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Uncertainty and Incentives for Nonpoint Pollution Control

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In dispersed or nonpoint pollution problems, monitoring of individual polluting actions is difficult and those actions cannot generally be inferred from observed ambient pollution because (i) ambient pollutant levels have a random distribution that is contingent on the level of abatement undertaken and/or (ii) the actions of several polluters contribute to the ambient levels and only combined effects are observable. This paper describes a general incentive scheme for controlling nonpoint pollution. Rewards for environmental quality above a given standard are combined with penalties for substandard quality. The mechanism is discussed in the context of both a single suspected polluter and multiple suspected polluters where free riding must be avoided. © 1988 Academic Press, Inc.

At least theoretically, appropriate reductions in pollution from point sources can be achieved by direct regulation or by a system of effluent charges, with transferable discharge permits offering a promising compromise to the practical problems of each. However, the appropriate economic incentives for control of nonpoint pollution (NPP) have not yet been addressed adequately at either a theoretical or a practical level. For example, the suggestion that "best management practices" (BMPs) be required to reduce nonpoint surface pollution does not allow for flexibility and cost-minimizing abatement strategies unless applied on a site-specific basis, which is generally impractical. Likewise, the suggested use of a soil loss tax to reduce agricultural NPP ignores the important distinction between "discharges" and the resulting pollutant levels that determine damages, since lands with high erosion rates are not necessarily those causing significant NPP problems and vice versa.

The standard solutions that have been successful in controlling point source problems are unworkable for NPP partly because it is generally not possible to observe (without excessive cost) the level of abatement or discharge of any individual suspected polluter or to infer those levels from observable ambient pollutant levels. There are two possible reasons for the inability to infer behavior from observed outcomes: (1) given any level of abatement, the effects on environmental quality are uncertain due to stochastic variables,[1] i.e., there is not a one-to-one relationship between discharge and ambient levels, or (2) the emissions of several

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[1] This may also be true for point sources of pollution. Many have studied the role of uncertainty in the control of point sources, including [1, 5, 6, 9, 12, 15, 16]. However, their discussion of policies is limited to those that apply directly to emissions. In addition, the analyses do not consider the problem of multiple polluters where only the joint impact of their behavior is observable. Thus, these analyses do not adequately address the policy questions that are relevant in the control of stochastic nonpoint pollution.

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polluters contribute to the ambient levels and only combined effects are observable. It is these characteristics that have made control of NPP so elusive, and policy instruments designed to address NPP must recognize them.

This paper describes an economic incentive scheme that could be used to control NPP even in the presence of uncertainty and monitoring difficulties. The general mechanism combines rewards for water quality above a given standard with penalties for substandard water, although a special case includes only penalties. It can be applied either when there is a single suspected polluter or when there are several suspected polluters. In the latter case it can be designed to eliminate problems of free riding.[2]

It should be noted that, although the discussion of economic incentives here is in the context of nonpoint surface water pollution, the results are applicable to other dispersed pollution problems characterized by uncertainty and monitoring difficulties, such as many cases of groundwater contamination and acid rain.

1. UNCERTAINTY AND INCENTIVES

The physical uncertainty feature of nonpoint pollution problems—that the ambient pollutant levels resulting from any given operating practice depend on a number of climatic and topographic conditions in a manner that cannot be predicted with certainty—implies that there will be a range of possible ambient levels associated with any given abatement practice or discharge level at any given time. More generally, there is a range of possible damages in terms of the impacts on human health and welfare that depend not only on pollutant levels but also on factors such as stream flow and exposure risks. The analysis could be applied to this broad range of impacts, but for simplicity we focus here only on the range of possible ambient levels. This range can be represented by a probability density function (pdf) that is conditional on the abatement practice. The pdf gives the probability that ambient pollutant levels of a given magnitude will occur at the specified time, where the probability depends on the abatement practices being used. The objective of pollution control policies is then to increase the probability that ambient levels will fall below some tolerance level, i.e., to shift the pdf to the left, as illustrated in Fig. 1, so that the new distribution dominates the old one in the sense of first-order stochastic dominance.[3]

If direct monitoring of all firm operations were economically feasible or voluntary compliance with regulations were guaranteed, then the distribution could be shifted through site-specific mandatory abatement practices. Alternatively, even in the absence of direct monitoring, direct regulation can be used if it is possible to infer the actions of an individual polluter (and thus detect noncompliance) from an observation of ambient pollutant levels. This would be possible, for example, if there were a single polluter whose emissions entered a given body of water and if the relationship between his discharge and ambient pollutant levels were determinis-

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[2] Free rider problems in the context of pollution control have been discussed by Dasgupta [5]. In his model the need for incentives arises from an information gap rather than a monitoring problem. He devises an incentive compatible scheme to ensure correct revelation of preferences for improvements in environmental quality.

