

TABLE I  
Sources Controlled under All Strategies

Source No.	Standard Industrial Classification
1	2010; Meat packing, boiler
2	2041; Feed and grain mill
3	2041; Feed and grain mill
4	2041; Feed and grain mill
5	2041; Feed and grain mill
6	2046; Wet corn milling, boiler
7	2082; Brewery, boiler
8	2082; Brewery, boiler
9	2600; Paper products, boiler
10	2800; Chemical plant, boiler
11	2816; Inorganic pigments, boiler
12	2819; Inorganic industrial chemical plant
13	2819; Inorganic industrial chemical plant, boiler
14	2911; Petroleum refinery
15	2911; Petroleum refinery
16	2952; Asphalt batching, boiler
17	3241; Cement plant, dry process
18	3241; Cement plant, dry process
19	4911; Powerplant
20	4911; Powerplant
21	4911; Powerplant
22	4911; Powerplant
23	4911; Powerplant
24	4911; Powerplant
25	4911; Powerplant
26	4911; Powerplant
27	4911; Powerplant

for achieving the federally set ambient air quality standards. For purposes of this study, a set of emission regulations suggested in the SIP guidelines and representative of those employed by many states has been selected to form the SIP control strategy. The particulate standards include a heat input standard for fuel combustion sources (0.30 lb. particulate matter/million Btu), a process weight standard for industrial process sources (46.72 lb/hr of particulates/million lb/hr process weight), and a refuse-charged emission standard for solid waste disposal sources (0.20 lb particulate/100 lb of refuse charged).

The total cost of applying the SIP strategy to the St. Louis model region was determined from the cost of control data by reducing particulate emissions to the SIP strategy levels for all 27 sources. Remaining emissions from the controlled sources were then run through the diffusion model to generate *ex post* concentrations. In order to generate a functional relationship between total regional control costs and various air quality levels, a number of SIP strategies were developed by scaling (up and down) and the levels of the suggested SIP emission regulations. Scale factors employed were 0.25, 0.5, 2, 4, and 10. Since the set of SIP control requirements were representative and not specific to St. Louis, *ex ante* levels of air quality can only be roughly associated with scale factors.

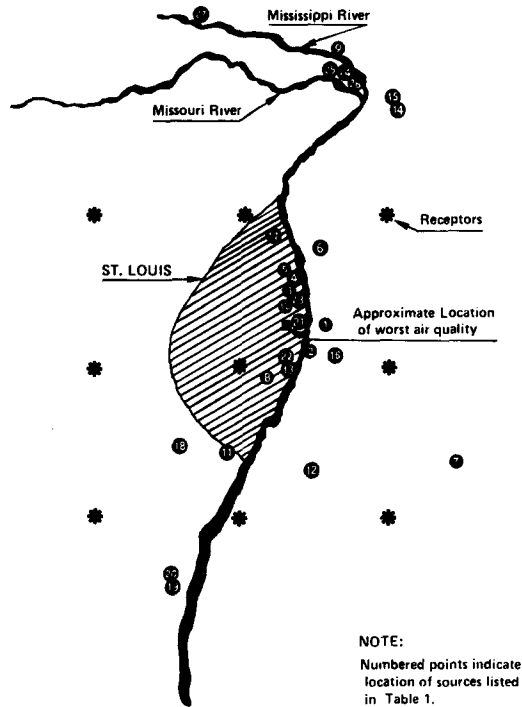


FIG. 1. Map of receptors and sources for St. Louis region.

