ENFORCEMENT COSTS AND THE CHOICE OF POLICY INSTRUMENTS FOR CONTROLLING POLLUTION

ARUN S. MALIK*

Economic incentive based policies have long been advocated for controlling pollution because they can minimize firms' abatement costs. However, the social costs of controlling pollution consist not only of abatement costs but also enforcement costs. I show that the conditions for minimizing abatement costs and minimizing enforcement costs differ. As a result, enforcement costs can be higher for incentive based policies than for policies based on direct controls. A complete evaluation of alternative policies requires a comparison of both abatement and enforcement costs.

I. INTRODUCTION

When evaluating policy instruments for controlling pollution, analysts generally agree that economic incentives are superior to direct controls in terms of minimizing abatement costs. However, when it comes to minimizing enforcement costs, there is no such agreement. Some analysts such as Freeman et al. [1973] and Anderson et al. [1977] argue that economic incentives would be much easier to enforce than direct controls, while others such as Drayton [1978] argue that they would be virtually unenforceable.

The debate typically centers on technical difficulties in continuously monitoring emissions and, to a lesser extent, on political and legal issues related to the assessment of penalties.[1] An issue that has not been examined is whether there are economic reasons for enforcement costs to vary across policy instruments. Although there is now a sizable economic literature on the problem of noncompliance with pollution control policies, there have been no attempts to formally compare enforcement costs across policy instruments.[2]

Accordingly, the purpose of this note is to examine whether there are economic grounds for arguing that enforcement costs would be lower for economic incentives than direct controls.[3] The policy instruments compared are marketable permits (or emissions taxes) and uniform

* Visiting Scholar, Economic Research Service, U.S. Department of Agriculture, Washington, D.C. I would like to thank Richard Brazee, David Letson, James Tobey and Marca Weinberg for helpful comments on an earlier version of this note. The suggestions of the editor of this journal and two anonymous referees are also appreciated. The views expressed are my own and not necessarily those of the U.S. Department of Agriculture.

1. For an excellent discussion of many of these issues, see Russell et al. [1986].

2. Examples of this work are Buchanan and Tullock [1975], Harford [1978], Beavis and Walker [1983], Lee [1983] and Harrington [1988]. The paper by Kambhu [1990] comparing incentives and direct controls when regulations are contestable is perhaps most closely related to this note. However, Khambu does not explicitly consider enforcement costs and restricts attention to a single firm.

3. There is very little data on enforcement costs. The U.S. Department of Commerce [1989] reports federal and state government expenditures on pollution-related "regulation and monitoring" activity, which is defined to be "activity that guides and stimulates action to reduce pollution emissions." Much of this activity can be considered to be enforcement related. For 1987, total expenditures on such activity were estimated to be a substantial $1.2 billion.

Economic Inquiry
Vol. XXX, October 1992, 714–721

standards. The instruments are compared in a setting where the penalty schedule is previously specified by some judicial or legislative body and the regulator's enforcement policy is limited to the choice of audit frequency. The analysis is based on the premise that for any policy instrument that targets emissions, the regulator will have to periodically monitor emissions and assess penalties for noncompliance. The relevant question, then, is whether less frequent monitoring would be required to ensure compliance with economic incentives. Casual analysis suggests this should be the case. Economic incentives minimize aggregate abatement costs, and lower abatement costs imply lower costs to firms of complying. This should imply, in turn, that less stringent enforcement is needed to achieve compliance. This argument, although intuitively appealing, is flawed. Using a simple model of pollution control with costly enforcement, I show that enforcement costs, narrowly defined, may be higher for economic incentives. For purposes of exposition, the result is established in a setting where the regulator ensures each firm is fully compliant. However, as shown in the appendix, the result generalizes to the more realistic setting where firms are partially compliant.

