"Editor's Introduction" in
"The Evolution of Emissions Trading:
Theoretical Foundations and Design Considerations"

by

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INTRODUCTION

Over the last twenty years the use of transferable permits to control pollution has evolved from little more than an academic curiosity to the centerpiece of the US program to control acid rain. It has also become a key ingredient in the UN program to control global warming. What explains this rather remarkable transition? How has the approach changed, and been changed by, these two decades of analysis and implementation experience?

In this two-volume collection I bring some of the articles that have helped to shape and to explain this evolution. While the first volume focuses on the evolution of the theoretical and design considerations, the second volume focuses more on the empirical research and actual implementation experience.

Each volume contains its own Editor's Introduction. This essay is designed to provide the context for the articles in that volume. If the book were a patchwork quilt, then the individual articles would be the patches. The introductory essay represents the master plan that explains not only how all the individual pieces are connected to each other, but also characterizes the overall image that emerges once the pieces are connected.

EARLY HISTORY

By the late 1950s both economists and policy makers had formed quite well-developed and deeply entrenched visions of how pollution control policy should be conducted. Unfortunately these two visions were worlds apart.

Economists viewed the world through the eyes of Pigou[1]. Professor A. C. Pigou had argued that in the face of an externality such as pollution, the appropriate remedy involved imposing a per-unit tax on the emissions from a polluting activity. The tax rate would be set equal to the marginal external social damage caused by the last unit of pollution at the efficient allocation. Faced with this tax rate on emissions, firms would internalize the externality. By minimizing their own costs

[1] A. C. Pigou, The Economics of Welfare (London: Macmillan, 1920)

firms would simultaneously minimize the costs to society as a whole. According to this view rational pollution control policy involved putting a price on pollution.

Policy makers, on the other hand, held an equally firm, if substantively different, view. According to this view the proper way to control pollution was through a series of legal regulations ranging from the location of polluting activities to the specification of emissions ceilings. The public sector should: (1) figure out how much pollution to allow each emitter, (2) monitor emissions to establish compliance with these mandates and (3) use penalties and other means of bring noncomplying sources into compliance.

While communication between the two groups took place, most of it was critical and not viewed by the recipient as particularly helpful. Economists would point out, for example, that these legal regimes, which became known as "command-and-control" regimes, were generally not efficient. Hence either more pollution control could be gained with the same expenditure or the same pollution control could be achieved with less expenditure if policy makers would simply switch to Pigouvian taxes.

Policy makers responded that the information burden imposed by the design of efficient taxes was unrealistically high. Furthermore, they continued, if bureaucrats had sufficient information to set efficient tax rates, they could use the same information to set efficient legal regimes.

The result was a standoff in which policy-makes focused on quantity-based policies, while economists continued to promote price-based remedies. While the standoff continued, the legal regimes prevailed. Taxes made little headway.

In 1960 Ronald Coase published a remarkable article in which he sowed the seeds for a rather different mind set. Arguing that Pigou had used an excessively narrow focus, Coase went on to suggest:

> "It is my belief that the failure of economists to reach correct conclusions about the treatment of harmful effects cannot be ascribed simply to a few slips in analysis. It stems from basic defects in the current approach to problems of welfare economics. What is needed is a change in approach." (p. 42)

The proposed change in approach involved a focus on property rights.

> "If factors of production are thought of as rights, it becomes easier to understand that the right to do something which has a harmful effect (such as the creation of smoke, noise, smell, etc.) is also a factor of production…. The cost of exercising a right (of using a factor of production) is always the loss that is suffered elsewhere in consequence of the exercise of that right- the inability to cross land, to park a car, to build a house, to enjoy a view, to have peace and quiet or to breathe clearn air." (p. 44)

Coase was arguing that by making these property rights explicit and transferable, the market could play a substantial role not only in valuing these rights, but also in providing a means of assuring that they gravitate to their highest and best use. To his fellow economists Coase pointed out that a property rights approach allowed the <u>market</u> to value the property rights (as opposed to the government in the Pigouvian approach.) To policy-makers Coase pointed out that legal regimes provided no means for the rights to flow to their highest valued use.

