Tradeable Permits for Pollution Control when Emission Location Matters: What have We Learned?

TOM TIETENBERG
Mitchell Family Professor of Economics, Colby College, Waterville, Maine 04901-8852, U.S.A.

Abstract. Our knowledge about tradeable permit approaches to pollution control has grown rapidly in the two decades in which they have received serious analytical attention. Not only have the theoretical models become more focused and the empirical work more detailed, but we have now had over a decade of experience with them in the U.S. This article draws upon economic theory, empirical studies, and actual experience with implementation to summarize what we have learned about applying tradeable permits to air pollution control in the special circumstance where the spatial aspects of the problem are a prime consideration.

Key words. Tradeable permits, air pollution control, acid rain.

I. Introduction

From their humble beginnings as mere academic curiosities in the late 1960's and early 1970's, tradeable permit approaches to pollution control have now entered the policy mainstream. The almost two decades during which they have been used have provided us with useful analytical insights and implementation experience upon which to draw as we chart the future.

This paper focuses mainly on the lessons we can extract from our experience with dealing with the spatial dimension in air pollution control. The spatial element is of particular interest, not only because it frequently figures prominently in policy discussions of acid rain, but also because it adds so much complexity both to the design of suitable policy instruments and to the modeling which supports that design process. Indeed, one recent commentator Smith (1993, p. 21) has gone so far as to suggest that market-based instruments may not be appropriate when spatial considerations are important. We shall examine the evidence behind that claim and we shall provide some evidence on the desirability of various second-best strategies designed to deal pragmatically, if suboptimally, with the special problems posed by an incorporation of spatial concerns.

II. Optimality Principles

Our inquiry begins by defining what is meant by an optimal allocation of pollution control responsibility and by extracting the principles that can

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be used to design economic incentive policies which fulfill the optimality conditions. Optimality theory can help us understand the characteristics of these economic approaches in the most favorable circumstances for their use and assist in the process of designing the instruments for maximum effectiveness.

2.1. OPTIMAL ALLOCATION OF CONTROL RESPONSIBILITY

What is meant by the optimal allocation of the control responsibility depends on how the 'policy target' is defined. Several possible targets have been considered in the literature. Chronologically the first forays into instrument design were based on traditional concepts of economic efficiency. The economically efficient allocation of control responsibility, defined in partial equilibrium terms, minimizes the total costs to society, where total costs are defined as the sum of the damage caused by unabated pollution and the costs of abating the rest.[1] Ignoring corner solutions, efficiency is achieved when the marginal control costs are equal to the marginal damage costs for each source of the pollutant.

Because the resulting allocation of control responsibility is quite sensitive to both spatial and temporal considerations, defining optimality in terms of efficiency imposes a heavy information burden on both modelers and those charged with the responsibility for implementing the policies. Not only does an efficiency target make it necessary to track the physical relationships underlying the emission, transport, and chemical reactions of the polluting substances, it also requires calculating the degree of exposure to those substances and relating that exposure to physical and, ultimately, monetized damage (both human and nonhuman). Each of these steps is subject to data limitations and uncertainties.

Even when the information burdens associated with it can be surmounted, the efficiency criterion is not universally accepted as appropriate outside the discipline of economics. Applying this criterion has several somewhat subtle implications, some of which are quite controversial. Take as just one example the class of pollutants having a major impact on human health. The efficiency criterion implies, all other things being equal, targeting more control resources toward emissions which affect larger numbers of people (because the marginal damage caused by a unit of emissions is higher in that setting). This particular allocation of control resources can result in *lower individual* risks for those in high-exposure settings. This contradicts a popular policy premise which suggests that citizens should face *equal individual* risks, regardless of where they work or reside.

To respond to both the information and moral concerns with an efficiency approach, other related policy targets have been proposed, analyzed and implemented. A *concentration target* focuses on a physical, rather than a monetized, entity – the maximum acceptable concentration level for pollutants. While different concentration targets can be associated with different geographic areas (to reflect, for example, varying ecological sensitivities), most current applications of this target have relied on uniform concentration ceilings which must be met everywhere. Once the concentration target or set of concentration targets has been established the analysis attempts to minimize the costs of reaching the prespecified concentration targets at every location.[2] Typically this approach also involves taking into account both the timing and the location of the emissions.[3] (Compared to concentrated emissions, emissions diffused over time and/or space tend to reduce the likelihood that a concentration target will be breached.)