[3] In the absence of uncertainty, the distribution simply collapses to its mean and the objective is then merely to reduce the non random ambient pollutant levels.

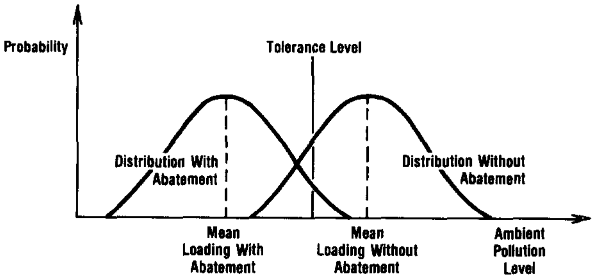

FIGURE 1

tic. However, when that relationship is stochastic, then the actions or discharge of the single polluter cannot be inferred from observed ambient levels. In this case, a mechanism that provides an incentive (either positive or negative) for compliance must be used instead of direct regulation of the polluter's discharge.

A similar problem arises when many polluters jointly contribute to ambient pollutant levels and the actions or discharge levels of the individual polluters cannot be directly observed. Since ambient pollutant levels depend on the behavior of all polluters, it is not possible to infer the actions of individual polluters from observations on ambient levels. Direct regulation of individual actions is not possible in this case either, regardless of whether the joint effect of individual actions on ambient levels is stochastic or deterministic. Because a deterministic relationship between discharges and ambient pollutant levels is a special case of the more likely stochastic relationship, in Section 3 we discuss the multiple polluter problem in the context of uncertainty even though this is not a necessary condition for incentive problems to arise. This discussion highlights the similarity between the single and multiple polluter cases: For both, it is possible to rely on an incentive mechanism based on the observable variable (ambient pollutant levels) to induce certain unobservable actions.

2. SINGLE POLLUTER PROBLEM

Consider first the problem when there is only one suspected polluter. Let x be the ambient level of a given pollutant in the stream, and let $\bar{x}$ be a specified cutoff level, which is set by authorities.[4] The ambient level x will depend upon both the abatement actions taken by the polluter and the random variables reflecting unpredictable weather and stream conditions, as illustrated in Fig. 1.

A general incentive scheme designed to shift the distribution of ambient levels could take the form of automatic, required payments $T(x)$ that depend upon the

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[4] In the short run the choice of $\bar{x}$ is somewhat arbitrary because it does not affect the socially optimal level of abatement undertaken. However, it does affect the values for t and k (the parameters of the incentive scheme) that are necessary to ensure that polluters choose that optimal level. The choice may also be important in terms of political acceptability and certainly determines the financial impacts of the incentive scheme, since it determines the cutoff for taxes/subsidies and penalties. Thus, it affects the long run market equilibrium position. This is discussed more fully below.

ambient level of pollutants as compared to the cutoff level $\bar{x}$ and are given by

$$T(x) = \begin{cases} t(x - \bar{x}) + k & \text{if } x > \bar{x} \\ t(x - \bar{x}) & \text{if } x \leqq \bar{x}. \end{cases}$$

The regulating authority sets the constants t and k so that the payment scheme provides the incentive necessary to induce the polluter to undertake the level of abatement that is deemed socially desirable.

The payment scheme is composed of two parts. The first, reflected in t, is a tax/subsidy payment that depends upon the extent to which x differs from $\bar{x}$. If ambient levels exceed the cutoff level, the suspected polluter pays a tax proportional to that excess, while ambient levels below the cutoff result in a subsidy or credit to the polluter. Note that ambient levels may differ from cutoff levels because of either the abatement actions of the polluter or the influence of the random variables. Thus, the polluter may be liable for tax payments that result from influences outside his control.[5] Likewise, his liability may be reduced (and he will even receive subsidies if x falls below $\bar{x}$) due to favorable environmental conditions even if he has taken no action to control pollution. In choosing his level of abatement, he gambles on what his tax liability will be and weighs the additional cost of pollution abatement against the decrease in expected payments that results from increased abatement (see further discussion below). However, once $\bar{x}$ is fixed, this feature will also allow him to take advantage of the naturally fluctuating assimilative capacity of the waterway. During periods of high stream flow when the waterway has a large assimilative capacity, the level of abatement can be reduced; and during periods of low assimilative capacity, firms will have an incentive to curtail polluting activities.

