Presented at the American Agricultural Economics Association meetings, 8/5/85, Ames, Iowa.

1985

Water quality

UNCERTAINTY AND INCENTIVES
FOR NONPOINT POLLUTION CONTROL

Kathleen Segerson*

* Assistant Professor of Agricultural Economics, University of Wisconsin.
The author would like to thank Michael Carter, Jean-Paul Chavas and Daniel Bromley for comments on an earlier draft, without implicating them for any remaining errors.

ABSTRACT

UNCERTAINTY AND INCENTIVES

FOR NONPOINT POLLUTION CONTROL

by

Kathleen Segerson

This paper describes a general incentive scheme for use in controlling nonpoint pollution problems where actual pollutant loadings have a random distribution that is contingent on the level of abatement undertaken and where direct monitoring of polluting activities is difficult. Special cases and their advantages and disadvantages are discussed.

UNCERTAINTY AND INCENTIVES FOR NONPOINT POLLUTION CONTROL

I. INTRODUCTION

It is well-known in the economics profession that appropriate reductions in pollution from point sources can, at least theoretically, be achieved by direct regulation or by a system of effluent charges, and that a promising compromise to the practical problems of each is the use of transferable discharge permits (e.g., Tietenberg and O'Neil et al.). However, the appropriate economic incentives for control of nonpoint pollution (NPP) have not yet been adequately addressed either at 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 (e.g., U.S. Environmental Protection Agency), and vice versa.

An important characteristic of NPP that makes the standard solutions that have been successful in controlling point source problems unworkable for NPP is that, although the likely polluters can often be identified, it is generally not possible to identify a one-to-one relationship between the level of abatement or discharge and the damages from pollutants in the water system. The reason for this is twofold: (1) given any level of abatement, the resulting water quality effects are uncertain due to the contributing effects of stochastic variables, and (2) the level of abatement or discharge often cannot be directly monitored by the overseeing authority without excessive costs. It is these characteristics that have made control of NPP so elusive, and policy instruments designed to address NPP must recognize these characteristics.

The purpose of this paper is to describe an economic incentive scheme that could be used to control NPP even in the presence of uncertainty and monitoring difficulties. The general mechanism combines a system of rewards for water quality above a given standard with a system of penalties for sub-standard water, although a special case includes only penalties. It can be applied either when there is a single suspected polluter or more generally when there are several suspected polluters, and in the latter case can be designed to eliminate problems of free-riding.

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

II. THE ROLE OF UNCERTAINTY

As noted above, an essential feature of NPP is physical uncertainty,[1/] i.e. the pollutant loadings that result from any given operating practice depend on a number of climatic and topographic conditions in a manner that cannot be predicted with certainty.

As a result, associated with any given abatement practice or discharge level at any given time is a range of possible loadings for each pollutant. (More generally, there is a range of possible damages in terms of the impacts on human health and welfare that depend not only on loadings but also on factors such as stream flow and exposure risks. Although conceptually the analysis could be applied to this broader range of impacts, for simplicity we focus here only on the range of possible loadings.) This range can be represented by a probability density function (p.d.f.) that is conditional on the abatement practice. The p.d.f. gives the probability that loadings of a given magnitude will occur at the specified time, where the probability depends on the abatement practices being used.

The objective of policies to reduce NPP is then to shift the distribution represented by the p.d.f. to the left, as illustrated in Figure 1, i.e. to increase the probability that actual loadings will fall below some tolerance level.