II. THE MODEL

Consider a group of N risk-neutral firms emitting a single pollutant. For simplicity, the damages from the pollutant are assumed to depend only on total emissions. Each firm's abatement costs are given by a strictly convex function $C_i(x_i)$ that is decreasing in emissions x_i. The firm's maximum emissions level is denoted $\bar{x}_i$, and is defined by $C_i'(\bar{x}_i) = 0$. With probability p_i, a regulator audits each firm and measures its emissions. If the regulator finds the firm's actual emissions x_i exceed its allowed emissions s_i, the firm is assessed a fine of $F(x_i - s_i)$. As is common in the literature on enforcement, I assume the fine schedule is previously specified (e.g., by a legislative body).[4] Thus, the regulator can choose the probability with which it audits firms but not the fine it assesses for noncompliance. I assume the fine schedule is such that both the total fine and marginal fine are increasing in the violation size $(x_i - s_i)$, $F' > 0$ and $F'' > 0$.

Because the regulator is assumed to ensure full compliance, no violations occur and no fines are collected. Therefore, enforcement costs consist solely of auditing (or monitoring) costs. To simplify the analysis, the cost of conducting an audit, A, is assumed to be the same across firms. Thus, total enforcement costs are given by $A\Sigma p_i$.

If the regulator controls emissions by issuing standards, each firm faces a decision problem of the form

$$\min_{x_i} C_i(x_i) + p_i F(x_i - s_i), \tag{1}$$

where s_i ($< \bar{x}_i$) represents the firm's emissions standard. The first-order condition for this problem is

$$C_i'(x_i) + p_i F'(x_i - s_i) \geq 0. \tag{2}$$

Examining (2), we can see that the firm would choose to be compliant and set $x_i = s_i$ iff the expected fine it faces when it is compliant is no smaller than its marginal abatement cost,

$$p_i F'(0) \geq -C_i'(s_i). \tag{3}$$

4. For example, see Beavis and Walker [1983] or Jones and Scotchmer [1990]. A more complete analysis would examine the influence of the shape of the fine schedule on enforcement costs (when firms are partially compliant), and determine its optimal shape.

III. MINIMIZING ENFORCEMENT COSTS

Let us now consider a benchmark problem in which the regulator minimizes just the enforcement costs associated with achieving a total emissions goal of S. The regulator's decision variables are the emissions standards s_i and the audit probabilities p_i. Formally, the benchmark problem is:

$$\text{(4)} \qquad \min_{s_i, p_i} \; A\sum p_i$$

subject to

$$\text{(5)} \quad p_i \geq -C_i'(s_i)/F'(0), \qquad i = 1,\ldots,N,$$

$$\text{(6)} \quad s_i \leq \bar{x}_i, \qquad i = 1,\ldots,N,$$

$$\text{(7)} \qquad \sum s_i = S.$$

The first constraint, (5), which is based on (3), ensures that each firm complies with its standard. The second constraint, (6), ensures that the firm is not required to emit more than its maximum level of emissions.

Since raising audit probabilities is costly, (5) will hold as an equality at an optimum.[5] We can therefore substitute $-C_i'(s_i)/F'(0)$ for p_i in (4). Let μ_i and λ be the Lagrange multipliers for the remaining constraints (6) and (7), respectively. Allowing for corner solutions ($s_i = 0$ or $s_i = \bar{x}_i$ for some i), the Kuhn-Tucker conditions for the standards include:

$$\text{(8a)} \quad \partial L/\partial s_i = -A[C_i''(s_i)/F'(0)] + \mu_i + \lambda \geq 0, \qquad i = 1,\ldots,N,$$

