Marketable Pollution Permits and Acid Rain Externalities: A Comment and Some Further Evidence

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Marketable pollution permits and acid rain externalities: a comment and some further evidence

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In a recent paper, Scott Atkinson (1983) has provided some important insights into the design of systems of marketable permits for the control of air pollution. Atkinson reaches two major conclusions:

1. A system of marketable permits that minimizes the control costs for the attainment of *local* ambient air-quality standards for SO_2 is likely to increase significantly the extent of long-range sulfate depositions (acid rain) as compared to a traditional command-and-control (CAC) strategy.
2. Solely from the perspective of local air quality, the cost-minimizing system of marketable permits *must* imply higher levels of local pollution relative to an alternative system of emissions permits or to a prototype CAC system.

We have no quibbles with the first point. Moreover, Atkinson's simulation results suggest that the trade-off between local air pollution and the long-range transport of sulfur is a serious issue. This is largely a matter of stack height. Higher chimneys allow sulfur emissions to escape the local environment only to result in increased sulfate pollution at more distant locations. This suggests that stack height must be treated as a critical variable in the design of systems to control jointly local and 'global' pollution.

Our concern in this note is with Atkinson's second point. We shall show, first, that the Atkinson theorem is formally incorrect: the cost-minimizing permit system need *not* result in increased local pollution. However, as a practical matter, Atkinson may well be right. We shall supplement his simulation results with some findings from another set of simulations for a different air pollutant, particulate matter, in the Baltimore Air Quality Control

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Region (AQCR). The latter results confirm Atkinson's findings that the cost-minimizing permit system produces more local pollution than an emissions permit system. However, there are ways to adapt the cost-minimizing approach to prevent deterioration in local air quality, while still realizing large cost-savings compared with either an emissions permit or a CAC system. We briefly describe the design of such a system and present some simulation results indicating the rough magnitude of the potential cost-savings.

THE ATKINSON THEOREM

Atkinson purports to prove the following proposition: 'Measured at local receptors, the ambient degradation of the local ADP strategy will equal or exceed that of the local EDP and SIP strategies and, consequently, the cost of the local ADP strategy will be less than or equal to that of the local EDP and SIP strategies' (711). Briefly, the three strategies (or systems) under comparison here are

1. Ambient discharge permits (ADP): a system under which the allowable pollutant concentration at each receptor point is available for sale in the form of permits. A source that contributes to pollutant concentrations at a particular receptor must purchase sufficient permits to validate its contribution to pollution at each receptor. Montgomery (1972) has shown that the competitive market equilibrium under an ADP system satisfies the conditions for the minimization of total control costs subject to the constraint of attaining the predetermined air-quality standard at each receptor.
2. Emissions discharge permits (EDP): a system under which the environmental authority issues a limited number of emissions permits that can be bought and sold among sources. The authority limits the total number of permits sufficiently to attain the air-quality standard at each receptor. Except under some extremely restrictive conditions, EDP will not generate the least-cost outcome.
3. State implementation plan (SIP): In Atkinson's terms, this is a CAC system under which all sources undertake an equiproportional cut-back in emissions (from a defined baseline) sufficient to attain the standards.

Atkinson's claim is that the least-cost system (ADP) will necessarily result in higher levels of local pollution than either EDP or SIP. We shall reject this claim by means of a simple counter-example that provides some insight and intuition into the working of the three systems.

Consider the local air-shed depicted in figure 1, where S_1 and S_2 are the two sources of pollution and R_1 and R_2 are the two receptor points. The a_{ij} are 'transfer coefficients'; they indicate the increase in pollutant concentration at receptor i that results from another unit of emissions from source j. For example, if source 2 increases its emissions by one unit, pollutant concentrations rise by one unit at receptor 1 and by 0.25 units at receptor 2. Both sources