The same type of incentive is provided by the second component of the payment scheme, reflected in k, which is a fixed penalty imposed whenever ambient levels exceed the cutoff.[6] The amount of the penalty is independent of the amount by which the cutoff is exceeded. When deciding on additional abatement, the suspected polluter can again weigh the cost of that abatement against the resulting decrease in the probability that x will exceed $\bar{x}$, i.e., that he will incur the penalty. Note that the effect of this penalty scheme differs from that of penalties applied to actions (or inactions) that are directly under the control of the polluter (e.g., penalties for point emissions in violation of standards). In the stochastic case where penalties depend upon ambient levels rather than emissions, there will always be an incentive for additional abatement since it will decrease the expected penalty by decreasing the probability that x will exceed $\bar{x}$. In contrast, when the penalties are for emissions in

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[5] Holmstrom [10] has shown that an incentive scheme can be improved by releasing an agent from liability for outcomes that are clearly outside of his control and could not have been influenced by the agent's actions, e.g., natural disasters. Thus, for example, farmers should not be held liable for loadings clearly attributable to an external cause such as a chemical spill from an upstream manufacturing plant. Holmstrom [10] and Shavell [14] investigate the conditions under which additional variables or signals that provide some generally imperfect information about the agent's actions can be used to improve incentive contracts. Although the use of additional information is not discussed here explicitly, appropriate modifications to the analysis could be made.

[6] An alternative formulation of the incentive scheme would be to have $T(x) = t(x - \bar{x})$ if $x \geqq \bar{x}$ and $T(x) = t(x - \bar{x}) - k$ if $x < \bar{x}$. In this case, there would be no fixed penalty for ambient levels above $\bar{x}$. Instead, an additional fixed bonus would be given when those levels were below $\bar{x}$.

excess of standards, incentives exist to reduce emissions to the standard level but not below.

2.1. Short Run Analysis

In the short run where output price is fixed, either component of the incentive mechanism can be used by itself to induce a desired level of abatement, or they can be used in combination. To see this, let a denote the level of abatement and write the ambient pollution level as $x(a, e)$, where e is a random variable and $\partial x/\partial a \leqq 0$. Let y be the level of the good produced by the polluting firm, let $C(y, a)$ be the cost of producing y while abating to level a,[7] and let $F(\bar{x}, a)$ be the probability that x is less than the cutoff level $\bar{x}$, given a, where $\partial F/\partial a \geqq 0$. If the benefit of increasing abatement from zero to a, denoted $B(x(0, e) - x(a, e))$, is known,[8] then the social planner seeks the levels of output and abatement that maximize[9]

$$py + E[B(x(0,e) - x(a,e))] - C(y,a), \tag{1}$$

where p is the output price (reflecting the marginal utility of the good) and E is the conditional expectation operator over the random variable e. The optimal levels of output and abatement, denoted y^* and a^*, are implicitly defined by the first-order condition

$$p - C_y = 0 \tag{2a}$$

$$E[B' \cdot x_a] + C_a = 0, \tag{2b}$$

where the subscripts denote partial derivatives. This is a necessary and sufficient condition for global optimality if the objective function is concave. Note that (2a) can be used to define y^* as a function of a. If (2b) is evaluated at $y = y^*(a)$, then (2b) alone can be used to define the optimal abatement level a^*.

Given the socially optimal abatement level, the incentive scheme can be designed to induce a competitive firm to abate to that level. The firm is assumed to choose the levels of output and abatement that maximize[10]

$$py - C(y,a) - E(T(x(a,e))). \tag{3}$$

Since $E[T(x(a, e))] = t \cdot E[x(a, e)] - t\bar{x} + k(1 - F(\bar{x}, a))$, his choices, denoted $\hat{y}$

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[7] These costs include all social opportunity costs of pollution abatement. We assume that the firm's cost function for output and abatement is identical to the social cost function.