$$\text{(8b)} \quad s_i(\partial L/\partial s_i) = 0, \qquad i = 1,\ldots,N,$$

$$\text{(8c)} \quad \mu_i(\bar{x}_i - s_i) = 0, \qquad i = 1,\ldots,N.$$

Whether or not the solution to these conditions is an interior one depends on the shape of the marginal abatement cost curves. If the curves are convex ($C''' > 0$) an interior solution is feasible, but if they are linear ($C''' = 0$) or concave ($C''' < 0$) the solution will invariably be at a corner. The conditions in (8) differ markedly from the conditions for minimizing abatement costs. This can be seen most easily if we assume an interior solution. Condition (8a) then holds as an equality with $\mu_i = 0$, and it implies that to minimize enforcement costs, emissions must be allocated so that the *second* derivatives of the cost functions are equated across firms. This differs from the rule for minimizing abatement costs, which calls for the *first* derivatives of the cost functions to be equated across firms. The difference between the two decision rules follows immediately from the expressions in (4) and (5). These reveal that enforcement costs depend on a firm's marginal abatement costs, and not its total abatement costs. Therefore, to minimize enforcement costs, the sum of marginal abatement costs must be minimized, rather than the sum of total abatement costs. The difference between the two decision rules implies that minimizing abatement costs will not ensure that enforcement costs are minimized. As a result, enforcement costs may well be higher when economic incentives such as emissions taxes or marketable emissions permits are used to control pollution. An example demonstrating this possibility is presented in the next section.

IV. COMPARING UNIFORM STANDARDS AND MARKETABLE PERMITS

Uniform Emissions Standards

Suppose the regulator controls emissions by issuing a uniform standard for all firms. Since total emissions must equal S,

5. I assume $F'(0)$ is large enough for these constraints to hold with $p_i \leq 1$ for all i.

the uniform standard must equal S/N.[6] The regulator would induce firms to comply with this standard by setting $p_i = -C_i'(S/N)/F'(0)$. The attendant enforcement costs would be

$$(9)\quad EC^{us} = A\sum p_i = [A/F'(0)]\sum -C_i'(S/N).$$

Marketable Emissions Permits

Now consider the case where emissions are controlled by means of marketable permits. The regulator issues a total of S permits and ensures that each firm's emissions (x_i) do not exceed its permit holdings (s_i). As before, the regulator would secure compliance by setting the audit probabilities equal to $-C_i'(s_i)/F'(0)$.[7]

Assuming price-taking behavior, firms would trade permits until an equilibrium is reached at which each firm's marginal abatement cost is equated to the (equilibrium) permit price: $-C_i'(s_i) = r^*$. Enforcement costs at this equilibrium would be given by

$$(10)\quad EC^{mp} = A\Sigma p_i = [A/F'(0)] \sum -C_i'(s_i) = ANr^*/F'(0).$$

Note that this expression could also represent the enforcement costs for an emissions tax policy. Simply redefine s_i to be reported emissions and r^* to be a tax that yields total emissions of S. Enforcement costs would be of the same magnitude as for the marketable permits policy.

6. I assume the uniform standard is binding for all firms: $S/N \leq \bar{x}_i$ for all i.

7. The firm's decision problem now is to minimize $[C_i(x_i) + rs_i + p_iF(x_i - s_i)]$, where r is the permit price. The first-order conditions for this problem are $[C_i'(x_i) + p_iF'(x_i - s_i)] \geq 0$ and $[r - p_iF'(x_i - s_i)] \geq 0$. If $p_iF'(0) \geq C_i'(s_i)$, the firm will set $x_i = s_i$, i.e., it will discharge an amount equal to its permit holdings.

Comparing Enforcement Costs

To successfully compare enforcement costs for the uniform standard and marketable permits policies, it is necessary to specify a functional form for $C_i(\cdot)$. Suppose

$$C_i(x_i) = \alpha_i(\bar{x}_i - x_i)^2.$$

Each firm's marginal abatement cost curve ($-C_i'$) is then linear, with slope $2\alpha_i$. As before, $\bar{x}_i$ represents the maximum amount of pollutant the firm would discharge.

With the above specification, the difference in enforcement costs for the two policies is given by[8]

$$(11)\quad EC^{mp} - EC^{us} = [2A/F'(0)] [N(\sum \bar{x}_i - S)/\sum(1/\alpha_i) - \sum \alpha_i\bar{x}_i + S\sum \alpha_i/N].$$

In general, the sign of this expression is ambiguous, but it can be determined for a few specific cases.