It remained for this key insight to become imbedded in a practical program for controlling pollution. Dales (1968) pointed out its applicablity for water and Crocker (1966) for air. Among his other contributions Dales pointed out that the legal regimes imposed by the government for pollution control in fact had established a property right in the right to emit. Unlike the property right system envisioned by Coase, however, this property right was not efficient because it was not transferable.

> "The "regulatory" branches of modern governments create an enormous variety of valuable property rights that are imperfectly transferable, and that tend to be capitalized and monetized in ways that are usually unsuspected by their creators." (p. 796)

One possibility, of course, would be to make the existing system of property rights transferable. In a section which foreshadows much of what is to come Dales suggested a means for doing this:

> The government's decision is, let us say, that for the next five vears no more than x equivalent tons of waste per year are to be discharged into the waters of region A. Let it therefore issue *x* pollution rights and put them up for sale, simultaneously passing a law that everyone who discharges one equivalent ton of waste into the natural water system during a year must hold one pollution right throughout the year. Since *x* is less than the number of equivalent tons of waste being discharged at present, the rights will command a positive price—a price sufficient to result in a 10 per cent reduction in waste discharge. The market in rights would be continuous. Firms that found that their actual production was likely to be less than their initial estimate of production would have rights to sell, and those in the contrary situation would be in the market as buyers. Anyone should be able to buy rights; clean-water groups would be able to buy rights and not exercise them. A forward market in rights might be established.…
>
> The virtues of the market mechanism are that no person, or agency, has to *set* the price—it is set by the competition among buyers and sellers of rights…. (p. 801).

Crocker noted that this approach fundamentally changes the information requirements imposed on the bureaucracy:

> Although the atmospheric pollution control authority's responsibilities will continue to be a good deal broader than the basic governmental function of providing legal and tenure certainty in property rights, its necessary work will not have to include the guesswork involved in attempting to estimate individual emitter and receptor preference functions. (p. 81)

While the authority has to set the amount of emissions, it does not have to know anything about either damage or cost functions.

THEORETICAL FOUNDATIONS

While the general properties of the system had been correctly anticipated by Dales and Crocker, it remained for Baumol and Oates (1971) to demonstrate them formally. Interestingly enough their paper is not about a marketable permits system, it is rather about a charge system designed to meet a predetermined environmental target. Nonetheless the mathematics is perfectly equivalent for the two cases and hence the result derived for a charge system immediately has relevance for a permit system.

Pezzey (1992) lays out this symmetry in a particularly concise and useful way. He also is careful to point out the important point that theoretical symmetry does not necessarily imply symmetry in practice. Political acceptability and distribution issues do differ and they do matter. The virtue of theoretical symmetry is that it offers policy makers much more latitude without sacrifice of cost/effectiveness.

The main Baumol and Oates result was that a uniform charge would result in meeting the predetermined environmental target cost-effectively. This was important because it suggested that the control authority had to set by one tax rate and impose that same tax rate on all polluters for the allocation to control responsibility to be achieve at minimum cost. Since all firms would equate their marginal control cots to this uniform charge, all marginal control costs would necessarily be equalized across emitters. Equalizing marginal costs was precisely the condition required for a cost-effective allocation. Significantly, this result also implies that the uniform price that would emerge from trading these permits would result in a cost-effective allocation.

The big practical difference between the two approaches, however, was how the “correct” price would be determined. While any price would result in equal marginal costs, only one price would be consistent with meeting the prespecified standard. In the tax and standards system, this price would be found iteratively. An initial tax would be tried. If the resulting emission reductions exceeded what was necessary to meet the target, the control authority would know that the tax was too high. If the reductions fell short, the tax rate was too low. After each round the control authority would have enough information to establish the necessary direction of change. And it would also have a stopping rule. Once the exact desired reduction was achieved, the associated tax rate would be shown to have been the correct one.

In the marketable permits system the tax would be established by the interaction of the demand for and supply of permits in the market. Not only would the control authority would have no role in rate setting, but rates would be set immediately, not following a long iterative procedure.

The Baumol and Oates results really only apply in a special case--when all emissions from all emitters have to have the same impact on the environmental target (Tietenberg, 1973). When the target involves meeting an ambient concentration standard, this case has become known as the “uniformly mixed” case. One prominent example involves climate change gases, since all emissions have the same impact on the environmental target regardless of the location from where they are emitted. The Baumol-Oates theorem is also valid when the environmental target is defined in terms of aggregate emissions.