An *emissions target* focuses on the aggregate amount of emissions from sources within a particular geographic area without regard to either their timing or location. The analysis based upon an emissions target attempts to minimize the cost of reducing emissions (rather than concentrations) to a prespecified level. From both a modeling and a policy point of view this is the easiest target to achieve of the three we have considered. From a modeling point of view it eliminates the need to incorporate a considerable amount of spatial and temporal detail into the models. From a policy point of view the resulting rules for allocating control responsibility for meeting an emissions target are relatively simple and easy to communicate – the responsibility for controlling the emissions of a particular pollutant in a particular geographic area should be allocated so as to equate the marginal costs of control across all sources of that pollutant in that area. Unfortunately this simplicity is achieved by sacrificing any control over the spatial aspects of the market, the focus of this article.

2.2. DESIGNING OPTIMAL POLICY INSTRUMENTS

The design of optimal policy instruments depends crucially on the nature of the target. Efficient instruments should be set so as to equate the marginal cost of control with the marginal damage caused by those emissions.[4] In practice this means these instruments should be tailored to the circumstances of the individual source, including location, local meteorology, stack height, and the sensitivity of deposition areas to that pollution. Less obvious, and even more difficult to integrate into the design, is the need to incorporate general characteristics, such as the amount of pollution arriving in that destination area from other sources. The process of implementing instruments which are consistent with the efficiency criterion is sufficiently complex that their use has been rather limited in practice.

Instruments designed to cost-effectively achieve a concentration target must also take into account the location (including injection height) and the timing of emissions, as well as the magnitude of the flows. Temporal effects can be included by defining time-sensitive permits (Howe and Lee, 1983; Tietenberg, 1985, Chapter 7). With respect to spatial aspects, as long as the control authorities can define a vector of transfer coefficients for each emitter, linking emissions at each location x with concentrations at each of the predefined receptor locations, specific trades can be defined which allocate the responsibility cost-effectively. The design which is consistent with cost-effectiveness in this context is called an *ambient tradeable permit* (Montgomery, 1972).[5]

Unfortunately while the design of the ambient instruments is not very complicated, implementing an ambient-based system is complicated. With an ambient permit system an emitter would have to acquire separate permits for each affected receptor. When the number of receptors is large, the result is a rather complicated set of transactions.[6]

III. Coping With the Spatial Dimension: Second-Best Alternatives

The administrative difficulties associated with the ambient permit system have precipitated a search for alternative administratively and legally feasible approaches which, while they may not sustain the least-cost allocation, at least may represent an improvement over the traditional approach. Three such approaches are considered here: (1) emission permits, (2) zonal permit systems, and (3) trading rules and trading ratios.

3.1. EMISSION PERMITS

One way to deal with the spatial complexity of pollution control is to ignore it. Actually this suggestion is not as far-fetched as might be assumed. Emission permits have been the basis for both the Sulfur Allowance Program (a main component of the U.S. policy to control acid rain) and the Lead Phasedown Program (the U.S. program designed to facilitate the phase out of lead in gasoline) and for controlling particulates in Santiago, Chile. In each of these cases, special circumstances played a role in the choice of an emission permits system.

In the Sulfur Allowance Program the preimplementation modeling showed that the expected reductions from an unrestricted trading system would take place in precisely the areas that would be targeted for greater control by a more complicated system. Therefore the gains from implementing a more complicated system appeared small in comparison to the administrative cost (Kete, 1992, p. 82) In the Lead Phasedown Program, concerns over 'hot spots' were mitigated by the fact that the gasoline distribution system (mainly the vast pipeline system) tended to mix gasoline from different producers, thereby averaging out any difference among refiners introduced by trading (Nussbaum, 1992, p. 29). In Chile the total required reductions were so large that any deviations from these reductions caused by trading could be expected to be small in comparison and could therefore be safely ignored.

Using an emissions permit system to reach a concentration target is clearly suboptimal, but just how suboptimal is it? To what extent do emission permits exact a cost penalty? How serious would the 'hot spot' problem be ? (Hot spots are unacceptably high concentrations of pollution; emission permits could contribute to the formation of hot spots if they allowed more clustering of emissions in vulnerable areas than permitted under command-and-control.) Theory can provide no evidence on these questions; empirical evidence is required.

The evidence on the size of the potential cost penalty when emission permit systems are used to control nonuniformly mixed assimilative pollutants from multiple sources for multiple receptor sites is presented in Table I. The potential abatement costs of reaching a vector of concentration targets using an emission permit system are compared with those of the command-and-control and the least-cost allocation. In each study all three allocations of pollution control responsibility are defined such that they meet comparable concentration targets.

In the fifth column of Table I the potential abatement cost of an emission permit system is compared with that of the traditional command-and-control approach. Since the traditional command-and-control policy is the benchmark in this table, a ratio of greater than 1.0 indicates that the emission permit approach achieves the objective at lower cost while a ratio of less than 1.0 indicates that the traditional regulatory approach is cheaper. Since the ratios range from a low of 0.42 to a high of 11.10, the cost-effectiveness of an emission permit system in this context is apparently quite sensitive to local conditions.