### *Separable Cost Functions*

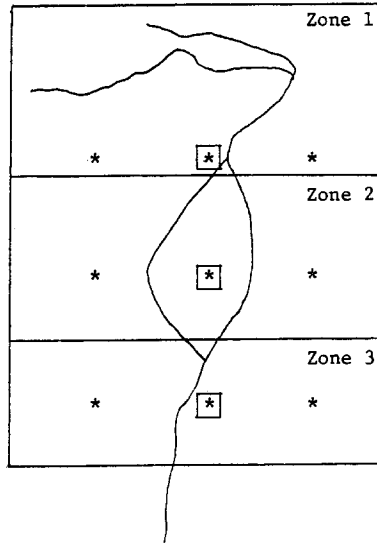
A separable linear programming algorithm is utilized to approximate all MEP quadratic programming strategies.<sup>12</sup> Marginal control costs rise rapidly with increasing levels of control, appearing to approach a vertical asymptote at complete pollutant removal. For each of 27 sources, a two-segment piecewise cost function is constructed by tracing out the lower bound of the total cost of the particulate control devices technologically applicable to each source. The objective function for all marketable permit strategies employs the marginal costs of each source's piecewise segments. Since each separable function is convex to the origin and all constraints are linear, all local optima will be global optima.<sup>13</sup>

### *Zonal Configurations*

Figure 2 presents the zonal configurations for the ZDP-SIP and ZDP-R strategies, while Fig. 3 depicts the zonal design employed for the UZDP system. Three zones are employed for the ZDP systems, roughly dividing the St. Louis AQCR into

<sup>12</sup>All computations were carried out using an IBM MPSX/370 separable linear programming package 5. For more details concerning the algorithm see IBM (1979).

<sup>13</sup>However, a single control device which removes the optimal tonnage may not exist for all sources. A convex combination of two control devices which border the optimal but nonexistent device must then be determined. Use of these two devices would require technological compatibilities sufficient to achieve splitting of the stack gas stream.

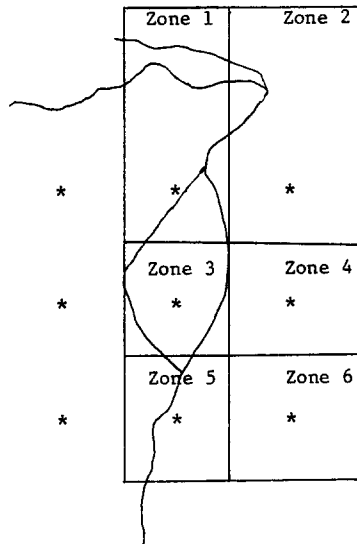


Zones

Sources

- |   |   |
|---|---|
| 1 | 9, 14, 15, 24, 25, 26, 27                       |
| 2 | 1, 2, 3, 4, 5, 6, 8, 10, 13, 16, 17, 21, 22, 23 |
| 3 | 7, 11, 12, 18, 19, 20                           |

FIG. 2. Zonal configurations—ZDP systems.



Zones

Sources

- |   |                          |
|---|--------------------------|
| 1 | 3, 4, 5, 17, 27          |
| 2 | 6, 9, 14, 15, 24, 25, 26 |
| 3 | 8, 10, 13, 21, 22, 23    |
| 4 | 1, 2, 16                 |
| 5 | 11, 18, 19, 20           |
| 6 | 7, 12                    |

FIG. 3. Zonal configurations—UZDP system.

thirds, but including nearly all of the city of St. Louis in Zone 2. Zone sizes are small enough to prevent trading of MEPs with remotely located sources, e.g., Zone 2 sources with the power plants and refineries to the north in Zone 1, while at the same time large enough to achieve substantial cost-saving through least-cost trading of permits. The air quality receptors utilized in the ZDP-R systems, enclosed by a small square in Fig. 2, correspond to the highest concentration receptor in each zone with one exception.<sup>14</sup>

The UZDP system, on the other hand, follows as closely as possible the EPA recommendation of uniform 16 kilometer-square grids—coincidentally the distance separating all St. Louis receptors—with a receptor in the approximate center of each grid. The exceptions are grids 1 and 2 which are each 16 by 32 kilometers. The other four zones conform very closely to the EPA recommendations.

#### IV. DISCUSSION OF EMPIRICAL RESULTS

There are five major empirical dimensions to be discussed: (1) the cost of compliance with alternative permit market designs, (2) the importance of permit expenditures in the total cost of control, (3) the effects of the various designs on the total amount of emissions removed, (4) the behavior of permit prices in the ambient permit markets, and (5) the magnitude of the divergence between *ex ante* and *ex post* air quality. Each of these five topics is covered in one of the five sections which follow.

