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Contracting for Nonpoint-Source Pollution Abatement

Olof Byström and Daniel W. Bromley

This study presents an incentive scheme to control agricultural nonpoint-source pollution. The analysis is based on a principal-agent framework with two parties: farmers and a regulating authority. Our incentive scheme proposes collective penalties as a way to control pollution. Unlike previous analyses of incentive schemes to control agricultural pollution, we suggest nonindividual contracts between farmers and a regulating authority, where farmers can trade pollution abatement efforts. Findings show that the information requirement of a regulatory agency can be substantially reduced if contracts can be made nonindividual.

Key words: agricultural pollution, cost effectiveness, incentives, information costs, policy

Introduction

Agricultural nonpoint-source (NPS) emissions of nitrogen and phosphorus are major sources of pollution in many watersheds, causing environmental problems such as algal blooms in rivers, lakes, and in the sea, and may also reduce biodiversity. Abatement of NPS pollution has received substantial attention, and there are numerous studies that analyze policy and cost-effective solutions to pollution problems. An area which has received less attention is the cost of information. Many studies have pointed out the potentially large transactions costs associated with NPS pollution regulation (e.g., Baumol and Oates; Loehman and Dinar; Stavins). If information is unavailable or costly, a regulatory agency may want to use policies that economize on information costs.

The purpose of this investigation is to formulate a model that allows and encourages cost-effective solutions to NPS pollution problems. We describe and discuss the problem of agricultural pollution in the context of uncertainty and provide a suggested solution to an agricultural NPS pollution problem on a national level. A principal-agent framework is used, with farmers and a regulating authority (government) as the parties involved in the pollution abatement process. The incentive scheme proposed is based on collective penalties for farmers. We show that neither individual contracts with each farmer, nor full information on the part of the regulatory agency, is necessary to achieve cost-effective abatement of NPS pollution. The benefits of this result, in terms of lowering transactions costs, could be substantial.

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Literature on NPS Regulation

Policies for reducing nonpoint-source pollution have been suggested by a number of authors. Griffin and Bromley evaluate economic incentives and standards applied to expected runoff or management practices. They show that both incentives and standards can be defined such that efficient solutions result, regardless of whether the policy is applied to expected runoff or management practices. Under less restrictive assumptions, Shortle and Dunn find that when emissions are stochastic, a first-best optimal solution cannot be achieved. They conclude that appropriately specified management practice incentives generally outperform other available policies. Using similar assumptions, Smith and Tomasi report that in the presence of transactions costs, only second-best solutions can be achieved by using input taxes.

A large body of literature evaluates the economic consequences of reducing NPS emissions by changing management practices (e.g., Braden et al.; Chowdhury and Lacewell; Taylor, Adams, and Miller; Walker, Calkins, and Hamilton). To regulate management practices, the regulating authority needs substantial information. The regulations allow farmers limited ability to use their private information in finding low-cost abatement measures. Thus, unless management practice policies are formulated under perfect information and perfect enforceability, these policies may fail to incorporate many low-cost abatement measures that may be taken on farms.

Incentive schemes that allow a more flexible approach to agricultural pollution problems have been suggested by Meran and Schwalbe; Segerson; and Xepapadeas. Suggested policies are based on collective rewards and penalties. Under these incentive schemes, farmers are free to choose the method to reduce pollution, as long as the aggregated pollution from a watershed does not exceed a certain level.

We briefly summarize and discuss some of the properties of these approaches, especially from the point of view of information requirements and efficiency. The general outline of the incentive systems that are proposed by the authors is given in Holmström. He designs a system, within a principal-agent framework, that enables the principal to obtain a first-best solution even though the actions of agents cannot be observed. Holmström also shows that the proposed system eliminates moral hazard.