In many other cases, however, the location of the emissions does matter. In these cases the contribution of any unit of emissions to the environmental target (say an ambient standard being monitored at a particular location in the air or water) will depend on its location. All other things being equal sources closer to the receptor are likely to have a larger impact than those further away. The importance of this insight is that for these cases a single tax rate or permit price will not suffice. Differentiation of rates among sources is necessary.

Montgomery (1972) formally solved the problem of proving the existence of a different cost-effective permit market equilibrium in this more complicated case. In general those sources having higher marginal impacts on the environmental target would pay higher prices per unit of emissions

This can be implemented by having separate permits for each receptor location. . (Tietenberg, 1974). When the environmental target is defined in terms of pollutant concentrations in the ambient air (as it is in most countries), the permits can be defined in terms of allowable concentrations units. Although each permit would degrade the concentration at the associated receptor location by the same amount, each permit would allow differing amounts of emissions depending on the location of the emitter vis a vis the receptor. Those emitters having a greater impact on the receptor location for each unit of emissions would get fewer emissions authorized by each permit.

THE INITIAL ALLOCATION

No other aspect of marketable permit design is as important and is as controversial as the initial allocation. In principle at least three possible ways to define the initial allocation exist: (1) an auction, (2) allocation by criteria, or (3) allocation by lottery.

In an auction the fixed number of permits would be allocated to the highest bidders. Several possible types of auctions exist. In an allocation by criteria the government decides on some specific criteria to allocate the permits (e.g. historical emissions) and allocates permits based upon the degree to which candidates fit the criteria. In the third case the permits are allocated randomly, usually by lottery.[2] A reliance on lotteries is usually motivated by a desire to provide an equal possibility of access to all potential claimants.

Lyon (1986) examines the theoretical consequences of various initial allocation methods. In general he discovers that some auctions can fall prey to the introduction of strategic considerations,[3] though incentive compatible auctions can be designed. Assuming an incentive compatible auction, in the long run regardless of whether permits are allocated by auction or by criteria the ultimate allocation of control responsibility will be the same. This is at first glance rather remarkable since nothing in the criteria allocation process guarantees that the initial allocation will be cost/effective. The reason for the result, of course, is that allowing transferability in purely competitive markets assures that the permits ultimately gravitate to those parties that value them the most (those with the highest marginal control costs) regardless of the initial allocation.

The importance of this proposition should not be overlooked. It implies that administrators have a considerable amount of leeway in deciding to allocate permits. This leeway can be used to pursue adminisitrative and/or distributional goals.

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[2] Though not currently used in pollution control, this approach is used in other circumstances such as allocating a limited number of permits to hunt moose in Maine. Due to its relative unimportance in pollution control we shall not discuss this option further here.

[3] Strategic considerations are not an idle concern. In fact the auction introduced for the sulfur allowance program in the United States suffers from incentives for strategic behavior. See Cason (1993)

While these results demonstrate that the ultimate allocation of control responsibility may be insensitive to the initial allocation of permits they do not imply the same distribution of costs. Auctions typically involve transfers of resources to the government,[4] whereas allocations by criteria do not.

At the time current command and control regulations in the United States were not sufficient to meet the ambient standards in some parts of the country. What difference would the method of initial allocation make?

One way to shed light on this question involves the use of empirical simulations of regional control problems. Atkinson and Tietenberg (1984) found that the cost-savings from switching from a command-and-control allocation to a permit system could be sufficiently large that the control authority could impose the tighter controls required to meet the ambient standards while lowering regional control costs. They also found, however, that the change to tighter controls would only be a Pareto Superior move if a criteria allocation were used. The financial transfers involved in auction markets (due to the need to buy all permits) would be sufficiently large that the financial burden born by sources would be much larger for the stringent allocation than the prevailing allocation. This was true despite the fact that the resulting allocation in the stringent case was much more cost-effective. In simulations of water pollution control markets Lyon (1982) also found the financial transfers involved in auction markets to be substantial.