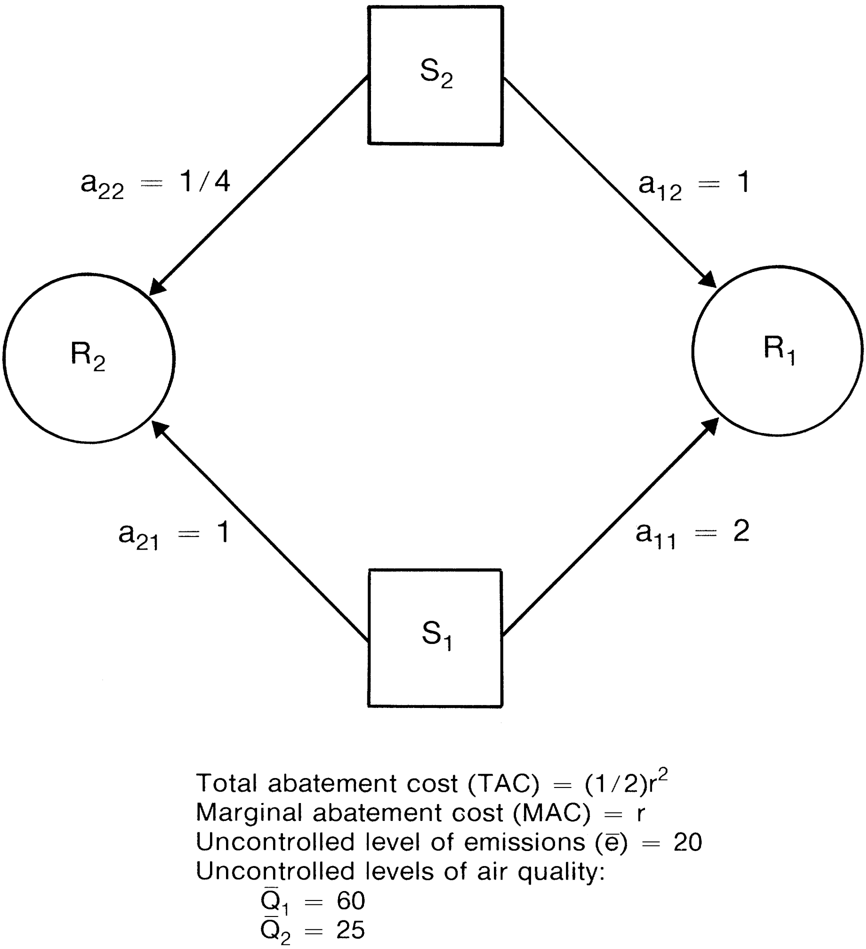

FIGURE 1

are assumed to have the same abatement cost function:

Total abatement cost (TAC) = $(1/2)\, r^2$

Marginal abatement cost (MAC) = $d(\text{TAC})/dr = r$,

where r is the reduction in emissions from a baseline, or uncontrolled, level of emissions, $\bar{e}$, of 20 units. If r equals 5, then emissions, e, are 15. The abatement cost function exhibits rising marginal control costs.

The outcome under each of the three systems is described in table 1. Consider, first, the Emission Discharge Permit (EDP) system. In a permit market cost-minimizing behaviour will lead each source to purchase permits to the point at which MAC equals the price of a permit. This implies under EDP

TABLE 1

Outcomes under three control systems

EDP	SIP	ADP
$r_1 = r_2 = 14$	Same as EDP	$r_1 = 16.8, r_2 = 8.4$
$e_1 = e_2 = 6$		$e_1 = 3.2, e_2 = 11.6$
$\text{TAC}_1 = \text{TAC}_2 = 1/2\,(14)^2 = 98$		$\text{TAC}_1 = 0.5\,(16.8)^2 = 141.1$
$\text{TAC} = 98 + 98 = 196$		$\text{TAC}_2 = 0.5\,(8.4)^2 = 35.3$
$Q_1 = 2\,(6) + 6 = 18$		$Q_1 = 2\,(3.2) + 11.6 = 18$
$Q_2 = 6 + 0.25\,(6) = 7.5$		$Q_2 = 3.2 + 0.25\,(11.6) = 6.1$

where

r_j = reduction in emissions for uncontrolled level by source j

e_j = level of emissions of source j

TAC_j = total abatement cost of source j

MAC_j = marginal abatement cost of source j

Q_i = pollutant concentration (air quality) at receptor i.

that MAC will be equalized across sources. Since, in our example, both sources have the same abatement cost function, it follows that they will adopt identical levels of control and, hence, emissions. We thus have, for the EDP outcome, that $r_1 = r_2$ (or $e_1 = e_2$). The air-management authority must limit the total number of permits sufficiently to attain the standard of $Q^* = 18$.[1] This implies a total quantity of permits of $Q = 12$; in equilibrium, each source will thus purchase 6 permits, and we shall have $e_1 = e_2 = 6$ (and $r_1 = r_2 = 14$). The contributions of sources 1 and 2 to the pollutant concentration at receptor 1 are 12 and 6, respectively, summing to the predetermined limit of $Q = 18$. Note that the pollution level at receptor 2 is only 7.5 – well below the limit so that the concentration at receptor 2 is not a binding constraint. Finally, the control costs for each source are 98, giving an aggregate abatement cost of 196.