Segerson presents an incentive scheme that builds on collective payments with individual contracts for all polluters. She assumes that, while the emissions from individual polluters cannot be measured, it is possible to measure ambient concentrations of the pollutants from a watershed. In her suggested incentive scheme, an ambient pollution standard is set. If the aggregate pollution is less than that dictated by the ambient standard, then firms receive a positive payment. If pollution levels exceed the standard, each polluter has to pay a fee that is linear in ambient pollution level, plus a penalty for exceeding the ambient pollution level. In the latter case, all polluters must pay the penalty, even if they have undertaken pollution abatement measures. The fact that the system relies on individual contracts, and does not allow for "pollution trading" among farmers, makes the system look more like a system of Pigouvian taxes than a "bubble," as was proposed by Segerson.

Meran and Schwalbe show that incentive schemes can be designed based on effluent taxes or effluent standards even though the effluent emission level cannot be observed.

They introduce a truth-telling mechanism based on collective penalties (fines). The system is structured on the ambient concentration of pollutants, where every polluter is liable if the ambient pollution level is exceeded. The researchers suggest two types of individually designed contracts where the polluter must pay a fine if the aggregate level of pollution exceeds the ambient standard. The polluter pays nothing if the ambient pollution standard is not violated. By this incentive scheme, they demonstrate that both effluent taxes and ambient standards can be used effectively, despite the fact that effluent levels of pollution are not observable.

Xepapadeas suggests a scheme where contracts are not individual, but each firm pays the same fine if deviations from the ambient standard are detected. He shows that even when using nonindividual contracts, a cost-effective reduction of emissions can be achieved. While the analysis is presented in a dynamic framework, Xepapadeas finds that the conclusions are equally valid under a static incentive scheme.

The incentive schemes suggested by Segerson, and by Meran and Schwalbe, build on individual contracting. This means that the regulating authority must design *n* different contracts requiring unique information about *n* different firms. This information requirement may be unrealistic or costly to obtain. If we include information costs in the design of incentive schemes for NPS pollution abatement, it is doubtful whether optimal solutions based on individual contracts would be the least-cost way of abating NPS pollution. The complexity of the design may undermine the efficiency gains induced by optimal contracting. This has also been pointed out by Cabe and Herriges, and by Loehman and Dinar.

An assumption in these studies is that the agents are risk neutral with respect to income, implying that agents have identical risk preferences.[1] If contracts are individual, nonhomogeneous risk preferences do not pose any problems since each contract can be designed to reflect individual risk preferences; thus an optimal allocation of abatement is reached. Xepapadeas suggests uniform contracts for all the polluters. In this case, a cost-effective solution may not be achieved if farmers do not have homogeneous risk preferences. Xepapadeas does not allow for any side payments, and thus closes the possibility for polluters to improve their utility by trading pollution with others.

The Model

Underlying Assumptions

In defining policies for NPS water pollution, we have parties acting on two levels. First, there are farmers who produce goods, but who also affect water quality by their actions. Second, there is a regulating authority which has an interest in increasing and maintaining environmental quality in the area. We assume that farmers produce output y, using a vector of inputs $\mathbf{x}$. The input vector includes all relevant farm-specific information. Let us also define a variable, $a(x)$, that describes farmers' efforts to reduce pollution from their farm. Following Segerson, and Meran and Schwalbe, and utilizing

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[1] This assumption is implicit in Xepapadeas, and in Segerson.

the envelope theorem, we can write farmer *i*'s production and cost functions as functions of abatement effort, $y^i(a^i)$ and $c^i(a^i)$.[2]

Stochastic events such as storms and temperature affect the level of nutrient runoff from agricultural land. There is an additional uncertainty in that farmers only have a limited knowledge of how their abatement efforts transfer into water quality improvements. Biophysical factors, such as soil type, slope, and spatial differences among farms, affect how a farmer's abatement efforts transfer into water quality. Let these two sources of uncertainty be captured in the stochastic variable δ. Assume now that there is a common perception (more or less correct) among farmers of how abatement efforts transfer into water quality. We can then write the stochastic production function for water quality as $e = e(\mathbf{a}, \delta)$, where $\mathbf{a} = (a^1, a^2, \ldots, a^i, \ldots, a^n)$ is a vector of all farmers' efforts in a watershed. Note that in defining $e(\mathbf{a}, \delta)$, we also assume that a farmer can observe the abatement efforts of other farmers in the watershed.