Given these results it is not surprising that most operating permit systems use an initial allocation based upon a specific criterion--historical emissions. Now known as "grandfathering" this approach minimizes the political controversy associated with moving from a command-and-control system to a permits system. It also, however, typically "gifts" exisiting sources with permits that can be very valuable.

The practice of grandfathering can actually increase pollution in the short run if sources are aware that larger current emissions result in larger future permit allocations. Naturally this can create an incentive to elevate current emissions for the purpose of qualifying for a large initial allocation of permits. In the earlier stages of permit system in the United States this problem was circumvented by basing the initial allocation on the command-and-control authorized (as opposed to actual) emissions. Increasing actual emissions in this system did not increase permit allocations.

The case for grandfathering is made primarily on grounds of political acceptability. With a grandfathered system existing sources can be no worse off than they were with the command-and-control system, but they might be better off.[5] Since existing sources will have the same initial allocation under both systems, the choice to not trade makes the firm equally well off. On the other hand those existing sources that do voluntarily trade are unambiguously better off.

One pervasive theme in this early literature was the notion that the desirability of the final outcome was insensitive to the form of initial allocation. Recent research using general equilibrium models (Parry, et. al., 1999) suggests that in the presence of severely distorted factor markets a revenue raising method (such as an auction or a tax) will generally dominate a permits system based upon a criterion allocation in terms of the welfare gains. Since additional control tends to exacerbate some of the distortions in the factor markets, revenue raising allocation mechanisms provide a source of revenue to counteract those distortions. The revenue can, for example, be used to reduce other taxes that are responsible for the factor market distortions.

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[4] This is not true for one type of auction--the zero revenue auction. We discuss this further below.
[5] In contrast new firms would have to purchase permits.

The importance of this result is tempered by the earlier results on political feasibility. Revenue raising methods, such as auctions, can help reduce the tendency of existing factor-market distortions to be intensified by pollution control policy, providing the revenue is used for this specific purpose. They also, however, impose a potentially large additional financial burden on sources. A theoretically superior policy that cannot be implemented is not very desirable in practice. So the ultimate question is "Can revenue-raising auction markets be implemented? The historical answer is clearly "no", but what the future holds remains to be seen.

The final question on initial allocations concerns what exactly is being allocated? In most operating pollution control systems the answer is that permits convey the right to emit a specified amount of tons of a specified pollutant. This is in sharp contrast to the approach taken in fisheries where entitlements are defined in terms of a share of an annually announced total allowable catch. (Townsend and Pooley, 1995).

Biological systems, in general, and fisheries, in particular, tend to exhibit a great deal of variability. Variability of this magnitude implies the need for an adaptive control mechanism that is flexible enough to respond to changing conditions. The "share" system provides that flexibility whereas the "tons" systems does not. With the share system the total allowable catch is determined anew each year after ascertaining the underlying biological conditions and what they can support. The "tons' system would involve an inflexible entitlement to a specific outcome.[6]

Should a share system for pollution control be considered? Pollution control has some uncertainty, though typically nowhere near the level of uncertainty found in managing fisheries. One experimental economics project that examined both systems thinks there is. Godby et. al (1997) found that trading shares led to more stable prices and to significantly higher efficiencies. To date most pollution control authorities have not gone this route.

THE SPATIAL DIMENSION

While the Montgomery work made clear how a fully cost-effective permit sytem should be designed in a multiple-receptor, nonuniformly mixed case, the resulting design is complex. 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.

Emission Permits

Using an emissions permit system (which ignores source location and controls only emission levels) 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 in particular locations; emission permits could contribute to the formation of hot spots if they allowed more clustering of

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[6] After New Zealand put in an extensive permit system to control catch in its fishery, it discovered to its chagrin that it had to reduce catch significantly. Since specific catches were already authorized it could only achieve the reduction by buying back the quota and retiring them. This was sufficiently expensive and cumbersome that they switched to a share system.

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 sights is mixed. Tietenberg (1985) examines the ratio of emission permit regional control costs to the traditional command-and-control policy. 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 in this analysis 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. This particular component of lower costs in principle can 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 emission 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 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 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.

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 for the control authority. 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 has 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 above 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 locating near binding receptors could jeopardize compliance. Nothing in the design of the emission permit system prevents these concentrations from exceeding the target.