Case I: $\bar{x}_i = k/\alpha_i$ for all i. Suppose $\bar{x}_i = k/\alpha_i$, where k is a positive constant. Firms then have identical marginal abatement costs when $x_i = 0$. The difference in enforcement costs for the two policies reduces to

$$(12)\quad EC^{mp} - EC^{us} = [2AS/F'(0)] [\sum \alpha_i/N - N/\sum(1/\alpha_i)].$$

As long as there is some variation in the value of α_i across firms, this expression has a positive sign (otherwise, it equals

8. Equation (11) is obtained by substituting $2\alpha_i(\bar{x}_i - S/N)$ for $-C_i'(S/N)$ in (9), and $2[\Sigma\bar{x}_i - S]/\Sigma(1/\alpha_i)$ for r^* in (10). The latter expression is obtained from the market-clearing condition $\Sigma s_i = \Sigma(\bar{x}_i - r^*/2\alpha_i) = S$.

zero).[9] Thus, in this case, enforcement costs are generally higher for the marketable permits policy.

This is illustrated in Figure 1a, assuming there are only two (price- taking) firms in the permit market. Firm 1's emissions are measured from the left edge of the box and Firm 2's emissions are measured from the right edge. The equal vertical intercept of the marginal abatement cost curves reflects the assumption that $\bar{x}_i = k/\alpha_i$. For the marketable permits policy, the equilibrium allocation of emissions is given by the intersection of the marginal cost curves, M. The associated enforcement costs are $2r^*A/F'(0)$. For the uniform standards policy, the allocation of emissions is given by the midpoint of the horizontal axis, which corresponds to $S/2$. The associated enforcement costs are $(a+b)A/F'(0)$. Since $(a+b) < 2r^*$, enforcement costs are lower for the uniform standards policy.

The following explanation can be offered for this result. Since the marginal abatement cost curves are linear, we know from the discussion accompanying (8) that the enforcement cost minimizing standards constitute a corner solution. Examining (8), one can verify that Firm 1, which has the steeper marginal cost curve ($C_1'' > C_2''$), would be allowed to emit the maximum amount $\bar{x}_1$, while Firm 2 would be required to reduce emissions to $S - \bar{x}_1$. This allocation is clearly closer to the uniform standards allocation ($S/2$) than it is to the cost-minimizing allocation (M) of the marketable permits policy. This occurs because the decision rules for minimizing enforcement costs and minimizing abatement costs favor different firms (compared to the uniform standards policy). As noted above, the former favors Firm 1 since it has the steeper marginal abatement cost curve; but the latter favors Firm 2 since it has the higher marginal (and total) abatement costs.

Case II: $\bar{x}_i = \bar{x}$ for all i. Now suppose that firms have identical maximum emissions $\bar{x}$. The difference in enforcement costs is then