The difference in the cost of control resulting from the use of these two rather different approaches can be decomposed into two components: (1) the *equal-marginal-cost component* and (2) the *degree-of-required-control component*. The equal-marginal-cost component refers to the lower costs of emission reduction associated with the equalization of marginal control costs. These lower costs can in principle be achieved by emission permits, but not by the command-and-control approach. For any comparable degree of required reduction, emission permits would achieve that reduction at a lower cost. This component unambiguously favors emissions permits.

The second component derives from the fact that the degree of required emission reduction is not usually the same for all policies despite the fact that they are constrained to reach the same concentration targets. If we were comparing aggregate emissions for command-and-control and an ambient permit system, the least-cost solution would typically result in more emissions (Atkinson and Tietenberg, 1987). That is not necessarily true for the emissions permits system, however, because the location of the sources matters in determining how much emission reduction is needed, and emission permits have no control over that aspect. The sign of the degree-of-required-control component is ambiguous.

In summary, whether permits or the command-and-control allocation provides a cheaper approach to reaching concentration targets depends on the sign and magnitude of the degree-of-required-control component. If the command-and-control allocation requires more control, the emission permit

Table I. Using emission-based system to attain concentration targets: The potential cost.

Study & year	Pollutants covered	Geographic area	CAC Benchmark	Ratio of CAC to EBS abatement cost[a]	Ratio of EBS to least cost[a]
Atkinson and Lewis (1974)	Particulates	St. Louis metro area	SIP regulations	6.00[b] 1.33[c]	1.67[b] 4.51[c]
Roach *et al.* (1981)	Sulfur dioxide	Four Corners in Utah, Colorado, Arizona, and New Mexico	SIP regulations	1.70	2.50
Hahn and Noll (1982)	Sulfates	Los Angeles	California regulations	1.05	1.07
Atkinson (1983)	Sulfur dioxide	Cuyahoga Country, Ohio	SIP regulations	0.78[d] 0.91[e]	1.91[d] 1.40[e]
McCartland (1984)	Particulates	Baltimore	SIP regulations	2.50[f]	1.88
Krupnick (1986)	Nitrogen dioxide	Baltimore	Proposed RACT regulations	0.69[g]	8.64[g]
Seskin, Anderson and Reid (1983)	Nitrogen dioxide	Chicago	Proposed RACT regulations	0.42	33.9
Spofford (1984)	Sulfur dioxide Particulates	Lower Delaware Valley	Equal percentage reduction	0.83[h] 11.10[i]	2.13[h] 1.97[i]

Source: Tietenberg (1985)

Definitions: CAC = Command and control, the traditional regulatory approach.
EBS = Emission based system.
SIP = State implementation plan.
RACT = Reasonably available control technologies, a set of standards imposed on existing sources in nonattainment areas.

[a] These columns assume emissions are reduced sufficiently by both policies to meet the ambient standards at all receptors.
[b] Assumes air quality of 60 μg/m^3 at worst receptor.
[c] Assumes air quality of 40 μg/m^3 at worst receptor.
[d] Assumes emission reduction sufficient to meet local ambient standards.
[e] Assumes emission reduction sufficient to meet local and long-range transport standards.
[f] Uses 100 μg/m^3 for EBS and 98 μg/m^3 for least cost.
[g] Assumes air quality of 250 μg/m^3 at worst receptor.
[h] Assumes air quality of 80 μg/m^3 at worst receptor and both point and area sources controlled.
[i] Assumes air quality of 75 μg/m^3 at worst receptor.

system unambiguously results in lower control costs; both the equal-marginal-cost and degree-of-required-control components act in the same direction, reinforcing one another. Whenever the emission permit system requires more control, then the two components are of opposite sign and tend to offset each other. If the extra amount of reduction required in the emissions permit system is sufficiently large, the degree-of-required-control component would dominate the equal-marginal-cost component, causing the cost of control to be higher with an emission permit system.

The relative degree of emission reduction required by emission permits is quite sensitive to the spatial configuration of sources. When a few large sources are clustered near the receptor requiring the largest improvements in air quality, they would have to be controlled to a very high degree. Because emission permits cause marginal control costs to be equalized across all sources, their resulting high marginal costs of control would be mirrored by equivalently high marginal costs of control for distant sources, despite the fact that emissions from distant sources have very little impact on the receptors where the greatest air quality improvement is needed. This over-control of distant sources results in much more emission reduction than is necessary to meet the ambient standard.

Other spatial configurations of sources lead to less overcontrol of distant sources by economic incentive systems. When sources are more ubiquitous and no cluster dominates the most polluted receptor, an emissions permit system is able to achieve more balance between distant and proximate sources. In this circumstance, the air quality could be brought to the target level with both lower control costs and possibly even less total emission reduction.