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 zoned 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, <u>at any point in time</u> it is possible to define a set of allowable zonal emissions which minimizes cost <u>given the zonal boundaries</u>. However, to define instruments that 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 that 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. 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. Treating sources with quite different transfer coefficients the same 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 that approach the least-cost allocation.

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.[7]

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). Proving 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 as to offset, or more than 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, Hendrix, et. al., 1994; Klaassen and FØrsund, 1994). Subsequent work by Burtraw, Harrison and Turner (1993), 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 that can be found in practice do not approximate those which might be used to approach cost-effectiveness. Some states in the United States, for

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[7] Similar spatial restrictions on trading were adopted in June 1990 by the Southern California Air Quality Management District (SCAQMD). (Foster and Hahn, 1994).

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, 69). As Hahn (1986, pp.8-9) demonstrates this approach is a relatively common, if misguided, administrative response.

Trading Rules and Trading Ratios

Two final options are available when a tradable 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 Verg, 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 percent 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 percent. 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.

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 that present problems, seems to be the most common choice of policy makers.

MARKET POWER

In marketable permit systems two rather different types of concerns about market power arise. The first concern arises when participants, acting as either buyers or sellers exercise power in the permit market in order to manipulate the price. The second arises when market power in the permit market is used strategically to gain leverage in the product market.

Price Manipulation

Hahn (1984) has shown that the importance of market power can be affected by the initial allocation of permits. The most important of his results demonstrates that the potential for market power to be exercised is a function of the particular baseline allocation of control responsibility chosen by the control authority. Intuitively, this result is obtained because the ability to exert market power depends on the degree to which the source can affect the price of credits actually traded. The number of credits traded as well as the degree to which the aggressive source can dominate these trades depends on how the pretrade control responsibility is allocated.

Several other conclusions follow from Hahn's analysis of the free distribution case:

- If the grandfathered baseline control responsibility is cost effective, the existence of one or more price-setting sources would not raise total control costs. Because no trades would take place in this case, no opportunity to exert the power exists.

- Whenever a single price-setting source receives a baseline control responsibility either exceeding or falling below its cost-effective allocation, total control costs would exceed the minimum. When the baseline control responsibility falls below the cost-effective allocation, the price-setter can exercise power on the selling side and when it is above, the price setter can exercise power on the buying side of the market.

- As baseline control responsibility is hypothetically transferred from price-setting to price-taking sources, the price which governs credit trades would rise and the number of credits retained by price-setting firms for their own use would increase.

- In a grandfathered credit market, the ability of any one source to affect permit prices is a function of its net demand for or net supply of credits (determined by the baseline control responsibility), not the size of the source *per se.*

These results suggest that the flexibility that control authorities have in principle in allocating the financial burden could be substantially less in practice if market power is a potential problem. Deviations from the cost-effective control baseline could cause control costs to exceed their minimum level by opening price-manipulating opportunities. The crucial question is how sensitive control costs are to these deviations. If they turn out to be insensitive, then the control authority's flexibility is not seriously jeopardized.

Hahn and Noll (1982, pp. 135-137) examine, in the context of sulfate control in Los Angeles, the effect of choosing a control baseline in which one large source is required to control all emissions while other sources control less than their cost-effective amount. This construction creates a situation in which the large source is the only buyer, facing a number of credit sellers. Calculations of the increase in control cost due to this form of market power were performed for a number of cases involving different assumptions about natural gas availability and levels of desired air quality. These calculations showed the losses to be relatively small, ranging from zero to 10 percent, depending upon the case examined.

In another set of published data from the Du Pont Corporation involving some 52 plants and 548 sources of hydrocarbons, Maloney and Yandle (1984) investigated the effects of cartelization of plants on the permit market. Assuming that all sources receive a proportional initial distribution of the permits based on their uncontrolled emissions, they calculate the effects on control costs if plants collude. Their analysis allows collusion to take place separately among buyers and sellers and allows the number of colluding plants to vary from 10 to 90 percent of the total number of plants buying or selling.