##### *The Cost of Compliance*

Perhaps the major question to be answered is how permit design affects the cost of compliance. Figure 4 depicts the compliance costs for each of the six permit designs as a function of the level of severity of *ex post* air quality at the worst receptor (with background pollution set to zero for simplicity). In order to focus on the real resource cost of compliance only control expenditures are considered in the figure. Permit expenditures will be discussed in subsequent sections.

A number of important conclusions emerge from an examination of Fig. 4. First, the AP strategy, as expected on theoretical grounds, is the most cost-effective strategy. Furthermore, the relative cost advantage of this system over the SIP strategy is not diminished at very high degrees of control. In contrast the relative cost advantage of the EP system diminishes sharply at high levels of control.

The total cost of the HAP strategy is very close to that of the AP strategy, due to the small number of receptors with positive permit prices in the AP strategy. The multizonal systems and the EP system, as expected, are substantially more expensive than the AP and HAP systems to achieve given levels of air quality. However, the multizonal systems perform somewhat better than the EP systems at stricter levels of control, presumably because the gains due to more precise control of air quality with the multizone systems outweigh the losses due to restricted permit trading.

Among the multizonal systems, the UZDP is the least cost-effective because smaller zone sizes limit cost-minimizing permit trading. Surprisingly, the ZDP-SIP

<sup>14</sup>The exception is zone 3 which utilizes the middle receptor while the right-most receptor registers the highest concentration.

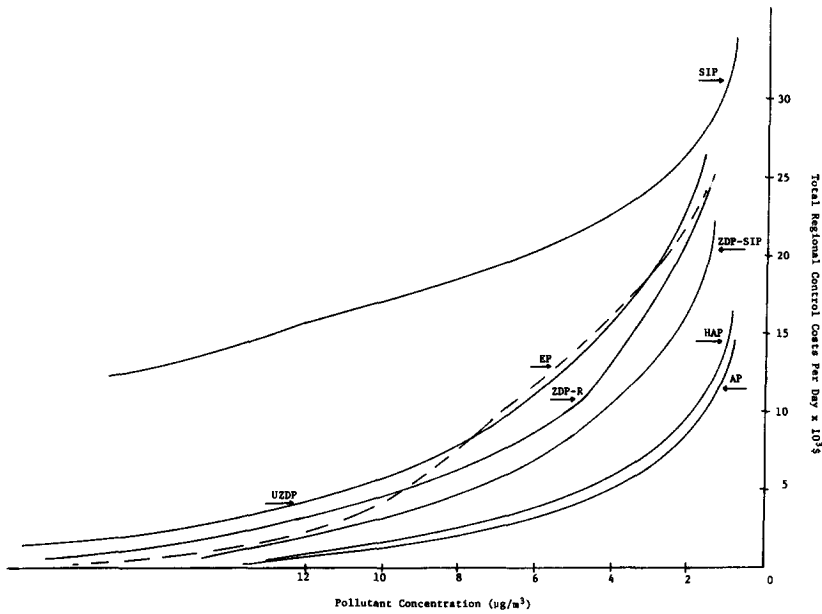


FIG. 4. Total regional control costs as a function of *ex post* air quality ( $\mu\text{g}/\text{m}^3$ ).

system is somewhat more cost-effective than the ZDP-R system, an unexpected result since the ZDP-R system relies on the rollback model to calculate each zone's control burden.

Finally, as a point of comparison for all MEP strategies, the cost of the SIP strategy is included for various *ex post* air quality levels between 1 and 10  $\mu\text{g}/\text{m}^3$ .

#### *The Magnitude of Permit Expenditures*

To the sources which have to buy them, permits represent an extra expenditure which has to be incurred over and above what the sources have to spend installing the control equipment. This is a cost not incurred by sources when the pollution control policy is based upon nontransferable emission standards. Therefore one of the dimensions of interest to the control authorities is how large these permit expenditures are *vis à vis* the control expenditures themselves. The larger they are the more serious the distributional impact of the initial allocation.