Of the five studies where the emission permit system abatement costs were higher than the command-and-control approach in Table I, *all* require larger emission reductions than the command-and-control allocation (Tietenberg, 1985, p. 71). For the two studies finding that economic incentives require less emission reduction, the economic incentive systems are cheaper, as expected, since the two components reinforce one another.

The data in Table I assume that the control authority is able to pick, in advance, the optimal second-best magnitude of the policy instrument. If it were perfectly omniscient, with full knowledge of the control costs of all emitters, defining the correct number of permits would be a simple matter. Combining its presumed knowledge of control costs with its presumed knowledge of all transfer coefficients, the authority could define a number of permits which would just meet the concentration target at the worst receptor.

But is that realistic? If the control authority were truly omniscient, second-best approaches would not be needed to achieve cost effectiveness. It could mandate cost-effective emission standards for all sources directly without the bother of initiating economic incentive approaches. Indeed, it was the absence of this very information that triggered the interest in economic incentives in the first place.

What is likely to happen in practice? Because the control authority would not normally know the ultimate spatial allocation of control responsibility, it would, in all probability, issue a smaller number of permits than assumed in Table I in order to build a 'safety margin' into its calculations. (With fewer permits issued the likelihood that any trade would trigger a violation of one of the concentration targets is reduced.) By forcing more control than necessary to meet the concentration targets under conditions of perfect information, the actual cost penalty associated with emission permits would be larger than modeled in the simulation studies.

How about the 'hot spots' problem? Emission permits give rise to this concern because hot spots are caused both by the amount of emissions (which is controlled by emission permits) and by their location and timing (which are not controlled by emission permits). Emission permits may increase the threat of hot spots in two main ways. First, trades may create unacceptably high local concentrations near sources that have acquired permits as an alternative to further control. Second, permits may allow the long-range transport of emissions to increase, thereby increasing deposition problems.

Both concerns are apparently empirically relevant. Atkinson and Tietenberg (1982, p. 118) for example, found that in a context where the command-and-control equilibria are guaranteed to satisfy ambient standards, emission permit trades can create violations. Similarly, Atkinson (1983) has investigated the significance of long-range transport problem by comparing the cost saving attributable to incorporating location when only local receptors were considered (a frequently modeled circumstance) to that when the contribution of emissions to long-range transport was also considered. The inclusion of long-range transport has two main effects: (1) it requires more total emission reduction and (2) it requires relatively more reduction from sources with tall stacks, since tall stacks enhance long-range transport. Atkinson's results indicate that, although consideration of long-range transport tends to diminish the cost penalty associated with the emission-based systems, it does not eliminate it. Even for long-range transport pollutants, the emissions-based systems still normally overcontrol emissions; location still matters, though its influence is less significant than when only local receptors are considered.

In conclusion, the normal presumption – that economic incentive approaches are more cost-effective than command-and-control approaches – does not automatically extend to the world of the second best. These results suggest that the relative cost-effectiveness of emission permits and command-and-control in a context where spatial considerations are important depends on local circumstances. Even in those cases where the short-run cost penalty may not be larger than estimated, the risk of violating the concentration targets at one or more locations is increased by changes over time in the composition and location of emitters. Even if the control authority would have fulfilled its statutory obligations when the program is initiated, as the number and composition of sources changed over time, those sources located near binding receptors could jeopardize compliance. Nothing in the design of the emission permit system prevents these concentrations from exceeding the target.

While these results are important and should serve to warn against the possibility of promising too much, it is equally important to place these results in a larger context. The costs simulated here are only the costs of meeting a specific target at a point in time; they ignore the important incentives created by economic instruments for the development and implementation of new approaches to control. In the United States, for example, emissions trading has opened the way for pollution prevention and demand-side management strategies to play an increasing role, whereas traditional policies have focused on identifying specific end-of-pipe technologies (Dudek and Palmisano, 1988). Over the long run these dynamic aspects may turn out to be the most important.

Since unconstrained emissions-based policies afford too little protection to the concentration targets over the long run by sending the wrong signals to potential polluters making location decisions, one potential solution is to add some kind of constraint on the pure emissions permit system. In the United States this problem has been attacked by 'regulatory tiering', which implies applying more than one regulatory regime at a time. Sulfur oxide pollution in the United States is controlled both by the regulations designed to achieve ambient air quality standards as well as by the sulfur allowance trading program. All transactions have to satisfy *both* programs. Thus *trading* is not restricted by spatial considerations (national trades are possible), but the *use* of acquired allowances is subject to local regulations protecting the ambient standards. The second regulatory tier protects against local hot spots (by disallowing any specific trades that would create them), while the first tier allows unrestricted trading of allowances. Because the reductions in sulfur are so large and most local ambient standards are not likely to be jeopardized by trades, this second tier is not expected to constrain very many, if any, trades.[7] Yet its very existence offers sufficient assurance that local air quality will be protected that the political feasibility of implementation is enhanced.