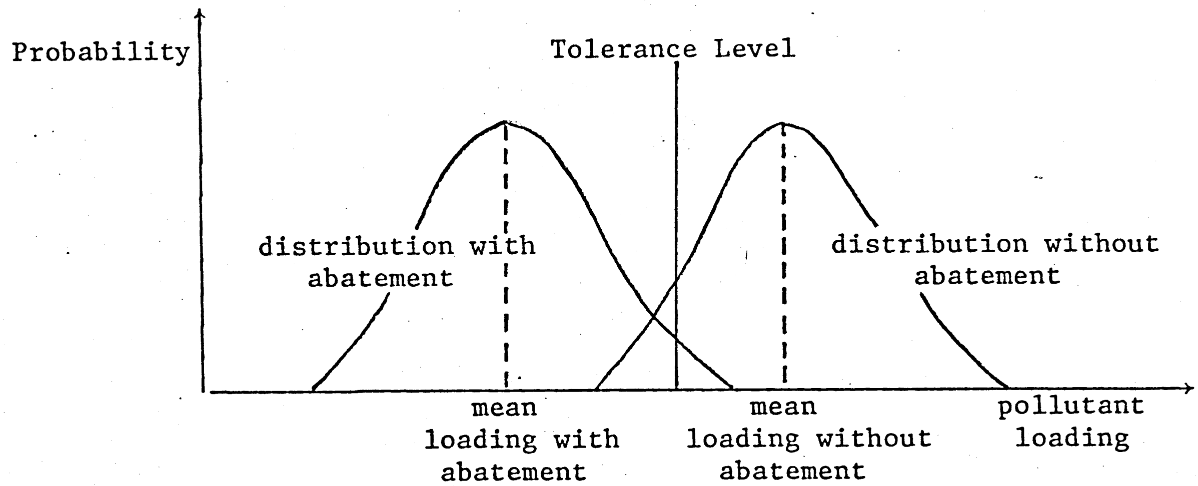

Figure 1: Distribution of Pollutant Loading With and Without Abatement

If direct monitoring of all farm operations were economically feasible or voluntary compliance with regulations were guaranteed, then the distribution could be shifted through site-specific mandatory abatement practices. However, when this is not possible, a mechanism that provides an incentive (either positive or negative) for compliance must be used instead.

The use of incentive mechanisms to induce desired behavior has been studied by many previous authors (e.g. Stiglitz, Holmstrom (1979 and 1982), Shavell, and Mookherjer) in the context of optimal organizational structure or labor contracts. The problem has come to be known in the economics literature as the "principal-agent" problem. A principal-agent problem exists when the welfare of one party, called the principal, depends directly on actions taken by another party, called the agent. The principal's challenge is to devise a payment schedule for the agent to induce the agent to take those actions that best serve the interests of the principal. However, the principal is unable to control the agent's actions directly and cannot even observe them. He can only observe his payoff that results from the agent's actions, which depends not only on those actions but also on stochastic conditions or events. The following question is then asked: what form of incentive mechanism should the principal use to induce the agent to take those actions that best serve the interests of the principal? The question can also be asked in the context of a more general model where there are many agents instead of just one.

If we interpret society as the principal and the farms generating NPP as the agents, the principal-agent problem describes the challenge faced by society to induce independent farmers to take steps that will contribute to improved water quality and thereby serve the interests of society. Viewing NPP in this way allows the insights that have been gained for solving general principal-agent problems to be applied in solving problems of NPP.[2/]

III. AN INCENTIVE MECHANISM

III. 1. Single Polluter Problem

Consider first the case of a single suspected polluter, e.g. a single farm whose land drains into a nearby stream. Let x be the level of actual loadings of a given pollutant in the stream, and let $\bar{x}$ be a specified target or tolerance level of loadings, which is set by authorities and could, for example, be adjusted seasonally. Actual loadings x will depend upon both the abatement actions taken by the polluter (e.g., the use of various BMPs) and random variables reflecting unpredictable weather and stream conditions, as illustrated in Figure 1.

A general incentive scheme designed to shift the distribution of actual loadings would take the form of automatic, required payments T(x) that depend upon the level of actual loadings as compared to the target level $\bar{x}$ and are given by

$$T(x) = \begin{cases} t(x - \bar{x}) + k & \text{if } x \geq \bar{x} \\ t(x - \bar{x}) & \text{if } x < \bar{x} \end{cases},$$

where t and k are constants that can be set by the regulating authority to ensure that the payment scheme provides the incentive necessary to induce the polluter to undertake the level of abatement that is deemed socially desirable (see discussion below). This mechanism is similar to one described by Holmstrom (1982) in the context of optimal organizational structure.

This payment scheme is composed of two parts. The first, reflected by t, is a tax/subsidy payment that depends upon the extent to which x differs from $\bar{x}$. If actual loadings exceed the target level, the suspected polluter pays a tax proportional to that excess, while actual loadings below the target level result in a subsidy or credit to the polluter. Note that actual loadings may differ from target 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. Likewise, however, his liability may be reduced (and he may even receive subsidies if x falls below $\bar{x}$) due to favorable environmental conditions even if he has taken no action to control NPP. Thus, in choosing his level of abatement, he gambles on what his actual 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).

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 loadings exceed the target. The amount of the penalty is independent of the extent to which the target is exceeded. Again, the suspected polluter can weigh the cost of abatement against the decrease in the probability that x will exceed $\bar{x}$, i.e., that he will incur the penalty, that results from increased abatement. Note that the effect of this penalty scheme is different 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, there will in general always be an incentive for additional abatement since it will decrease the expected penalty by decreasing the probability that x will exceed $\bar{x}$, whereas under penalties for emissions in excess of standards incentives exist to reduce emissions to the standard level but not below.