[8] If the benefits of abatement are not known, then the social planner could simply choose the level of abatement that would on average meet an exogenous target level of ambient pollution $\hat{x}$. Then the optimal level of abatement a^* would be implicitly defined by $E[x(a, e)] = \hat{x}$, and y^* would be chosen to maximize $py - C(y, a^*)$.

[9] For simplicity, it is assumed that society is risk neutral. An optimal abatement level could also be chosen under a more general expected utility framework. For a discussion of the appropriate attitude of the public sector toward risk, see [2 and 7].

[10] This assumes that polluters are risk neutral. If they are not but the polluter's utility function is known, the values of t and k can still be set to ensure that the socially optimal level of abatement is undertaken.

and $\hat{a}$, are implicitly defined by

$$p - C_y = 0 \tag{4a}$$

$$t \cdot E[x_a] - k(F_a) + C_a = 0. \tag{4b}$$

If it is assumed that the objective function is concave, then (4) is necessary and sufficient for a global maximum. Again (4a) can be used to define $\hat{y}$ as a function of a, which is identical to the function defined by (2a). Then (4b) evaluated at $y = y^*(a)$ alone defines $\hat{a}$.

Condition (4b) implies that the polluter will be induced to choose the socially optimal level of abatement (i.e., $\hat{a} = a^*$) if, given $\bar{x}$, t and k are set in one of the following ways:

(a) $k = 0$ and $t = E[B' \cdot x_a]/E[x_a]$,[11] (5a)

(b) $t = 0$ and $k = -E[B' \cdot x_a]/F_a$, (5b)

or

(c) t is arbitrary and $k = (-E[B' \cdot x_a] + tE[x_a])/F_a$, (5c)

where in each case the derivatives are evaluated at a^* and $y^*(a^*)$.[12] Thus, in the short run a pure tax/subsidy scheme, a pure penalty scheme, or a combined scheme can be used to ensure optimal abatement. However, the implications of these alternatives in terms of total polluter or government payments are clearly different. Because they imply different total costs for the polluters, they imply different industry sizes in the long run (see, e.g., [3]). The following subsection discusses the appropriate design of the incentive scheme in the long run where output price adjusts endogenously to the entry and exit of firms.

2.2. *Long Run Analysis*

In the above partial equilibrium analysis where output price is assumed to be fixed, short run efficiency could be achieved by an infinite number of combinations of $\bar{x}$, t, and k given in (5). However, this apparent indeterminacy in the short run actually provides the flexibility necessary to ensure efficiency in the long run, where long run efficiency is defined not only in terms of the optimal abatement of the firm but also in terms of its output level and the industry size.

To see this, let N be the number of firms in the industry and let $p(Ny)$ be the inverse demand curve for the output. Then the long run efficiency conditions

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[11] In this case, if benefits are known, then the optimal tax rate is equal to marginal benefits B' if B' is constant. Under a nonlinear benefit function $t \neq E(B')$. However, $E(B')$ may be a sufficient local approximation to the optimal t, or serve as a guide in setting t. The case of a linear benefit function is discussed more fully in the context of the multiple polluter problem.

[12] Thus, setting the optimal levels of t and k requires that the regulating authority know the effect of abatement on the distribution of ambient pollutant levels. It does not require that it know a one-to-one relationship between abatement and ambient conditions. The premise of the problem discussed here is that no such relationship exists. If it did, there would be no need for a control scheme based on ambient levels since abatement could be inferred and thus controlled directly.

become

$$p(Ny) - C_y = 0, \tag{6a}$$

$$E[B' \cdot x_a] + C_a = 0, \tag{6b}$$

and

$$p(Ny)y + E[B(x(0,e) - x(a,e))] - C(y,a) = 0, \tag{6c}$$

where the first two conditions correspond to (2a) and (2b) and the third condition requires that the expected benefits from operation of the firm equal the costs of that operation. These three conditions define the efficient levels of abatement and output per firm and the efficient industry size (a^*, y^*, and N^*).

Under the incentive scheme given above, the long run equilibrium conditions of a competitive market are given by

$$p(Ny) - C_y = 0, \tag{7a}$$

$$t \cdot E(x_a) - kF_a + C_a = 0, \tag{7b}$$

and

$$p(Ny)y - t(E[x - \bar{x}]) - k[1 - F(\bar{x}, a)] - C(y,a) = 0, \tag{7c}$$

where the first two conditions are from profit maximization and the third condition states that in equilibrium profits must be zero. These three conditions simultaneously define the equilibrium levels of a, y, and N as functions of the parameters of the incentive scheme (t, k, and $\bar{x}$).