Locally based ambient standards may not, however, provide adequate protection for distant sources. The problem could arise, for example, when the source buying permits has a tall stack and is upwind of an ecologically sensitive area. Despite the preimplementation modeling which suggested that this problem would not materialize, states with especially sensitive ecological areas have not remained convinced. On March 11, 1993 New York State's Department of Environmental Conservation joined with a coalition of other litigants to file a suit designed to force EPA to add a 'deposition standard' to the current program. Such a standard would, if included, restrict the use of purchased allowances in geographic areas which impact especially sensitive ecological areas. (New York's Adirondack Park area is one such area.)

3.2. ZONAL PERMIT SYSTEMS

One much-studied variation of the emissions permit approach deals with the spatial dimension by dividing the control area into a grid containing a specific number of zones. In the most restrictive form of this approach trades would be allowed within zones, but not between zones; in less restrictive versions of the approach trades between zones are allowed using predefined trading ratios.

Zonal approaches have a certain surface appeal because they appear to provide a middle ground between the excessive simplicity of emissions-based policies and the excessive administrative complexity associated with tailoring the instrument design to the unique circumstances of each emitter. Whereas emissions-based systems normally overcontrol distant sources, the zones system allows differential treatment of distant and proximate sources. Whereas an emission-based system is vulnerable to the creation of hot spots, the zoned system appears to lower this vulnerability by targeting greater control on those zones containing the emitters which are the main contributors to the most severely affected receptors. As long as all sources within each zone are closely clustered, and stack heights are ignored (two very strong assumptions), all sources within each zone might be expected to have similar transfer coefficients. As long as the sources within the zone have similar transfer coefficients, allowing emission trades within the zone would not cause large changes in concentration at the relevant receptors.

Unfortunately the appeal of zonal systems begins to fade somewhat upon closer inspection. The implementation of a zonal system places a larger burden on the control authority than the implementation of a pure emission permits system. With the zonal permit system, the control authority has to define a vector (with the elements corresponding to the level of authorized emissions in each zone) rather than the scalar (the aggregate emissions level) that is necessary to implement an emission permit system. These administratively determined, initial zonal assignments turn out to be an important determinant of the resulting regional control cost.

In principle, *at any point in time* it is possible to define a set of allowable zonal emissions which minimizes cost *given the zonal boundaries.*[8] However, to define instruments which are optimal even in this restricted sense, the control authority would have to know the control cost functions and the transfer coefficients for every source. Whenever such omniscience is unrealistic for a control authority, zonal allocations will in practice deviate from these full-information allocations and the cost penalty associated with a zonal system cost will be increased.

Allocating too much control responsibility to one zone (relative to the cost-effective allocation) and too little to another would raise compliance costs above the least-cost solution, even if the control authority were able to achieve the correct total emission reduction for the region as a whole. Even if the control authority were able somehow to make the cost-minimizing assignment of control responsibility among zones for a particular point in time, the normal evolution of the local economy would require changes in this assignment over time.

This discussion has suggested two sources of a cost penalty in the design of zonal permit systems: (1) the administrative allocation of control responsibility to zones and (2) the uniform treatment of all sources within the zone, given an assignment among zones. In full-information simulations, those which presume omniscient control authorities both the least-cost total emission reduction and the least-cost assignment of this reduction among zones, given the particular zonal configuration in that simulation, are assumed. Though unrealistic in their treatment of control authority behavior, the studies described below do tend to show the potential for zonal systems under the most congenial circumstances. They serve as a benchmark for our subsequent discussions of limited-information zonal systems.

In this full-information approach, as the number of zones is increased (by reducing the size of each zone) the cost effectiveness of the policy must increase. Smaller zones not only mean less *within-zone* cost penalty, but the *between-zone* cost penalty is eliminated by assumption as well. In the limit, where each source is in its own zone, full cost-effectiveness can be achieved.

How sensitive the remaining cost penalty is to the size of the market is an empirical question. The first study (Roach *et al.*, 1981) to attack this question examined the effects of applying a zonal system where the zones were defined alternately on a regional, state, or airshed level. Another study, by McGartland (1984), examined the effects of creating multiple zones within an urban airshed. Together these studies encompass a wide range of market sizes.

The Roach *et al.* (1981, p. 44) study found that rather large reductions in the cost penalty could be achieved by reducing the size of the zones when moving from 'very large' to 'large' zones. When the entire multistate Four Corners region was treated as a single zone, the control cost was estimated to be three to four times higher than if separate zones were created for each of the region's airsheds. The higher cost of the single zone, as discussed above, is caused by the overcontrol of distant sources. To ensure the attainment of the concentration targets in all locations, larger regional emission reductions are required. With multiple zones, the reductions can be selectively concentrated on those zones where they are most needed. Targeting the reductions reduces the costs.