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 as given above. To see this, let a denote the level of abatement and write the random level of loadings as x(a). Let C(a) be the cost of abating to level a, and let $F(\bar{x},a)$ be the probability that x(a) is less than the target level $\bar{x}$, given a. Finally, let B(x(o)=x(a)) be the benefit of increasing abatement from a base zero level to a. Then society seeks the level of abatement that maximizes E[B(x(o)-x(a))] - C(a), where E is the expectation operator over the random variable x.[3/] The optimal level of abatement, denoted a*, is implicitly defined by the first order condition

$$E[B' \cdot dx/da] + dC/da = 0. \qquad (1)$$

The polluter, on the other hand, chooses the level of abatement that minimizes E[T(x(a))] + C(a).[4/] Since $E[T(x(a))] = t \cdot E[x(a)] - t\bar{x} + k(1 - F(\bar{x},a))$, his choice, denoted $\bar{a}$, is implicitly defined by

$$t \cdot E[dx/da] - k(\partial F/\partial a) + dC/da = 0. \qquad (2)$$

The polluter will be induced to choose the socially optimal level of abatement, i.e. $\bar{a} = a*$, if t and k are set in one of the following ways:

a) $k = 0$ and $t = -(dC/da)/E[dx/da]$ evaluated at a*,[5/]

b) $t = 0$ and $k = (dC/da)/(\partial F/\partial a)$ evaluated at a*, or

c) t is arbitrary and $k = (dC/da + tE[dx/da])/(\partial F/\partial a)$ evaluated at a*.

Thus, 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. This is discussed more fully below in the context of multiple polluters.

III. 2. Multiple Polluters Problem

In many cases of NPP, it is likely that several polluters, will be suspected of contributing to the loadings 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

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

Note that each polluter's liability depends on loadings from the whole group, not just his individual contribution, since at any given time individual contributions are not known or observable. Again, t_i and k_i can be set to ensure optimal levels of abatement by each source. To see this, let a_i be the abatement level of polluter i, let $C_i(a_i)$ be i's abatement cost, and interpret a in x(a) and $F(\bar{x},a)$ as the vector $a = (a_1,...,a_n)$ where n is the number of suspected polluters. Individual polluters choose a_i to minimize $E[T_i(x(a))] + C_i(a_i)$ given a set of expectations about the actions of all other polluters.[6/] A Cournot-Nash equilibrium where all expectations are 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 $t_i = -(dC/da_i)/E(\partial x/\partial a_i)$ evaluated at a* for all i,

b) $t_i = 0$ and $k_i = (dC/da_i)/(\partial F/\partial a_i)$ evaluated at a* for all i, or

c) t_i is arbitrary and $k_i = (dC_i/da_i + t_iE[\partial x/\partial a_i])/(\partial F/\partial a_i)$ evaluated at a* for all i.

Note that the free rider problem is eliminated under this scheme since the costs of additional pollution are not shared among polluters in a way that distorts marginal incentives. As noted by Holmstrom (1982), breaking the budget-balancing constraint, i.e. not requiring, for example, that total payments equal total damages, allows a pareto optimal solution to be attained. Since there is no a priori reason why budget balancing must hold in the case of environmental regulation, the problem of providing correct marginal incentives and eliminating free riding is greatly simplified in this context.

The lack of budget balancing implies that the three alternative forms of the incentive scheme have differing implications for overall payments. For example, under the pure tax/subsidy scheme, combined subsidy payments to all polluters when $x < \bar{x}$ could far exceed the benefits of the reduced loadings, since each polluter would in some sense get credit for the entire reduction in loadings. In addition, it provides no way to reward or compensate polluters who abate "more than their share" and thereby create additional benefits for all other polluters. A pure penalty scheme has the advantage of requiring no government outlays for low loadings, but also suffers from the inability to compensate "good" polluters. The combined scheme avoids some of these problems. Under this scheme the t_i values are not constrained and thus can be chosen so that the sum of subsidy payments when $x < \bar{x}$ does not exceed the benefit of the reduced loadings. Although this still requires government outlays when $x < \bar{x}$, those outlays can theoretically be set as low as desired (as long as the k_i are adjusted to maintain proper incentives). In addition to choosing the sum of the t_i to avoid excessive outlays, the regulatory authority can also set the individual t_i's to reward "good" polluters. Thus, the combined scheme allows the distributional effects of the incentive mechanism to be adjusted to satisfy non-efficiency objectives.

IV. ADVANTAGES AND DISADVANTAGES

Regardless of which form of the incentive mechanism is chosen, the use of such a mechanism has several advantages for controlling NPP.

First, it involves a minimum amount of government interference in daily farm operations, and farmers are free to choose the pollution abatement techniques that are least cost for their farms. Since individual farmers are in a better position to determine the abatement practices that will be most effective for their land (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.