In general, these data support the notion that high degrees of cartelization are necessary before control costs are affected to any appreciable degree and that even high degrees of cartelization do not sign)ficantly erode the large savings to be achieved from permit markets. At the 90 percent credit monopoly (achieved when the cartel controls 90 percent of all credits sold), for example, yielding a 41 percent increase in control costs, Maloney and Yandle point out that the cost savings from this severe market power situation, compared with command-and-control regulation, is still 66 (instead of 76) percent. The presence of market power does not seem to diminish the potential for cost savings very much. Even with market power, transferable permit systems seem to result in lower control costs than the command-and-control allocation.

These data also support the notion that market power on the seller side is a more serious problem than market power on the buyer side, though they do so indirectly. The number of plants selling credits (eight) is estimated to be substantially fewer than the number of plants purchasing credits (forty-four). This is a natural consequence of the proportional distribution rule used by Maloney and Yandle, which favors sources with large economies of scale. Because the transaction costs associated with forming a cartel with a large number of small sources are sign)ficantly greater than those for forming one with a small number of large sources, proportional initial allocation rules make power on the seller side more likely than on the buyer side by creating a situation involving a few plants selling permits to a much larger number of buyers. Other rules could lead to power on the buyer side only if they created a few buyers and a large number of sellers.

Strategic Considerations

Quite a bit of work has now been accomplished on the second case as well. In this case firms leverage power in a permits market into power in a product market.

Misiolek and Elder (1989) point out that the use of permit markets for strategic purposes will only be possible only if (1) a significant share of the product of an industry is produced by firms located in the same geographic region and (2) the permits market in this region is susceptible to price manipulation. They further derive the result that the dominant firm's purchase of marketable permits would have a greater impact on the price of the product;

- the more responsive is the price of marketable permits to the dominant firms purchases.
- the more responsive is the rival's product supply to the price of marketable rights.
- the more inelastic is the market demand for the product of the dominant firm, and
- the more inelastic is the rival's supply with respect to changes in product price. (p. 161)

Von der Fehr (1993) extends these results using a duopoly model of two symmetric firms competing as Cournot quantity setters. In this model complete monopolisation will only occur if pollution permits are essential for profitable operations, i.e. abatement costs are substantial, and furthermore, that the supply of permits is inelastic.

This analysis finds two main channels through which such strategic use of emission rights may be exercised. First, the number of permits bought determines a firm's cost structure and hence it's strategic position. Second, manipulation of the permit price affects rivals' costs
Strategic considerations typically strengthen incentives for investment in pollution permits and this overinvestment reduces marginal production costs and makes firms more aggressive. At the same time overinvestment, by driving up the price of pollution permits, increases the marginal costs of rivals.

THE TEMPORAL DIMENSION

Emissions trading offers three sources of cost-saving: (1) trading among discharge points within sources, (2) trading among sources and (3) trading across time. Providing temporal flexibility to sources is important not only because of the effect of discounting, but also because of the importance of timing investments.

Temporal flexibility can be provided either by allowing sources to bank unused entitlements or to borrow entitlements authorized for future use. Banking occurs when entitlements authorized for a current year are not needed for compliance and therefore can be used in some subsequent year. Borrowing occurs when entitlements authorized for some future year can be used in a previous year.

Various combinations of these options are possible. Systems can prohibit banking and borrowing (as the RECLAIM system in Los Angles does), allow banking, but not borrowing (as the sulfur allowance program does), allow borrowing, but not banking or allow both.

In general banking encourages sources to make early investments by allowing them to either use or sell entitlements not needed for compliance during the current year. Borrowing gives flexibility by allowing firms to delay investments until such time as they may be optimal from the firm's perspective. (Reasons for delaying investments can include anticipated changes in production or the cost of capital). The danger of providing this temporal flexibility is that it changes the resulting pattern of emissions and, in principle, could result in a clustering of emissions at a particular point in time. Since clustered emissions cause more damage than dispersed emission, this is a source of concern.

Rubin (1996) develops the theory behind borrowing and banking. In general he finds that all firms that discharge some emissions should have present discounted marginal abatement costs equal to the marginal cost of an additional unit of banked emissions. In addition the marginal abatement costs should be equal for all firms that discharge emissions.

Rubin (1996) also examines emissions paths from various banking and borrowing options and their welfare consequences. He finds that when social damages are an increasing function of the level of pollution emitted at any one time and future entitlements are declining, allowing firms to bank simultaneously lowers firm costs and social damages. On the other hand when future entitlement allocations are constant or increasing, allowing borrowing lowers firm costs, but increases social damages.