The McGartland study (1984) found further gains from multiple zones even within a typical urban airshed. According to this study, it takes at least three, and possibly as many as six, zones to cut the cost penalty in half.

Although it is reasonable to expect that smaller zone sizes would also afford better control over concentrations, that is not necessarily the case. Studies have found that the hot spot problem can be severe even with very small zones

(Spofford, 1984, p. 82; Atkinson and Tietenberg, 1982, p. 120). Close inspection of the results indicates that different stack heights among sources within the same zone are the major reason for this discrepancy. The practical implication is that zones should have a vertical as well as a horizontal component. Stack heights matter and they are not adequately controlled when zones are defined purely in terms of surface coordinates. When within-zone stack heights vary considerably, even contiguous sources may have very different transfer coefficients. Similar treatment of sources with quite different transfer coefficients could either produce hot spots or overcontrol. Ignoring stack heights in instrument design defeats one of the central purposes of a zonal permit system – the prevention of overcontrol.

Whereas smaller zones unambiguously mean lower costs in the full-information world modeled by the studies described above, this is not necessarily the case when the assumption that bureaucrats have full information is weakened. According to the available evidence from simulation models (McGartland, 1984; Spofford, 1984; Atkinson and Tietenberg, 1982), the total cost of a limited-information system would be quite sensitive to the initial allocation of permits among zones. Several rules of thumb which might be used by a control authority to make these zonal allocations were examined. They included (1) equal percentage reductions based upon uncontrolled emissions, (2) equal percentage reductions in currently allowed emissions, and (3) reductions based on the need to improve air quality at the nearest within-zone receptor. All these imposed large cost penalties; none emerged as particularly superior or desirable. None of the conventional limited-information administrative approaches result in equilibria which approach the least-cost allocation.

However, while small zones allow more targeting, they also reduce trading opportunities. Would the restricted set of trading opportunities arising from a zonal permit system so undermine the zonal permit approach as to make its use inappropriate in this setting?

Apparently not in all cases. Some empirical work suggests that substantial savings can be achieved in emissions trading even when the trading areas are rather small. One study of U.S. utilities, for example, found that even allowing a plant to trade among discharge points within that plant could save from 30 to 60% of the costs of complying with new sulfur oxide reduction regulations, compared to a situation where no trading whatsoever was permitted (ICF, Inc., 1989). Expanding the trading possibilities to other utilities within the same state permitted a further reduction of 20%, while allowing interstate trading permitted another 15% reduction in costs. If this study is replicated in other circumstances, it would appear that even small trading areas may offer the opportunity for significant cost reduction in some circumstances. The point of this finding is **not** that small trading areas are desirable; they do retard progress toward reaching the concentration target. But even when small trading areas are necessary, emissions trading still may represent an improvement over traditional regulatory policies which allow no trading at all. The fact that so many emissions trades in the United States have actually taken place within the same plant or among contiguous plants provides some confirmation of this result.

In light of these results it should not be too surprising to learn that these pure zonal systems are rarely found in practice. One approximation can be found in the 1990 Clean Air Act Amendments approach to controlling ozone by means of multistate trading. In the 1990 Clean Air Act Amendments ozone nonattainment areas (those areas currently experiencing pollution levels in excess of the levels allowed by the ambient standards) are further classified into one of five categories depending on current ozone concentration levels (marginal, moderate, serious, severe, and extreme). Purchased compensating reductions (or offsets) must come from an area with equal or more severe nonattainment. Thus trading is restricted between zones; the most severe nonattainment areas can sell offsets, but not purchase them.

Similar spatial restrictions on trading were adopted in June 1990 by the Southern California Air Quality Management District (SCAQMD). After June 1990, the Los Angeles basin was divided into 38 distinct zones and firms were only allowed to sell emission reduction credits to downwind trading partners (Foster and Hahn, 1994).

While pure zonal systems are rare, existing administrative regulations associated with the EPA's Emissions Trading Program have the effect of creating a similar result due to the modeling requirements imposed on distant trades, a significant administrative burden. Under the Emissions Trading Program, trades involving distant sources will normally only be approved pending a demonstration of air quality equivalence (51 Federal Register 43814). Providing a nondetrimental air quality impact may involve the use of air quality diffusion modeling, an expensive undertaking. Indeed, the expenses can be sufficient to eliminate any gains from trading. Trading with contiguous sources circumvents the need for this demonstration.