$$EC^{mp} - EC^{us} = [2A/F'(0)]$$

$$[\textstyle\sum \alpha_i/N - N/\sum(1/\alpha_i)]$$

$$(S - N\bar{x}).$$

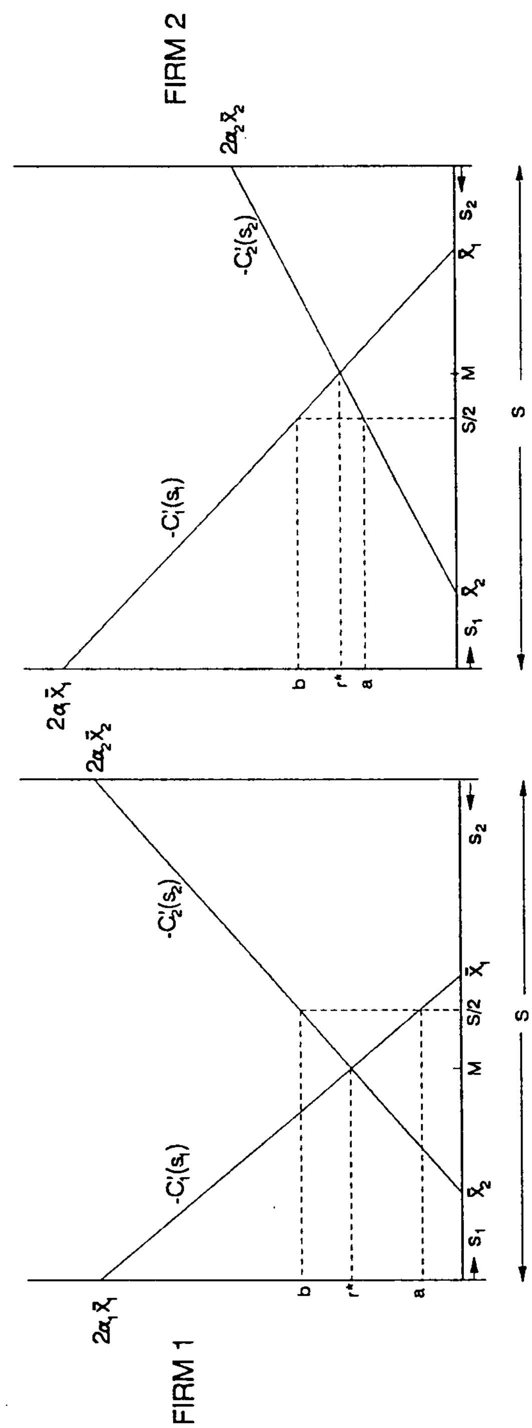
This expression differs from (12) by the presence of the last term in parentheses. For a pollution problem to exist, the term must have a negative sign: total desired emissions must be smaller than total maximum emissions. Thus, in this case, enforcement costs are lower for the marketable permits policy.

This result is illustrated in Figure 1b. Given $\bar{x}_1 = \bar{x}_2$, the firms' marginal cost curves have the same horizontal intercept. Now Firm 1 has higher abatement costs as well as the steeper marginal abatement cost curve. Hence, the decision rules for minimizing enforcement costs and minimizing abatement costs both favor Firm 1. (The enforcement cost minimizing allocation is still given by $\bar{x}_1$.) As a result, enforcement costs are lower for the marketable permits policy: the expressions for enforcement costs are the same as for the previous case but now $(a+b) > 2r^*$.

Case III: $\alpha_i = \alpha$ for all i. Finally, suppose that firms have the same cost parameter . The firms' marginal cost curves then have identical slopes. In this case, the conditions in (8) are satisfied by any allocation of emissions, hence enforcement costs are the same for the two policies:

9. $\Sigma\alpha_i/N$ can be interpreted as the expected value of α, $E(\alpha)$. Similarly, $\Sigma(1/\alpha_i)/N$ can be interpreted as the expected value of $1/\alpha_i$, $E(1/\alpha_i)$. Viewed in this manner, the sign of the expression in brackets in (12) is identical to that of $[E(\alpha)E(1/\alpha) - 1]$. By Jensen's inequality, $E(1/\alpha) > 1/E(\alpha)$ since $1/\alpha$ is a strictly convex function. Therefore, $[E(\alpha)E(1/\alpha) - 1] > 0$.

FIGURE 1
Comparison of Enforcement Costs



(a) Case I

(b) Case II

$$EC^{mp} - EC^{us} \equiv 0.$$

Comparing Total Policy Costs

The total costs associated with each policy also merit comparison. For the above model, total policy costs consist of the sum of enforcement and abatement costs. Since economic incentives minimize abatement costs, they will have unambiguously lower total costs than direct controls if they have lower enforcement costs.[10] This is true in the second case examined above, therefore total costs are lower for the marketable permits policy. The same conclusion holds for the third case. Although in this case enforcement costs are identical for the two policies, abatement costs are higher for the uniform standards policy because it does not ensure marginal abatement costs are equated across firms.

For the first case, the relative magnitude of total costs is ambiguous: the uniform standards policy has lower enforcement costs but higher abatement costs—again because of the divergence in marginal abatement costs. If the difference in abatement costs dominates the difference in enforcement costs, total policy costs will be lower for the marketable permits policy (and vice versa). The relative magnitude of the cost differences will depend, in part, on the magnitude of the audit cost A.