A second temporal dimension involves the use of marketable permits to ease the transition to a zero discharge outcome. The U. S. lead phaseout program was one example. In this program the use of a marketable permits program lowered the cost of compliance and made it possible to achieve the zero discharge goals earlier than otherwise would have been possible. (Nussbaum, 1992 and Tietenberg, 1998)

The theory behind this particular use of marketable permits is developed by Toman and Palmer (1997). They investigate a market in which the cumulative number of permits (and hence the cumulative amount of emissions) is defined and allocated among participants. They find that if the permits are freely tradable and if the number of industry particpants is sufficient to generate competitive trading, the product market will be guided to the cost-effective path. (Note that since these permits are undated, both borrowing and banking are implicitly allowed.)

A final temporal dimension deals with tailoring the policy response to the temporal severity of the problem. As Tietenberg (1985, p. 155) points out constant control is excessively costly for two reasons: (1) larger emission reductions are necessary with constant controls (to assure the ambient standards are met at all times) and (2) it does not take into consideration that some emissions can be controlled more cheaply at the specific time when control is needed.

How a temporally tailored system would work is explored in Howe and Lee (1983). Basing their proposal on the current system of water rights in the US, they suggest a system of priority pollution rights. Under this system the control authority would announce the allowable level of emissions for this time period (say 200 units) and those holding the most senior rights (numbered from 1 to 200) would be authorized to emit up to the limits established by their holdings. Those with less senior rights than established by the cutoff for that time period would not be allowed to emit. Prices would presumably be higher for the more senior rights and they would flow to those sources facing the highest costs for abating on short notice. How this concept could be implemented for automobiles is explored in Goddard (1997).

THE ETHICAL DIMENSION

Economists have historically not been very interested in ethical issues, assuming that they belong appropriately in the domain of other disciplines. Yet when it comes to the implementation of policies revered by economists, ethical considerations can play a substantial role. Like it or not, the profession cannot ignore them.

In the early days of economists' efforts to move economic incentive approaches into the policy mix in the United States, Steven Kelman (1981) found considerable ethical reluctance to go this route among member of Congress and their staffs. This nature of this ethical argument was subsequently updated (Goodin, 1994) and recast into an explicit comparison with the medieval practice of selling indulgences to sinners.[8] Indulgences were granted by church officials, for a price, to sinners. Sinners could use them to remit time served in purgatory.

According to Goodin (1994) economic incentive system approaches to environmental protection are morally suspect because they share with medieval indulgences several characteristics.

- the seller is selling something (the right to degrade the environment) that the seller has no right to sell
- it is selling something that can ethically only be given away, not sold
- it legitimizes and removes the stigma from acts (of environmental degradation) that are morally wrong, and
- it plays favorites, allowing some (permit holders) to do what none ought to do.

The moral concerns that prevented the use of economic incentives policies were subsequently at least partially overcome by a variety of measures that attempted to respond to at least some of the concerns. (Tietenberg, 1998)

- The supply of pollution permits was fixed (not subject to change in the face of higher prices) and it was set on the basis of health and other physical considerations (not on the basis of willingness to pay).
- Entitlements were defined in terms of a "limited authorization to emit" rather than conveying ownership of a portion of the airshed to private owners. This addressed the concern that the airshed, which was seen as part of the common heritage, should not become private property.
- Shut down credits, those earned when a plant that is allowed to emit terminates production, were typically treated much differently than credits created by making significant investments in control technology. In theory a credit is a credit regardless of the circumstances of its creation, but in ethics some types of credit transfers are deemed more ethically justified than others. Emissions trading responded to these ethical distinctions.
- Trades that could reduce air quality in specific neighborhoods would be prohibited even if they resulted in aggregate emission reductions and air quality remained better than required by the ambient standards.

All of these exact an efficiency penalty, but they may well have increased the acceptability of the programs by reducing the potential for backlash. Designing programs to reduce backlash is apparently common in public policy. (Roe, 1998).

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[8] A similar argument, though one directed at charges rather than permits, is made by Beder (1996).

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