To shed light on this issue we have computed both the average cost of a permit per ton emitted as a function of the degree of severity of control and the ratio of permit expenditures to the sum of control cost plus permit expenditures. The first of these calculations is presented as Table II and the second as Table III.

There are several interesting characteristics of these results. The first of these is the striking lack of differences among the permit systems for a given level of control except for the EP system. The EP system generally requires more control than the other systems to achieve a given standard. As demonstrated in Table III this results in very high permit prices. These prices are sufficiently high that even though few permits are purchased under this system total permit expenditures are a higher percentage of total cost.

TABLE II  
Average Permit Expenditures (\$) per Ton Removed per Day for *Ex Ante* Air Quality Levels

MEP strategy	<i>Ex ante</i> air quality ( $\mu\text{g}/\text{m}^3$ )					
	1	2	4	6	10	20
AP	225.44	121.64	44.04	30.99	15.13	2.32
EP	15076.07	4941.98	1977.00	1053.99	617.99	132.00
HAP	321.68	82.90	45.02	22.79	15.97	2.26
ZDP-SIP	581.72	341.56	164.77	65.16	36.16	12.05
ZDP-R	1137.74	495.43	268.50	150.38	49.75	7.54
UZDP	562.08	453.14	181.25	145.12	57.83	11.83

TABLE III  
Ratio of Permit Expenditures to Total of Permit Expenditures and Control Costs  
for *Ex Ante* Air Quality Levels

MEP strategy	<i>Ex ante</i> air quality ( $\mu\text{g}/\text{m}^3$ )					
	1	2	4	6	10	20
AP	0.34	0.42	0.46	0.53	0.63	0.86
EP	0.75	0.80	0.85	0.87	0.92	0.96
HAP	0.40	0.40	0.50	0.50	0.68	0.76
ZDP-SIP	0.29	0.41	0.50	0.59	0.72	0.73
ZDP-R	0.31	0.36	0.50	0.56	0.60	0.64
UZDP	0.22	0.38	0.43	0.58	0.67	0.80

The second striking result is the trend for permit expenditures to be a less important part of total expenditures as the degree of control becomes more severe. This is true for all six types of permit systems considered. This does not imply, as might appear at first glance, that the demand for permits is elastic. If this were the case then permit expenditures would decrease with increasing severity. We did not find that. What was discovered was that the costs of control rise faster than permit expenditures when the severity of control is increased.

### *The Quantity of Emissions Removed*

In part the differences in the cost of compliance registered by the various permit systems are due to the fact that they require different degrees of emission control. The spatially differentiated systems (AP and HAP) allow more emissions for each microgram per cubic meter of pollution recorded at the receptor locations than the other systems because they reduce those sources having the heaviest impact on the receptor locations most, leaving the other, more distant, sources to emit more. The effect of this is to allow the distant sources an increase in emissions which is greater than the additional reductions imposed on the proximate sources; total emissions increase.

In spite of the Clean Air Act's reliance on ambient air quality standards as the chief policy target it is clear that the courts have interpreted the Act in such a way as to suggest that strategies which achieve the air quality standards while permitting