V. CONCLUDING REMARKS

The above analysis shows that there are no a priori economic grounds for arguing that economic incentives would be less costly to enforce than direct controls. Depending on the characteristics of firms' abatement cost functions, economic incentives can be more costly to enforce than direct controls. This result was established in a setting where the regulator ensures each firm is perfectly compliant. This setting was chosen for the expositional economy it provides. The result generalizes to the more realistic setting where the regulator can only ensure partial compliance. As shown in the appendix, the explanation underlying the result is the same in this case: the decision rules for minimizing enforcement costs and minimizing abatement costs are different.

However, in the partial compliance setting, enforcement costs are likely to consist of more than just audit costs. Since firms are only partially compliant, violations will occur and fines will be levied. These fines are unlikely to be costless transfers given the cumbersome legal procedures that characterize the process of levying fines. At the very least, administrative costs are likely to be incurred.[11]

The addition of these fine-related costs affects the conclusions reached above only if the costs differ across policy instruments. Although there are no obvious economic reasons for this to be true, there may be legal ones. As Drayton [1980] points out, judges have frequently been reluctant to impose stiff penalties on firms violating emissions standards because they consider the standards to be arbitrary, and they have no clear basis for determining how large the penalties for noncompliance should be. Both these problems may be less severe for economic incentives. First, there is an obvious lower bound for the unit fine, namely the permit price or the emissions tax. Second, firms essentially set their own "standards" when they choose the number of permits to buy or the quantity of emissions to report. Moreover, buying emissions permits or paying taxes on emissions may be perceived as a

10. In general, neither of the policies examined minimizes the total costs of achieving the emissions goal. Assuming an interior solution, a least (total) cost policy would require equating the sum of marginal abatement costs and marginal enforcement costs across firms.

11. In addition, there may be avoidance costs (Malik [1990]), and if the firm is risk averse, risk-bearing costs (Polinsky and Shavell [1979]).

normal cost of business that is borne by all firms. As a result, levying fines for noncompliance may be substantially easier with economic incentives, and socially less costly. In sum, it may be possible to argue on legal grounds that economic incentives would generally be less costly to enforce than direct controls, but it is not possible to do so on economic grounds.

APPENDIX

The partial compliance case is briefly examined here using a modified version of the benchmark problem in (4)-(7). Given partial compliance ($s_i \leq x_i \leq \bar{x}_i$), (5) is replaced with a single constraint restricting total actual emissions to some level X. To simplify the analysis, I shall restrict attention to interior solutions, so constraint (6) can be dropped; and I shall assume that fines are costless transfers, so the objective function in (4) is still appropriate. The Lagrangean for the modified problem is $L = A\Sigma p_i + \lambda[\Sigma s_i - S] + \gamma[\Sigma x_i(p_i,s_i) - X]$, where $x_i(\cdot)$ represents the firm's actual emissions as defined by (2) when $x_i > s_i$.

The modified problem can be viewed as one of finding the permit allocation (s_i) and audit probabilities (p_i) that minimize the enforcement costs associated with achieving a specified emissions target X. The first-order conditions for the modified problem are

$$\text{(A1)} \qquad A + \gamma(\partial x_i / \partial p_i) = 0$$

and

$$\lambda + \gamma(\partial x_i / \partial s_i) = 0, \qquad i = 1,\ldots,N.$$

These require that the p_i and s_i be set so that $\partial x_i / \partial p_i = -A/\gamma$ and $\partial x_i / \partial s_i = -\lambda/\gamma$ for all firms. From (2), we find (given an interior solution)

$$\partial x_i / \partial p_i = C_i' / [p_i C_i'' + p_i^2 F''],$$

$$\partial x_i / \partial s_i = p_i F'' / [C_i'' + p_i F''],$$

where the arguments of the functions have been omitted. Inspecting these expressions, one can verify that satisfying the conditions in (A1) is generally not consistent with equating marginal abatement costs, $-C_i'$, as would occur in a transferable permits market even with partial compliance. (From footnote 7, one can verify firms would set $-C_i'(x_i) = p_i F'(x_i - s_i) = r^*$.)

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