The objective of the regulatory agency is to maximize welfare. In order to control agricultural pollution, the agency needs an instrument that is feasible and that ensures low abatement costs as well as low costs of information. Following the assumptions above, farmers have a common perception of how abatement efforts transfer into water quality. We also assume that farmers can observe one another's abatement efforts. Finally, we assume that farmers can obtain this information without cost. It is plausible that it is difficult, or associated with high costs, for the regulatory agency to obtain farm-specific information that is sufficient to directly monitor farmers' abatement efforts and/or emissions. We therefore assume that the agency can observe aggregate output of crops and ambient water quality, but not the abatement efforts by individual farmers.

In this setting, farmers have an informational advantage over the regulatory agency. This asymmetry of information motivates a principal-agent approach. In order to maximize welfare, the authority needs an incentive scheme that induces farmers to improve water quality. Due to the asymmetry of information, it is also desirable to identify a system of payments that allows farmers to use their private information in improving water quality. Indeed, a system that corresponds to a regime of "marketable permits" would take care of potential inefficiencies. The problem, however, is that it is difficult, or expensive, to trace pollution back to the polluter, and thus there are limited opportunities to control compliance with any direct regulation of emissions at the individual farm level.

We propose an incentive scheme that reduces the information required by the regulating authority. The suggested system rests on collective penalties and an ambient standard for a watershed. We also allow the farmers to negotiate and trade abatement efforts among themselves. In this case, the role of the principal is to enforce the penalties rather than to directly monitor the actions of farmers. Using contracts that are not individual allows us to reduce the information requirements for the authority, since there is only one contract for the whole watershed. Since our incentive scheme allows for trade among farmers, the incentive scheme can be regarded as a "virtual" tradeable

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[2] The optimization problem that allows us to write the production and cost functions as functions of a can be stated as: $\max py(x) - c(x)$ with respect to x, subject to a constraint in abatement effort, $a(x) \geq a^*$. If $a(x)$ is continuous in x, solving this problem for all levels of a^* and applying the envelope theorem gives $x(a)$, and thus $y^i(x^i(a^i)) \equiv y^i(a^i)$, and $c^i(x^i(a^i)) \equiv c^i(a^i)$ (Varian). If x is a polluting input, it is clear that $\partial x(a)/\partial a < 0$. In order for the envelope problem, $\max y(a) - c(a)$, to be consistent with the standard properties of the profit function, we also require that $x(a)$ is concave, i.e., $\partial^2 x(a)/\partial a^2 < 0$.

permit system. The suggested system is based on the works of Holmström, and Meran and Schwalbe. The differences here are that we propose nonindividual contracts with the polluters, that we open the possibility for farmers to trade abatement efforts, and that we apply the methodology to a nonpoint pollution problem.

Model Development

Assume that emissions from a particular farm cannot be observed. However, the authority can measure ambient water quality along a river or stream. Based on measured ambient water quality, the authority then formulates an incentive scheme according to the criteria discussed below.

Let $T(e)$ be a per hectare payment scheme that is identical for all farms; let e^* be the minimum required ambient water quality, and $e(\mathbf{a}, \delta)$ the observed ambient water quality. $T(e)$ will be zero if ambient water quality is higher than the required e^*, and strictly positive if the observed water quality is below e^*. We can thus write $T(e)$ as:

$$T(e) = \left\{ \begin{matrix} 0 \text{ if } e \geq e^* \\ \beta \text{ if } e < e^* \end{matrix} \right\}, \tag{1}$$

where $\beta > 0$, and β is a per hectare penalty that all farmers pay when the observed water quality is below e^*. The total amount paid by the farmer is then $T(e)L^i$, where L^i is the total arable land on farm i. It was noted earlier that water quality is stochastic. Due to δ, the probability of paying the penalty is therefore never zero, but varies with farmers' efforts to comply with the standard and with the level of the ambient standard itself (e^*) set by the authority. We can write the probability of paying the penalty as $\int_0^{e^*} f(e; \mathbf{a})\, de$, that is, the probability that observed water quality will be less than the required e^*, given farmers' efforts, $\mathbf{a}$, to comply with the standard. The probability of paying the penalty decreases with abatement effort, since effort increases water quality. This means that $\int_0^{e^*} f_{a^i}(e; \mathbf{a})\, de < 0$, where the subscript a^i denotes the derivative with respect to farm i's efforts.