Secondly, once in place, the incentive mechanism can be easily administered since it does not require continual monitoring of farm practices or metering of runoff or soil loss. It instead requires that the regulatory authority monitor pollutant loadings regularly and calculate the necessary tax or subsidy payment. 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 even under the pure tax/subsidy or combined approaches. The subsidies would simply act as credits against tax liability.

Thirdly, the cost-sharing mechanisms of the existing NPP programs can be maintained to prevent placing excessive burdens on the agricultural sector, and other considerations regarding an appropriate distribution of costs can be accommodated, as long as the parameters of the payment scheme are adjusted accordingly to maintain proper incentives. As mentioned above, under the combined approach the t_i values can be chosen to reflect distributional considerations. In addition, federal or state cost-sharing to cover a portion of investment or operating expenses is consistent with use of the incentive scheme. The payment mechanism simply provides the incentive for participating in cost-sharing programs that seems to be missing under the current structure.

Finally, the incentive scheme focuses on water quality rather than erosion or runoff, which is more appropriate for controlling NPP. In addition, to the extent that some of the fluctuations in pollutant loadings can be anticipated, there would be an incentive for farmers 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 pollutant loadings, and estimates of how each polluter's abatement affects the distribution of those loadings, which would require the use of individual watershed models.

A second possible disadvantage of the mechanism is its implications with regard to distortionary 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 distortionary taxation, since distortionary taxation is illegal.

V. CONCLUSION

Despite substantial progress in the control of point source pollution, relatively little success can be claimed to date in controlling NPP. Both physical uncertainty and the difficulties of direct monitoring of polluting activities imply that the standard solutions that have been used for point sources are inappropriate in cases of NPP. An alternative incentive scheme that could be used to control NPP in a socially efficient way has been suggested. The scheme eliminates free-riding and allows non-efficiency objectives to be met. In addition, once established it can be easily administered.

FOOTNOTES

1/ For a discussion of the role of uncertainty in control of point source pollution, see for example Adar and Griffin, Dasgupta, Fishelson and Weitzman.

2/ In the standard principal-agent problem the agent's participation is voluntary and thus the principal is constrained in setting his incentive scheme by the alternative opportunities available to the agent; if the proposed payment is too low, the agent can simply refuse to sign the contract. In the case of NPP, if the (negative) incentive scheme is a form of taxation or penalty as described below, farmers cannot simply refuse to be subject to the tax while remaining farmers. However, they can refuse the contract by leaving farming. Thus, as in the standard problem, society is conceivably constrained in setting its payment scheme by a desire not to penalize the farming sector too heavily. This is discussed briefly in section IV.

3/ For simplicity, it is assumed that society is risk neutral. The results are not qualitatively changed by assuming risk aversion.

4/ This assumes that polluters are risk neutral.

5/ Note that in this case the optimal tax rate is equal to marginal benefits B' if B' is constant, while 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.

6/ See footnote 4.

REFERENCES

Adar, Z. and J.M. Griffin (1976). "Uncertainty and the Choice of Pollution Control Instruments." Journal of Environmental Economics and Management, 3, 178-188.

Dasgupta, P. (1982). "Environmental Management Under Uncertainty," in V.K. Smith and J.V. Krutilla, eds. Explorations in Natural Resource Economics (Baltimore: Johns Hopkins University Press).

Fishelson, G. (1976). "Emission Control Policies under Uncertainty." Journal of Environmental Economics and Management, 3, 189-197.

Holmstrom, B. (1979). "Moral Hazard and Observability." Bell Journal of Economics, 10(1), 74-91.

Holmstrom, B. (1982). "Moral Hazard in Teams." Bell Journal of Economics, 13(2), 324-40.

Mookherjee, D. (1984). "Optimal Incentive Schemes with Many Agents." Review of Economic Studies, 51(3), 433-446.

O'Neil, W. M. David, C. Moore and E. Joeres (1983). "Transferable Discharge Permits and Economic Efficiency." Journal of Environmental Economics and Management, 10, 346-355.

Shavell, S. (1979). "Risk Sharing and Incentives in the Principal and Agent Relationship." Bell Journal of Economics, 10(1), 55-73.

Stiglitz, J. (1974). "Incentives and Risk Sharing in Sharecropping." Review of Economic Studies, 4, 219-255.

Tietenberg, T.H. (1980). "Transferable Discharge Permits and the Control of Stationary Source Air Pollution: A Survey and Synthesis." Land Economics, 56(4), 391-416.

U.S. Environmental Protection Agency. (1984). Report to Congress: Nonpoint Source Pollution in the U.S., Office of Water Program Operations, Water Planning Division, January.

Weitzman, M. (1974). "Prices vs. Quantities." Review of Economic Studies, 41(4), 477-491.