Prohibiting trades across zonal boundaries is an excessively severe response to spatial concerns. In principle it would be possible to formulate a more measured response by allowing transboundary trade subject to predefined trading ratios. While normally a one-ton permit can be used to fulfill a one-ton reduction obligation, that need not always be the case. An acquiring source in an ecologically sensitive area, for example, might be allowed to purchase a permit created from another upwind zone, providing that the reduction is sufficiently large to offset the deposition effects in the receiving zone.

In practice this is a difficult refinement to implement. First, the exchange ratios must be defined. While a number of possibilities exist (Bailey, Gough, and Millock, 1993), they all turn out to be rather unstable over time. As the geographic pattern of emissions changes over time in response to the normal locational and life-cycle changes in economic activity, the exchange ratios will change.

Furthermore, the response to these ratios can create a path dependence (Atkinson and Tietenberg, 1991) in which early trades can rule out later ones which would have been more cost-effective. Subsequent analysis in the European context of trading between nations seems to confirm these results (Klaassen and Amann, 1992; Kruitwagen, 1992; Van Ierland, Kruitwagen and Hendrix, 1993; Klaassen and Førsund, 1993). Subsequent work by Burtraw, Harrison and Turner (1994), however, suggests that trading between sources, rather than between nations, substantially increases the proportion of total available cost savings that can be achieved by trading. Decentralizing the process increases the gains to be achieved by introducing trading, a subject explored in the next section.

The examples of zonal trading ratios which can be found in practice do not approximate those which might be used to approach cost-effectiveness. Some states in the United States, for example, in essence use their ability to manipulate trading ratios as a means of creating small trading zones. In California's Bay Area Air Quality Management District, for example, the offset ratio is 1.1:1 for distances of less than 2 miles; 1.2:1 for distances between 2 and 15 miles; and 2.0:1 for distances over 15 miles (Dwyer, 1992, p. 69). As Hahn (1986, pp. 8–9) demonstrates, this approach is a relatively common, if misguided, administrative response.

3.3. TRADING RULES AND TRADING RATIOS

Two final options are available when a tradeable permit approach is used: (1) ruling out certain classes of trades while allowing others, and (2) allowing the permits to be traded at something other than a one-for-one ratio without imposing zonal boundaries or predetermined fixed exchange rates. Both of these approaches represent a departure from previously discussed approaches because they focus on the *transaction* rather than on the *market* as a whole.

Three different trading rules have been proposed in the analytical literature: (1) the pollution offset (Krupnick, Oates, and Van de Berg, 1983), (2) the nondegradation offset (Atkinson and Tietenberg, 1982) and (3) the modified pollution offset (McGartland and Oates, 1985). The *pollution offset* approach allows offsetting trades among sources as long as they do not violate *any* ambient air quality standard. The *nondegradation offset* allows trades among sources as long as no ambient air quality standard is violated *and* total emissions do not increase. The *modified pollution offset* allows trades among sources as long as neither the pretrade air quality not the concentration target (whichever is more stringent) is exceeded at any receptor. Total emissions are not directly controlled.

Despite the fact that *actual* cost savings from actual trades involving the pollution offset and the modified pollution offset rules are not likely to coincide with the *maximum possible* cost savings for those systems as derived from programming models (Atkinson and Tietenberg, 1991), it is instructive to compare the cost effectiveness and emission loading characteristics as if they were to coincide. McGartland and Oates (1985) found that for particulate control in the Baltimore region, the modified pollution offset system could achieve the pollution target at less than half the cost of the command-and-control approach, but it was still 70% more expensive than the pollution offset approach. Interestingly, both systems resulted in more emissions than the command-and-control system. The excess emissions created by the modified pollution offset trades were transported by local winds to the ocean and therefore did not degrade the air quality at local receptors. McGartland and Oates did not examine the nondegradation offset.

Atkinson and Tietenberg (1984) have examined all three systems in the context of particulate control in St. Louis. Since the size of the cost deviation from the least-cost allocation depends on the pretrade allocation of control responsibility for both the modified pollution offset and the nondegradation rule, three different initial allocations were considered. The results indicate that when the primary ambient standard is the target, the nondegradation offset is only slightly more expensive than the ambient permit system. For two out of the three initial administrative allocations, the cost penalty associated with the use of the nondegradation offset was less than 10%. The modified pollution offset was not only more expensive, it resulted in more emissions. Substantial savings were possible for all three trading rules compared with the pretrade command-and-control allocations.

These results for the nondegradation offset tend to reinforce the results described in the previous section. It is better to implement a basic system built around emission permit trades, dealing individually with those circumstances which result in hot spots or excess pollution at the most severely affected receptors, than to establish wholesale restrictions on trades as occurs in rigid grid zonal system.