We also allow a payment among farmers, where they can buy or sell water quality improvements. Instead of increasing the efforts on their own farms, farmers may choose to bribe other farmers and thereby affect the probability of paying the penalty. The payment that a bribing farmer will make to the others is then determined by other farmers' costs, risk aversion, and current allocation of factors. Let $k^i(a^j)$ denote the bribe that farmer i makes to farmer j in order to affect j's abatement effort. Hence, $k^i(a^j)$ also denotes farmer j's income from farmer i for changing abatement effort. Further, let $k^j(a^i)$ denote the payment that farmer i receives from farmer j for increasing i's abatement effort.

Assume that farmers are risk averse and put some value on a certain income. Let $V(\cdot)$ denote the utility of income, and assume that $V(\cdot)$ is strictly concave in income. Farmers will maximize expected utility both with respect to their own efforts and with respect to the efforts of other farmers. There is an interdependence among farmers in that the probability of paying the penalty is determined through the efforts of all farmers. To simplify notation, let WH^i denote farmer i's income when the penalty is not paid, and let WL^i denote income if the penalty is levied. We can then define

$$WH^{i} = py(a^{i}) - c(a^{i}) - \sum_{j} k^{i}(a^{j}) + \sum_{j} k^{j}(a^{i}), \quad \forall j \neq i,$$

and $WL^{i} = WH^{i} - \beta L^{i}$, where β is the per hectare penalty, and L^{i} is the amount of land on farm i. The expected utility-maximization problem of farmer i can now be formulated as:[3]

$$\text{(2)} \qquad \max_{a^{i},a^{j}} \left(1 - \int_{0}^{e^{*}} f(e;\mathbf{a})\,de\right) V(WH^{i}) + \int_{0}^{e^{*}} f(e;\mathbf{a})\,de\, V(WL^{i}) i, \quad \forall j \neq i.$$

Farmers maximize their expected utility and take the levels of penalty and ambient standard as given. Note that the probability of paying the penalty is affected by the level of the ambient standard. The first-order conditions for an optimal solution are written as:

$$\text{(3)} \qquad \begin{aligned} &\left[\left(1 - \int_{0}^{e^{*}} f(e;\mathbf{a})\,de\right) V'(WH^{i}) + \int_{0}^{e^{*}} f(e;\mathbf{a})\,de\, V'(WL^{i})\right] \\ &\quad \times \left(py_{a^{i}}(a^{i}) - c_{a^{i}}(a^{i}) + \sum_{j} k^{j}_{a^{i}}(a^{i})\right) \\ &\quad - \int_{0}^{e^{*}} f_{a^{i}}(e;\mathbf{a})\,de\left[V(WH^{i}) - V(WL^{i})\right] = 0, \end{aligned}$$

and

$$\text{(4)} \qquad \begin{aligned} &\left[\left(1 - \int_{0}^{e^{*}} f(e;\mathbf{a})\,de\right) V'(WH^{i}) + \int_{0}^{e^{*}} f(e;\mathbf{a})\,de\, V'(WL^{i})\right] \\ &\quad \times \left(-k^{i}_{a^{j}}(a^{j})\right) - \int_{0}^{e^{*}} f_{a^{j}}(e;\mathbf{a})\,de\left[V(WH^{i}) - V(WL^{i})\right] = 0. \end{aligned}$$

From the first-order conditions, we derive optimal allocations of abatement effort and production on each farm (see also the appendix). There is a possibility that farmers' profits will be negative in this case, depending on the level of penalty and the probability of paying the penalty.