The planner can ensure long run efficiency by choosing t, k, and $\bar{x}$ such that

$$\hat{a}(t,k,\bar{x}) = a^*, \tag{8a}$$

$$\hat{y}(t,k,\bar{x}) = y^*, \tag{8b}$$

and

$$N(t,k,\bar{x}) = N^*. \tag{8c}$$

The unique combination of t, k, and $\bar{x}$ that solves these three equations will ensure long run efficiency. Thus, of the infinite number of combinations of t, k, and $\bar{x}$ that yield short run efficiency only one also yields long run efficiency.[13] For the special case where the benefits of abatement are linear (B' is constant) the unique combination that ensures long run efficiency is $k = 0$, $t = B'$, and $\bar{x} = E[x(0,e)]$. This is analogous to the pure tax policy given in (5a) with an appropriate choice of $\bar{x}$.

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[13] The reader may wonder why adding only one additional equilibrium and efficiency condition in moving from the short run to the long run reduces the degrees of freedom in the choice of parameters by two. In the short run, choosing the parameters to ensure $\hat{a} = a^*$ is sufficient to also guarantee that $\hat{y} = y^*$ since $\hat{y}$ does not depend on t, k, or $\bar{x}$ directly but only indirectly through their effect on a. Thus, in the short run only one degree of freedom is necessary to meet two goals. However, in the long run $\hat{a} = a^*$ is not sufficient to guarantee $\hat{y} = y^*$ since $\hat{y}$ depends on the parameters directly as well as indirectly through a. In other words, it depends on the expected total payment under the incentive scheme (since this affects average costs) and not just on the scheme's marginal effects.

3. MULTIPLE POLLUTERS PROBLEM

In most NPP cases, it is likely that several polluters will be possible contributors to the ambient pollutant levels of a given waterway. An incentive scheme similar to the one introduced above can still be used, if t and k are allowed to vary across polluters, i.e., if the payments of polluter i are given by

$$T_i(x) = \begin{cases} t_i(x - \bar{x}) + k_i & \text{if } x > \bar{x} \\ t_i(x - \bar{x}) & \text{if } x \leqq \bar{x}. \end{cases}$$

This mechanism is similar to one described by Holmstrom [11] as a solution to free riding in the context of organizational structure. Note that each polluter's liability depends on ambient levels that are determined by emissions from the whole group, not just his individual contribution, since at any given time individual contributions are not known or observable. This is equivalent to putting a "bubble" over the entire group of suspected polluters and setting standards for the whole bubble rather than for each source within the bubble. It is also similar to imposition of the legal doctrine of strict (no-fault) joint liability.

Again, t_i and k_i can be set to ensure optimal levels of abatement by each source. To see this for the short run where output price is fixed, let a_i be the abatement level of polluter i, let $C_i(y_i, a_i)$ be i's cost function, and interpret a in $x(a, e)$ and $F(\bar{x}, a)$ as the vector $a = (a_1, \ldots, a_n)$, where n is the number of suspected polluters. If individual polluters are risk neutral and competitive in their output markets, they will choose y_i and a_i to maximize

$$py_i - E\left[T_i(x(a, e))\right] - C_i(y_i, a_i) \tag{9}$$

given a set of expectations about the actions of all other polluters. For simplicity we assume that (i) each polluter is a Cournot firm and takes the abatement levels of all other polluters as given when deciding on his own abatement level and (ii) the regulatory agency setting the incentive parameters knows that this is how individual expectations are held.[14] A Cournot–Nash equilibrium where all expectations are

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[14] Alternative assumptions regarding expectations are possible. For example, one could specify a set of conjecture functions $a_j^i(a_i)$ that indicate firm i's expectation about the reaction of firm j to i's choice of a_i. In this case, firm i would seek to maximize

$$py_i - C_i(Y_i, a_i) - E\left[T\left(x\left(a_1^i(a_i), \ldots, a_i, \ldots, a_n^i(a_i), e\right)\right)\right].$$