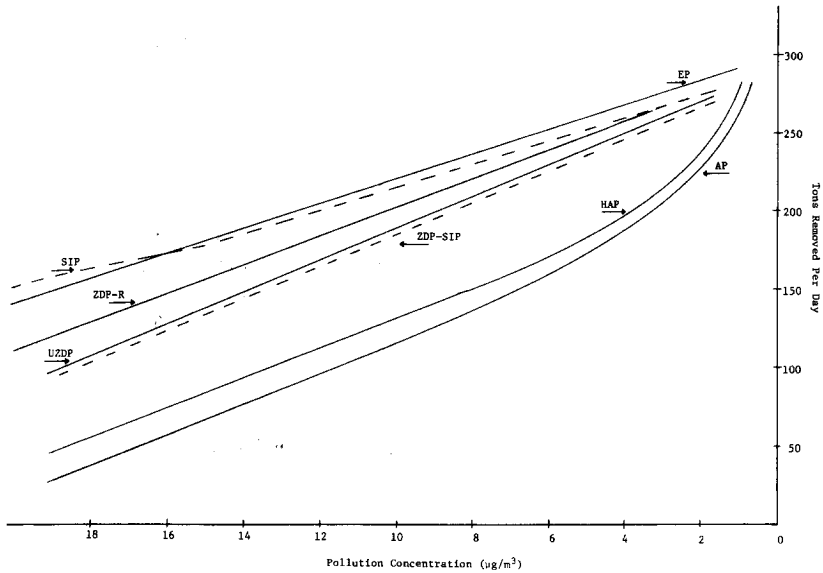


FIG. 5. Tons of pollutant removed per day as a function of *ex post* air quality.

increases in emissions are not to be allowed.<sup>15</sup> In addition it has become increasingly clear that some pollutants are transported long distances (e.g., the acid rain problem) and therefore the total amount of emissions may have policy significance beyond its contribution to the local pollution problem.

Figure 5 presents the tons of pollutant removed per day as a function of *ex post* air quality. It is clear that a substantial portion of the compliance cost savings achieved by the spatially differentiated permit system (AP and HAP) are directly due to the fact that they require less control. At lower levels of control they allow at least twice as many tons of pollutant emitted as the nondifferentiated systems while meeting the same ambient targets. Interestingly this is less true for very high degrees of control when, it may be remembered from Fig. 4, the ADP and HAP systems still maintain a significant cost advantage relative to the SIP strategy.

This finding suggests that EPA and the courts should differentiate between those pollutants which have almost exclusively a local impact (e.g., particulates) and those which travel long distances (e.g., sulfur oxides). For the former the cost savings to be achieved by using differentiated permit systems are substantial while the extra emissions are not harmful (assuming the ambient standards are correct). For the latter the extra emissions may cause serious harm and therefore the control authority may wish to forego these substantial savings as a way of indirectly controlling the long-range transport problem.<sup>16</sup>

<sup>15</sup>See, for example, the ruling in *Natural Resources Defense Council, Inc. v. Environmental Protection Agency*, 489 F. 2d 390 (1974) reversed, in part, on other grounds in *Train v. Natural Resources Defense Council, Inc.*, 421 U.S. 60 (1975).

<sup>16</sup>An alternative approach would be to define a system which required additional permits for exported pollution. To be cost effective such permits would have to be standardized to take into account the contributions of those exported emissions to concentrations at remote locations, a task requiring models to characterize the interstate or international transport of pollutants. The state of the art in modeling the long distance transport of pollutants is not yet sufficiently advanced to make this a viable alternative yet, though it may well be so in the future.

*Permit Prices in the AP Market*

The ambient permit market is a complicated one in which each source generally has to purchase several of the receptor-oriented permits. These permit markets are highly interdependent since a reduction in emissions by any particular source will affect a number of receptor locations.

The complexity of this market raises the question as to whether the prices of the permits in each and every market are monotonic with respect to the increasing severity of control. While it is clear that the marginal costs of control for each source will be monotonic with respect to increasing severity of control, it is not clear that a similar monotonicity would characterize the permit prices.

As Table IV demonstrates in this particular market under investigation permit prices are not monotonic. Note, for example, that reversals occur in each of the four markets characterized by positive prices for at least one level of control. In other words for each of these four markets there is at least one point where a higher level of control results in lower permit prices.

Since this result may, at first, seem counterintuitive, it is important to understand why it occurs. The exercise generating the data in Table 4 increases the severity of control at all receptor locations simultaneously. If we had increased the required degree of control at one receptor location while leaving the others unchanged, the expected monotonicity of permit prices would have been achieved for that one receptor location.

As the severity of control is increased the air quality standards will prove more difficult to attain for some receptor locations than for others. In general there will be different troublesome receptor locations at each different degree of control. As responsibility is allocated among the sources to attain the air quality standards at these troublesome locations the resulting emission reductions increase air quality at other locations as well. The most graphic example of this phenomenon can be seen in Table 4. At the highest severity of control considered ( $1.0 \mu\text{g}/\text{m}^3$ ) the degree of control required at receptor location 8 is so high that when the air quality standard at that location is met all of the others are automatically met so their associated permit prices are appropriately zero.