Now, how large is the payment $k^{i}(a^{j})$, and why do we need this payment? Let us begin with the latter question. Assume that farmers have different attitudes toward risk. A risk-averse farmer will then undertake more efforts to reduce the probability of paying the penalty than will a risk-neutral farmer. If farmers also have different resource endowments, their production possibilities, and thus costs, will vary. The difference in factor use among farmers opens the possibility of trade. By trading abatement efforts, cost-effective pollution abatement can be ensured since rational farmers who maximize utility will attempt to minimize their costs of abatement effort. Consequently, marginal costs of effort are equalized among farms under the proposed incentive scheme. (For proof, see appendix.)

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[3] Note that under full information, our suggested incentive scheme would simplify to a system of Pigouvian effluent charges where trade among farmers is not necessary for an efficient outcome. The penalty in that case is determined as a function of farmers' emissions and the ambient standard.

Without side payments, farmers act independently and will solve only equation (3). As side payments are introduced, farmers can affect one another's abatement by paying the other farmers (at least) their marginal costs of effort as given by the other farmers' first-order conditions. Thus, the effect of the side payment $k^i(a^j)$ is that we convert farmers' private profit-maximization problem into that of joint profit maximization for all farmers. The bribe is the key to why nonindividual contracts can be used.

In order to avoid free riding, we require each farmer's profits to be maximized under the incentive scheme. Consequently, we need the expected (dis)utility of the penalty to be sufficiently high to provide each farmer with private incentives to undertake abatement efforts. If we denote the expected marginal abatement cost by v, then the expected marginal utility of abatement must be at least as large as the marginal costs in optimum; that is, $q \geq v > 0$, where q is the expected marginal utility of abatement. By changing the penalty, the regulatory agency can affect farmers' utility of abatement efforts, and thus their optimal abatement. Now, if marginal costs are equalized among farms, such that $v^1 = v^2 = \ldots = v^n$, then one standard contract, where the penalty is set such that $q \geq v^i > 0$ for all i, is obviously sufficient to avoid free riding in the abatement process.[4]

With an incentive scheme defined according to the above, we have reduced the information requirement on the regulating authority. We assume that farmers hold information, not only about their own profit function, but also about the abatement efforts of other farmers. However, each farmer's own information does not have to be substantial. A farmer will offer to buy abatement efforts from other farmers as long as the expected cost for that service is less than the costs of undertaking abatement on his/her own farm. Other farmers will accept this offer if it increases their profit. Therefore, by using a uniform contract and allowing for side payments, we can reduce the information requirement of the authority.

Note that in solving the pollution problem, we are not dependent on farmers' participation in the program. An incentive scheme according to our suggestion would be compulsory for all farms within a watershed. It is therefore not necessary to have a participation constraint in the maximization problem above. In this setting, there is no optimal number of participants in the incentive scheme since the number is given by the natural borders of a watershed. If the threat of a penalty creates negative profits for some farmers, they may find ways (new technologies) to make profits nonnegative, they may go out of business, or they may sell their farm to a more efficient farmer who can make the farm profitable even under the new circumstances.[5]

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[4] The expected marginal abatement cost is shown in the appendix as the left-hand side of (A1) and (A8). The marginal utility of abatement is defined as Q^i in the appendix. For a more rigorous discussion of this problem, see Holmström. (See also "Implications" section here for a discussion of feasible contract designs.)

[5] If an additional restriction were imposed requiring that all farmers should stay in business, i.e., a participation constraint, the cost of achieving the abatement would be likely to increase. It is also questionable whether the idea of nonindividual contracts holds under these circumstances. Note also we assume here that there are no economies of scale, and that farmers have no market power. Both of these assumptions limit the possibilities for strategic behavior. Although alternative assumptions may affect the performance of the incentive scheme, this analysis does not evaluate model performance when relaxing these assumptions.