If mistaken expectations are not detectable so that consistency of expectations with actual outcomes is not necessary for equilibrium, then the results discussed under the simpler Cournot assumption still will follow for arbitrary a_j^i functions if partial derivatives with respect to a_i are replaced with total derivatives that reflect both direct effects and anticipated indirect effects through the behavior of other firms. If consistency is required for equilibrium, then the allowable forms for $a_j^i(\cdot)$ must be restricted to ensure the existence of an equilibrium set of abatement actions (see, e.g., [4, 8, 13]). If the consistent conjectures are independent of the parameters of the incentive scheme, then the results in the text would again hold by using total derivatives. Alternatively, if the consistent conjectures depend on those parameters or if the polluters are assumed to collude under an enforceable agreement, then the regulator could still be able to set the t_i's and k_i's to ensure optimal abatement by all firms. However, the optimal values for t_i and k_i will not take the forms discussed below. Of course, in any of these cases, the ability to induce optimal behavior requires that the regulatory agency know (or be able to deduce) the conjecture functions of the individual firms.

realized and each polluter is induced to choose its socially optimal level a_i^* would be possible under any one of the following incentive schemes:

(a) $k_i = 0$ and $t_i = E[B' \cdot \partial x/\partial a_i]/E[\partial x/\partial a_i]$, (10a)

(b) $t_i = 0$ and $k_i = -E[B' \cdot \partial x/\partial a_i]/E[\partial F/\partial a_i]$, . (10b)

or

(c) t_i is arbitrary and $k_i = (-E[B' \cdot \partial x/\partial a_i] + t_i E[\partial x/\partial a_i])/(\partial F/\partial a_i)$, (10c)

where in each case the derivatives are evaluated at a_i^* and $y_i^*(a_i^*)$ for all i.

The free rider problem is eliminated under this scheme since the costs of additional pollution are borne by polluters in a way that does not distort marginal incentives.[15] To see why this eliminates free riding, assume that the benefits of abatement are known and consider the simple case of a linear benefit function, i.e., constant B', and the pure tax/subsidy form of the incentive scheme where $k_i = 0$ for all i. In this case, the optimal tax/subsidy rates are given by

$$t_i = \frac{E[B' \cdot \partial x/\partial a_i]}{E[\partial x/\partial a_i]} = B'.$$

Thus, each polluter pays the full marginal benefit of reduced ambient pollutant levels, rather than just paying a share equal to B'/n. For example, if marginal damages are valued at \$100, the regulatory agency will collect \$100 from each polluter for the marginal unit of ambient pollution, for a total collection of \$(100n). Although the total collection for the marginal unit exceeds the marginal damages, in deciding on a marginal unit of pollution each polluter faces the correct marginal incentives since each will compare his potential abatement cost savings to the full marginal damage (rather than just $1/n^{\text{th}}$ of it) times the likely effect of his reduced abatement on ambient levels, given by $E[\partial x/\partial a_i]$. In this case all polluters face the same tax/subsidy rate B' per unit of ambient pollution regardless of whether they are likely to contribute heavily to marginal ambient levels, i.e., regardless of the magnitude of $E[\partial x/\partial a_i]$. This is necessary because, if their pollution does contribute to those levels, the damages associated with that contribution are assumed to be the same regardless of the source. Note that although they pay the same marginal rate *per unit of additional ambient pollution*, they do not pay the same expected rate *per unit of abatement*. (This latter rate depends upon each polluter's expected contribution to marginal ambient levels.) Thus, despite the constant tax rate in this case, the correct marginal incentives are maintained; polluters weigh the expected marginal benefits of abatement against their marginal abatement costs.

As in the case of the single polluter problem, the alternative forms of the incentive scheme imply different total costs, since the expected values of incentive payments by polluters are different. Thus, in the short run, the planner can alter the financial impact of the plan on any individual firm by appropriately changing t_i, k_i,

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[15] This is analogous to the result obtained by Holmstrom [11], where free riding in an organization can be avoided by breaking the balanced-budget constraint, i.e., by allowing total payments to contributors to be less than total output.

and $\bar{x}$ without altering marginal incentives. However, in the long run this flexibility is again lost. Because the alternative forms in (10) differ in terms of total costs, they will result in different long run equilibrium positions. If all firms are identical with respect to output costs, abatement costs, and polluting characteristics, then the extension of the above short run analysis to incorporate long run exit and entry is the same as it was for the single polluter case. However, if polluting characteristics differ across firms, then the zero net benefit/profit conditions no longer can hold for all firms. Those firms with low contributions to ambient pollution levels (for example, farms with flat land located far from waterways) would in general be expected to earn positive profit under an efficient abatement policy,[16] while firms with higher contributions (and thus higher efficient abatement levels) would have lower profits. The marginal firm would earn zero profit. Although the efficiency and equilibrium conditions are more complicated in this case, the planner still can choose the parameters of the incentive scheme to achieve long run efficiency. In the special case of a linear benefit function, a pure tax scheme with $t_i = B'$ for all i and $\bar{x} = E[x(0, e)]$ is the form of the incentive scheme that guarantees long run efficiency.