For our example the outcome under the SIP system is identical to that under EDP. Since the air-management authority must impose an equi-proportionate reduction in emissions on both sources sufficient to attain the standard ($Q^* = 18$), it follows that the agency will require a cutback of $r_1 = r_2 = 14$. Each source will thus end up with emissions of 6; the resulting level of abatement costs and pollutant concentrations at receptors 1 and 2 will be the same as under EDP.

Under ADP, however, the response of the two sources will differ. With receptor 1 as the binding constraint, source 1 will have to purchase two permits (from receptor 1) to validate each unit of emissions, while source 2 need purchase only one permit per unit of emissions. Cost-minimizing behaviour thus implies that $\text{MAC}_1 = 2(\text{MAC}_2)$, or, given our abatement cost functions, that

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[1] The contribution of source j to the pollutant concentration at receptor i is determined by multiplying the source's level of emissions, e_j, times the relevant transfer coefficient, a_{ij}. In our case, for example, the effect of source 1's emissions on receptor 1 is found by multiplying $e_1 = 6$ times $a_{11} = 2$, yielding a contribution of 12 to the pollutant concentration at receptor 1.

$r_1 = 2r_2$. The market equilibrium now implies that $r_1 = 16.8$, $r_2 = 8.4$, or, in terms of emissions, that $e_1 = 3.2$, $e_2 = 11.6$.[2] Note that under the ADP outcome, source 1, whose emissions are the more damaging at receptor 1, will undertake the larger share of the abatement effort – which is as it should be for an efficient outcome. We find that total abatement costs (corresponding to the least-cost solution) are 176.4, less than the total control costs of 196 under EDP and SIP. But of central interest here, not only are control costs less, but air quality is *better* under ADP than under the other systems. We find that the pollutant concentration at receptor 2 is only 6.1 under ADP, compared with 7.5 under EDP or SIP. For this case ADP results in *both* cost-savings and cleaner air relative to the alternatives.

The rationale for this result is straightforward. Since the emissions from source 1 are the more damaging at the binding receptor, R_1, the least-cost solution for attaining the ambient air-quality standard implies that source 1 should undertake the larger share of the abatement effort. But source 1's emissions are also the more damaging at the other, non-binding receptor, R_2; source 2's emissions result in comparatively little damage at R_2. As a result, the substitution of emissions by source 2 for those of source 1 produces less pollution at R_2 as well as R_1.[3] In contrast, if $a_{22} > a_{21}$, then air quality under ADP would be worse than under EDP or SIP. But the general point here is that because of the inefficiencies inherent in the EDP and SIP systems, it is possible for the least-cost system, ADP, to result in both reduced costs and improved air quality.

SOME FURTHER EVIDENCE ON CONTROL COSTS AND AIR QUALITY

While the trade-off between abatement costs and local air quality among our three control systems is not logically necessary, it may well represent the typical case. In his simulations, Atkinson finds that the ADP system 'leads to the greatest local environmental loading with SO_2. Under the local ADP strategy, air quality is degraded to the level of the ambient standard at four of eight receptors. However, under both the SIP and EDP strategies, this occurs at only

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[2] We determine the market-equilibrium outcome by the simultaneous solution of the following two equations: $r_1 = 2r_2$; and $2(20 - r_1) + (20 - r_2) = 18$. The second of these equations describes the air-quality constraint at the binding receptor, R_1.

[3] Since $a_{11} > a_{21}$ and $a_{12} > a_{22}$, R_2 will always be cleaner than the air-quality standard whenever the pollutant concentration at R_1 is at (or below) the target level. Thus, for this configuration of polluters, R_2 is never binding. Our general result, however, does not depend upon this characteristic of one non-binding receptor. Consider, for example, the case where

$$a_{11} = 1.33 \qquad a_{12} = .667$$
$$a_{21} = 1.3 \qquad a_{22} = .7$$

For this case, each receptor can be binding. When ADP is substituted for EDP, both total control costs and the pollution concentration at receptor one fall, while the pollution level at receptor two remains at the standard of 18.

TABLE 2

Costs and emissions under four control systems to achieve a TSP standard of 98 μg/m^3 in the Baltimore AQCR

	SIP	EDP	ADP	MOS
Annualized costs (in millions of 1980 dollars)	112.9	46.1	27.1	46.3
Total emissions (in tons per year)	23,358	21,420	49,352	24,325

one receptor' (717). For the Atkinson case of sulfur pollution in the Cleveland region the least-cost system does appear to imply more local air pollution.