One illustration of how this type of constrained trading could be implemented has surfaced in the United States in the trading rules developed by a new entity for controlling tropospheric ozone – the Ozone Transport Commission (OTC). Attempting to implement a truly regional strategy which deals realistically with the spatial elements of the problem, the one currently operating commission (with jurisdiction over the Northeastern United States from Washington, DC to Maine) has allowed regional trading of NO_x offsets subject to some specific trading constraints.

In the Northeast Corridor the ozone plume moves up the east coast from Washington through New York and Boston and on up into Maine before heading out to sea. Due to the regular pattern of movement of this plume not all emissions in the region affect nonattainment status equally. Without any constraints on trading it would be possible for offset trades to actually worsen the degree of nonattainment. To allow interstate trading while assuring environmental improvement in the most severely affected areas the OTC Plan imposes two restrictions on trading: (1) offsets must come from an area with equal or more severe nonattainment, and (2) offsetting reductions must have contributed to violations of the ambient standard in the area of the new emissions. The first rule offers protection against trades which worsen pollution in the most severely affected areas, while the second rule, in effect, creates trading zones which conform to wind flow patterns. Compared to a pure emissions permits system these rules have the effect of reducing the size of trading areas and, hence, the number of possible trades. Compared to a grid zonal system, however, this approach does allow trades across large distances (rather than ruling them out *a priori*), while offering better environmental protection by targeting the restrictions on those transaction which raise concerns.

In principle tailoring trading ratios to the individual circumstances posed by each proposed trade offers an alternative to prohibiting broad classes of trades. Different trading ratios can be used to take stack heights into account or to relax the normal assumption of no interzonal trading. In practice, however, as Hahn (1990) has shown, manipulating trading ratios can extract an efficiency penalty and can have ambiguous effects on trading activity and air quality. The alternative, broadly allowing one-for-one trades, while retaining the right to prohibit specific trades which present problems, seems to be the most common choice of policy makers.

IV. Conclusions

When emission location matters, the dominance of economic instruments over traditional command-and-control strategies is less clear cut in practice than it might appear from theory. Nonetheless economic instruments do have a role to play in air pollution control, even in this most challenging of circumstances. The economic and environmental benefits from their use both in the short run and the long run (particularly their ability to stimulate technological progress and pollution prevention) certainly justifies attempts to implement second-best instrument designs. Though all second-best designs involve an element of compromise with the cost-effectiveness goal, they can still represent an improvement, sometimes a substantial improvement, over more traditional approaches.

The menu of compromise possibilities is growing. In this paper I have reviewed what we have learned about the most common second-best alternatives such as regulatory tiering, nondegradation offsets, tailored trading ratios, three-dimensional zones and the use of constrained trading rules. While the most commonly discussed second-best strategies all have problems, slight modifications of those approaches, as embodied in this new generation of policies, appear to offer the prospect for significant reductions in compliance costs, while assuring environmental improvement. While considerably more work need to be done, it does appear that even when emission location matters, economic incentive strategies which are both feasible and desirable are within our grasp.

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Notes

[1] For a general equilibrium treatment that derives the efficient allocation using a utility framework see Tietenberg (1973).
[2] As a practical matter much of the modeling has proceeded to minimize costs of reaching the concentration targets at *prespecified* locations. As the number of prespecified locations increases this solution approximates the more general solution.
[3] Sometimes the temporal dimension is simplified by modeling average pollution levels. This simplification is particularly inappropriate for pollutants where the damage has an important seasonal component. Ozone is one example of such a pollutant, since in colder climates the condition for its formation are only present in the summer.
[4] An efficient permits system would require an incentive-compatible mechanism for creating the correct number of permits. Some work is being done in this area. See, for example, Brough, Clarke, and Tideman (unpublished).
[5] While Krupnick, Oates, and Van de Verg (1983) demonstrated the existence of a cost-effective equilibrium of a simpler version of a permits system, Hahn (1986) and Tietenberg (1985) demonstrate that this equilibrium is unlikely to be sustained in normal permit markets.
[6] This problem is exacerbated when control technologies are capable of controlling more than one pollutant will depend on the number of credits obtained for the other pollutant, and vice versa. Not only would the source be required to conduct simultaneous negotiations in different markets of the *same* pollutant, it would also need to conduct simultaneous negotiations among the various markets associated with the different but related pollutants. The ability of sources to deal effectively with these interdependencies in the current policy environment is questionable.
[7] Conversation with Renée Rico, Chief of the Market Innovations Branch in the Acid Rain Division of the U.S. EPA.
[8] This would be a least-cost allocation among the set of possible zonal allocations for a given set of zonal boundaries; it would not in general produce the regional least-cost allocation because the zonal permit system causes the marginal costs of *emission* reduction to be equalized across sources within each zone, rather than the marginal costs of *concentration* reduction. The zonal permit allocation of control responsibility would coincide with the regional least-cost allocation in general only if each zone contained one and only one source and each such source received its cost-effective allocation.

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