4. ADVANTAGES AND DISADVANTAGES

The use of the incentive mechanism described above has several advantages for controlling dispersed sources of pollution. First, it involves a minimum amount of government interference in daily firm operations, and firms are free to choose the least cost pollution abatement techniques. Since individual firms are in a better position to determine the abatement practices that will be most effective for them (and will have an incentive to do so), their freedom to choose the techniques used provides the flexibility necessary to ensure that any given level of abatement is achieved at the lowest possible cost.

Second, the incentive mechanism does not require continual monitoring of firm practices or metering of "emissions." It does, however, require that the regulatory authority monitor ambient pollutant levels. The difficulty and expense of this form of monitoring would depend upon the specific pollutant of concern.[17] This might be reduced by identifying a small number of "hot spots" and crucial time periods that could be targeted for monitoring. Once ambient pollutant levels are recorded, the necessary tax or subsidy payment could be calculated easily. Accounts can be cumulated over time with payments made periodically. If, over the time period, tax liability exceeds subsidy payments, then no government outlays would be necessary under the pure tax/subsidy or combined approaches. The subsidies would simply act as credits against tax liability.

Third, if desired, in the short run cost-sharing mechanisms could be used to prevent placing excessive burdens on the polluting sector, and other considerations regarding an appropriate distribution of costs could be accommodated, as long as

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[16] This assumes that there is a limit on the number of locations with low polluting characteristics. If there were no limit, all firms would eventually locate in low polluting areas (ceteris paribus), and thus in equilibrium all firms would be identical.

[17] As with many policies that are theoretically appealing because of their efficiency properties, the practical difficulties and administrative costs of implementation may be sufficiently high to offset any efficiency gains. This would have to be judged on a case-by-case basis.

the parameters of the payment scheme are adjusted accordingly to maintain proper incentives. In the long run, the parameters of the scheme can be chosen to ensure long run efficiency.

Finally, the incentive scheme focuses on environmental quality rather than emissions or erosion, which is more appropriate for controlling many forms of stochastic pollution. To the extent that some of the fluctuations in ambient pollutant levels can be anticipated, there would be an incentive for polluters to try to offset peaks by, for example, avoiding heavy pesticide or fertilizer applications prior to anticipated rain or wind storms.

The disadvantages of this incentive scheme include the information requirements that are necessary to set the levels of the t_i and k_i parameters initially to provide the correct incentive. (In general, this is a problem with any regulatory device seeking to achieve socially optimal outcomes.) The necessary information includes abatement cost estimates, estimates of damages from ambient pollution, and estimates of how each polluter's abatement affects the distribution of those ambient levels.

A second possible disadvantage of the mechanism is its implications with regard to discriminatory taxation. It would have to be structured so that allowing the t_i and k_i parameters to vary across sources would not be considered to be discriminatory taxation, since discriminatroy taxation is illegal. Of course, in the special case of a linear benefit function, the pure tax/subsidy approach would have t_i be the same for all firms, thereby eliminating this potential problem.

5. SUMMARY

The standard pollution control devices such as direct regulation or the use of emission taxes are inappropriate for nonpoint pollution problems characterized by physical uncertainty and monitoring difficulties. In these cases, we cannot identify with certainty the source of an observed pollutant or infer a firm's level of abatement from observations of ambient pollution levels, especially when there are many suspected polluters contributing pollutants to a common waterway. Thus, mechanisms that focus on ambient pollutant levels rather than emissions are needed in order to control environmental quality efficiently. However, these mechanisms must be designed to ensure socially optimal abatement levels. In the context of multiple polluters, this requires that the mechanism eliminate free riding. This paper has suggested a possible incentive scheme that could be used to induce optimal abatement for single or multiple suspected polluters. The mechanism has several advantages, including an emphasis on environmental quality, flexibility regarding choice of abatement technique, elimination of the need to monitor individual polluting activities, and the ability to alter financial impacts in the short run and/or ensure efficiency in the long run.

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