We find a similar result for another air pollutant, particulate matter (TSP), in the Baltimore Air Quality Control Region (AQCR). These results, presented in table 2, are derived from a computer-based model constructed for the analysis of particulate emissions in the Baltimore region (McGartland, 1984). The model incorporates control-cost estimates, associated collection efficiencies, and dispersion characteristics for over 400 sources. The control-cost estimates take the form of integer step functions and were estimated using the costing algorithm developed in a series of articles by Vatavuk and Neveril (1980-1). In addition, a careful listing of all CAC requirements was assembled which allowed a simulation of the SIP system currently employed in Baltimore. Our version of the SIP system is thus based on actual, required treatment procedures for each source.

Table 2 indicates the total control costs and aggregate emissions under the various systems where the predetermined TSP standard not to be violated at any receptor point is taken to be 98 μg/m^3.[4] We find that ADP promises very large cost savings compared with SIP and EDP outcomes. However, as Atkinson suggests, these cost savings come at the expense of local air quality. Total emissions under ADP are about twice the level of those under SIP and EDP. Moreover, our simulations show that the higher level of emissions under ADP translates into substantially higher TSP concentrations at virtually every receptor point in the region. Our results thus confirm Atkinson's concern: the least-cost permit system, in both our case studies, implies higher levels of local air pollution.

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4 The assumed TSP standard of 98 μg/m^3 (annual arithmetic mean) is not, incidentally, the EPA-determined primary standard for TSP concentrations. It is, instead, the existing TSP concentration in the central business district, which is in excess of the primary standard. We use the existing concentration to permit comparisons with the current SIP system. We note that annual standards for TSP are generally stated as geometric means. With a standard deviation of roughly 1.5, the EPA primary standard of 75 μg/m^3 expressed as a geometric mean translates into a standard of 85 μg/m^3 as an arithmetic mean.

AN ALTERNATIVE PERMIT SYSTEM: THE MODIFIED OFFSET SYSTEM (MOS)

However, there must be (and is) a better way. Both SIP and EDP are inherently inefficient: whatever level of environmental quality they achieve, they do so with excessive control costs. There thus exists a less costly allocation of abatement effort among sources that can achieve the same level of air quality.

We have elsewhere (McGartland and Oates, forthcoming) described a system of marketable permits that can, in principle, accomplish this. More precisely, this system, which we call the 'Modified Offset System' (MOS), will, in general, sustain an outcome that involves *both* cleaner air and lower control costs than SIP. In brief, MOS takes the existing SIP outcome as its point of departure. Sources are then free to buy and sell emissions entitlements subject to the constraint that a trade does not increase pollutant concentrations at any receptor point above the level under the initial SIP state. Trading, then, can only improve – it cannot degrade – air quality. Moreover, we show that the market equilibrium under MOS satisfies the first-order conditions for the solution to the following problem:

$$\text{Minimize} \sum_j C_j(e_j)$$

$$\text{s.t. } EA \leqq \min(Q^*, Q_0)$$

$$E \geqq 0,$$

where $C_j(e_j)$ is the abatement cost function of source j, E is the vector of emissions of the j sources, A is a matrix of transfer coefficients, Q^* is the predetermined air-quality standard (in terms of pollutant concentration), and Q^0 is the initial pollutant concentration under the existing SIP system. A MOS equilibrium thus represents the least-cost solution for the resulting level of environmental quality. As we indicate in the fourth column of table 2, the potential cost savings of MOS relative to SIP and EDP are very large - over 50 per cent for our TSP case in Baltimore. Moreover, the pollutant concentration at every receptor point under MOS is, by design, equal to, or less than, the TSP level under SIP.[5] Finally, we note that compared with the initial SIP state, the equilibrium under MOS represents a Pareto-improvement for all parties involved, including both environmentalists and polluters. Sources realize reduced control costs, while consumers enjoy a cleaner environment. In sum,

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[5] If we return to our illustrative case in figure 1, we find that MOS, in that particular instance, coincides with the ADP outcome. Using SIP as the initial state, sources 1 and 2 would find it mutually profitable for two to purchase emissions entitlements from one. These transfers of entitlements would continue until $\text{MAC}_1 = 2(\text{MAC}_2)$. Note that since source 2's emissions are less damaging at receptor 2 (as well as at receptor 1), this transfer of emissions would not violate the MOS constraint preventing degradation of air quality at *any* receptor point.

the inefficiencies under existing CAC systems provide us with an opportunity to design more efficient systems of marketable permits that promise *both* large cost-savings and reduced pollution.[6]

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[6] As we indicated at the outset of this note, our treatment of pollution control addresses only the 'local' issues. Our Baltimore simulations involve a pollutant, TSP, for which long-range transport and deposition are not a real problem. Obviously, our claim that the modified-offset system results in a Pareto-improvement for both polluters and environmentalists will not generally be true for something like SO_2 emissions unless we introduce a further constraint requiring no increase in the long-range transport of the pollutant.

LINKED CITATIONS

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