The fact that these prices can exhibit erratic behavior as the supply of permits is changed has not, to our knowledge, been recognized. It is a troubling result. It indicates a kind of instability which could make forward planning by the sources difficult, for example. Though far from conclusive this result seems to suggest that

TABLE IV  
Ambient Permit Prices at Various *Ex Ante* Air Quality Levels ( $\$/\mu\text{g}/\text{m}^3/\text{day}$ )

Receptor	1	2	4	6	10	20
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	0	0	0	0	0	0
5	0	740	129	281	143	29
6	0	2606	653	0	100	0
7	0	0	0	0	0	0
8	7469	181	321	125	15	1.7
9	0	0	0	230	0	0

further research on the behavior of prices in ambient permit markets would be desirable.

### *The Ex Post/Ex Ante Problem*

Because they specify the amount of emissions each source is allowed, command and control systems allow the control authorities to maintain a high degree of control over air quality in their region. When the control responsibility becomes transferable, as it does in marketable permit systems, the ultimate allocation of control responsibility, as determined by the permit market, is not known at the time the system is implemented. Since ambient air quality at the various receptor locations depends on the spatial distribution of emissions as well as the amount emitted, and that spatial pattern cannot be determined in advance, with the exception of the ambient permit system the *ex post* air quality which prevails after the transfers have taken place may be quite different from what the control authority intended *ex ante*.

The ambient permit system allows the control authority to retain complete control over air quality because, by design, the allowable trades do not violate the air quality standards. The number of permits required to achieve the standard can be defined prior to the initiation of the market. This is not true for any other permit system considered in this paper. Therefore for those systems the control authority is required to guess how permits should be issued to insure that the air quality at the worst receptor just meets the standard. In this paper the control authorities are assumed to use the roll back model to determine the number of permits. The question of interest is how far astray this commonly used procedure will lead the attempt to achieve the standard.

The discrepancies between *ex ante* and *ex post* levels of air quality are displayed in Table V. Even strategies which are highly cost-effective in terms of *ex post* air quality may be deemed unacceptable if *ex post* and *ex ante* air quality levels differ substantially. This inability to assure that the air quality standards will be met may well require iterative adjustment of the volume of permits. Since pollution control devices are generally lumpy investments which are often incompatible with larger or smaller devices, adjustment of the volumes of permits would most likely be highly disruptive, costly, and add great uncertainty to future investment decisions.

Only the AP strategy guarantees that *ex ante* air quality levels will be actually achieved, as expected. Among the other systems none uniformly dominates the others. No system is best or worst at achieving all *ex ante* air quality levels. The

TABLE V  
Highest Recorded *Ex Post* Concentrations Corresponding  
to *Ex Ante* Air Quality Levels ( $\mu\text{g}/\text{m}^3$ )

MEP strategy	1	2	4	6	10	20
AP	1.00	2.00	4.00	6.00	10.00	20.00
EP	1.61	4.44	6.62	7.14	10.04	18.77
HAP	1.10	2.68	5.22	8.00	11.88	21.81
ZDP-SIP	1.70	2.61	6.80	8.95	12.37	18.45
ZDP-R	1.51	1.93	4.95	7.54	12.21	21.16
UZDP	1.75	2.88	5.25	7.45	13.22	20.02

emissions permit system at low pollutant concentration levels introduces a substantial degree of error. Interestingly, the UZDP system, which relies on small trading zones, does not achieve smaller errors in the attainment of air quality goals as might be expected. This anomaly is apparently due to the inability in such a simple system to consider interzonal pollutant flows in structuring this strategy. It is also interesting to note that the use of the roll back model to determine the number of permits generally results in too little, as opposed to too much, control. Control authorities who use the roll back model would therefore have to build a safety margin into their determination of the number of permits to issue.

## V. CONCLUSIONS

This paper has derived a number of empirical conclusions about various permit designs. Since they emanate from a single pollutant, single geographic location model, these results should be considered suggestive, rather than conclusive, until such time as they are replicated for other pollutants and other locations. Nonetheless, to the extent they are subsequently replicated, some specific design characteristics emerge as worthy of further consideration.

The most important of these results, along with their potential policy implications, are:

- Although the ambient permit design, as expected, is the most cost effective, a modified version of that design (the HAP) which has a single permit market defined in terms of the “worst case” receptor location achieves the desired air quality goals at a cost only slightly higher. This is an important result because the HAP system is administratively much simpler than the AP system. The policy implications of this result are not as strong as it might at first seem, however, due to the static nature of the model. To the extent that new sources move into the area and are influenced by permit cost they may tend to cluster at some location far moved from the existing “worst case” receptor. This clustering could then trigger a violation of the air quality standard at this new location. In this case the HAP system would be less desirable; at least two markets would then be necessary.
- All permit designs result in a lower compliance cost at all levels of control than the current SIP approach which focuses on nontransferable emission standards.
- The smaller zone sizes in the UZDP system have a significant positive effect on compliance cost, but they do not, in general, make the hot spot problem less severe. For most *ex ante* air quality levels at least one of the larger zone systems (ZDP-SIP or ZDP-R) has a lower reading at the worst receptor than the UZDP system. These results suggest that any reform designed to restrict geographically the trading areas to zones as small as implied by the UZDP system in order to reduce the “hot spot” problem would be ill-advised.
- The results for the ZDP-SIP system, which allows only within-zone emissions trades but defines the zones to encompass a larger geographic area than the UZDP system, indicate that substantial cost savings can be achieved by moving from the SIP system to this modified version. This is an important result indeed since this is precisely the direction the “bubble” policy is taking, although it remains to be seen how far away sources can be and still be permitted to engage in a “bubble” trade.

- For all permit designs, permit expenditures are more than half of total cost for less severe degrees of control but they become a less significant proportion of total cost as the degree of control is increased. This suggests that the importance of the distributional issues associated with the initial allocation of permits diminishes as the degree of control becomes more severe.
- Permit expenditures as a percentage of total cost are highest for the emission permit system.
- The significant cost advantages of the HAP and AP systems are achieved because they allow substantially more emissions while achieving the predetermined air quality standards. While this may not be a problem for truly local pollutants (e.g., particulates) it will cause problems for pollutants which are transported long distances (e.g., sulfur oxides).
- As the ambient air quality standards are increased simultaneously at all receptor locations, the permit prices in an ambient permit system do not necessarily increase monotonically. This behavior introduces another element of complexity into the ambient permit market when, for example, sources have to meet more stringent secondary standards subsequent to their meeting the primary standards.
- The "hot spot" problem is a serious one. All of the permit systems examined herein except the ambient permit system allow air quality at some receptor locations to exceed the standard. This suggests that all permit systems other than the ambient permit system will have to be designed with some safety margin to insure compliance at all receptor locations.

These results suggest the possibility of a design which is an amalgam of all these designs.<sup>17</sup> Suppose that we define the exchange ratio as the number of tons of pollutant the purchaser is permitted to emit for each ton of the same pollutant that the seller agrees to control further. Further imagine a case by case system in which region wide trades could take place providing the exchange ratio was no larger than the smaller of (a) 1.0 or (b) the ratio of the seller's transfer coefficient to the purchaser's transfer coefficient for the worst receptor (or what would be the worst receptor after the trade). The former constraint insures that emissions do not increase when trades improve local air quality. The latter constraint guarantees that trades do not make air quality worse at the most susceptible receptor location.

Our results indicate that this system would have substantial advantages. Since region wide trades are permitted, the possibilities for cost reduction are enhanced as compared to restricting trades to proximate sources. Yet air quality could be protected without recourse to multiple markets. This system would combine the prevention of emissions increase usually found in an emission permit system with the cost reduction possibilities and lack of complexity of the HAP system with the control over air quality usually associated with an ambient permit system. Based on our results this amalgam would seem a logical next step in EPA's expansion of the controlled trading reforms.

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<sup>17</sup>A similar proposal is advanced in Anderson *et al.* (1979, pp. 7-9 to 7-11).

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