An Illustration

To illustrate the characteristics of the incentive scheme proposed in this study, we take a simple example by comparing the incentive scheme to a tax regime and to a cost-effective reduction of pollution. Consider a drainage basin with two farms. Both farmers have identical Cobb-Douglas production functions of homogeneity less than unity. However, because of differences in soil quality, crops, location, and management practices, the two farms have different runoff of pollution from their land. Assume also that differences in runoff are reflected in the probability function for detection. This means that the effects on probability are different depending on the farm at which pollution abatement measures are taken. If the problem of nitrogen emissions is considered, we can define the following expressions for emissions and the probability function:

$$E(e) = 0.3N^A + 0.7N^B, \tag{5}$$

and

$$\int_0^{e^*} f(e; N^A, N^B)\, de = \frac{\bar{e} - e^*}{\bar{e}} \left(0.3 \frac{N^A}{\overline{N}^A} + 0.7 \frac{N^B}{\overline{N}^B} \right), \tag{6}$$

where e is emissions of nitrogen; N^A and N^B are nitrogen use on farm A and farm B, respectively; and e^* is an ambient pollution standard. Variables with an overbar $(\bar{e}, \overline{N})$ denote initial values of the variables before the incentive scheme is introduced.

To continue our exercise, assume that farmers produce crops using two inputs: nitrogen and other inputs, denoted x. Assume further that farmers have different levels of risk aversion, such that farmer A is risk averse, while farmer B is risk neutral. Following previous notation, we can define farmer A's income as:

$$WH^A = \Phi(x^A)^{0.4}(N^A)^{0.2} - w^x x^A - w^N N^A + k^B N^A - k^A N^B,$$

and $WL^A = WH^A - \beta L^A$, where Φ is a positive constant. Factor prices are represented by w, and β is the penalty per hectare of arable land. The terms $k^A N^B$ and $k^B N^A$ are linear payments between farmers that can be used for buying and selling abatement effort. Farmer B's income is defined analogous to A's. We now can define the maximization problem for farmers A and B:

$$\max_{x^A, N^A, N^B} \left[1 - \int_0^{e^*} f(e; N^A, N^B)\, de \right] (WH^A)^{\alpha} + \int_0^{e^*} f(e; N^A, N^B)\, de\, (WL^A)^{\alpha}, \tag{7a}$$

$$\max_{x^B, N^A, N^B} \left[1 - \int_0^{e^*} f(e; N^A, N^B)\, de \right] WH^B + \int_0^{e^*} f(e; N^A, N^B)\, de\, WL^B, \tag{7b}$$

and

$$\max_{x^i, N^i} \Phi(x^i)^{0.4}(N^i)^{0.2} - w^x x^i - (w^N + t)N^i, \quad i = A, B, \tag{7c}$$

Table 1. Farmers' Private Profits and Allocation Under Four Different Policy Scenarios to Reduce Nitrogen Emissions by 50%

Policy Scenarios	N^A (kg)	N^B (kg)	x^A (kg)	x^B (kg)	Expec. Profit (SEK)	β (SEK)	Tax (%)
Cost-Effective	65.8	43.2	2,610	2,268	3,787	0	0
Incentive Scheme	65.8	43.2	2,610	2,268	3,263	1,048	0
Incentive Scheme (no trade)	33.8	59.1	2,560	2,307	2,785	1,970	0
Tax Scheme	50.0	50.0	2,381	2,381	3,174	0	58.7

Notes: These results were generated using the following parameter values: $w^x = 2/3$, $w^N = 10$, and $\Phi = 80$. N^A denotes nitrogen use by risk-averse farmer A; N^B denotes nitrogen use by risk-neutral farmer B; x^A and x^B denote other inputs used by farmer A and farmer B, respectively, to produce crops; and β is per hectare penalty paid by farmers when observed water quality is below the ambient standard. SEK is Swedish currency units.

where $\alpha \in [0, 1]$ measures the concavity of farmer A's utility function, and t is a tax on nitrogen use. Equations (7a) and (7b) are the maximization problems under the incentive scheme, and (7c) is the maximization problem under the tax scheme.[6] To illustrate the outcome of different policies, table 1 shows the allocation and farmers' profits under four scenarios:

- A cost-effective reduction of emissions. Here, (7c) is maximized setting $t = 0$, subject to (5), and to a pollution constraint that requires total emissions of nitrogen to be less than an ambient standard, e^*.
- Reduction of emissions under the suggested incentive scheme. Under this scenario, (7a) and (7b) are maximized, where β is set such that an ambient standard, e^*, is not violated.
- Reduction of emissions under the incentive scheme, but where no trade is allowed among farmers. In this case, (7a) and (7b) are maximized, while setting the side payment, k, to zero for all levels of nitrogen use. This scenario corresponds to a non-cooperative Nash equilibrium where farmers do not trade pollution abatement.
- Reduction of nitrogen emissions by taxing the use of inputs. Here, (7c) is maximized subject to (5), where t is set to a level such that the ambient standard is not violated.

In table 1, we observe that the suggested incentive scheme generates the same allocation of factors as the cost-effective reduction of nitrogen emissions, as was proposed earlier. The level of aggregate profits under the tax scheme may seem surprisingly high. The reason for this result is that the tax payment is considered certain, and thus farmers do not allocate resources according to their risk aversion [compare (7a)–(7c)]. Figure 1 shows the difference in farmers' private profits under the four policy scenarios.

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[6] Note that the tax scheme includes only a uniform tax on inputs. Differentiated input taxes, properly specified, could in this case also achieve the cost-effective reduction of nitrogen emissions. However, as has been argued by Shortle and Dunn (and others), it is rarely the case that the regulatory agency has sufficient information to formulate efficient differentiated taxes. We have assumed that the agency does not have sufficient information for detailed regulation of farmers' abatement efforts. Therefore, differentiated taxes are not included as an alternative in this illustration. We can also note that our suggested incentive scheme is equivalent to the system of uniform input taxes as a special case: If not only the profit functions of farmers are identical, but also the water quality impact, then a uniform input tax would be sufficient to achieve the cost-effective allocation of factors.

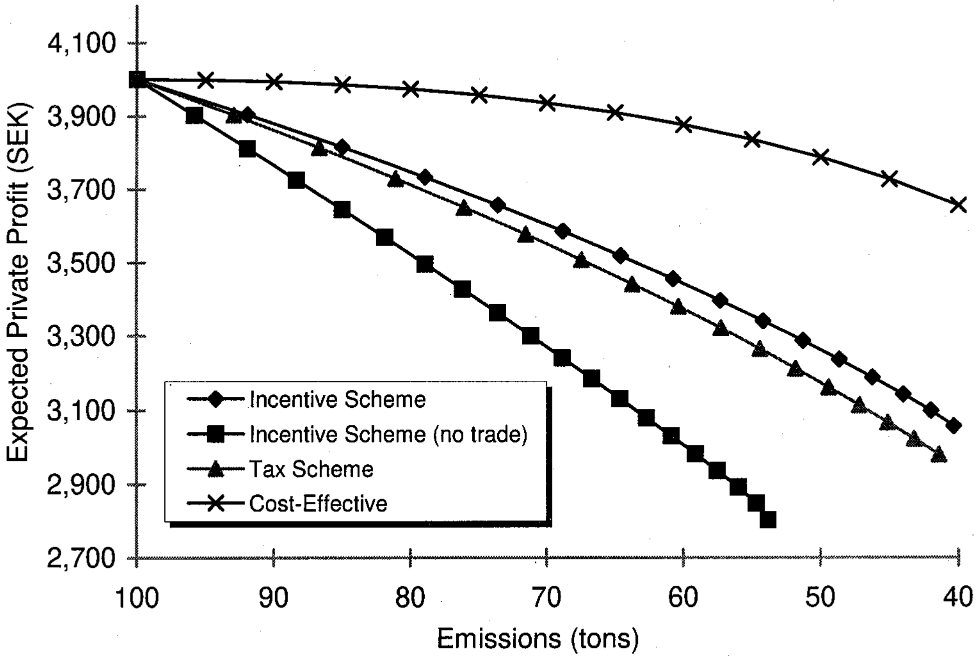

Figure 1. Private profits under four different policy scenarios

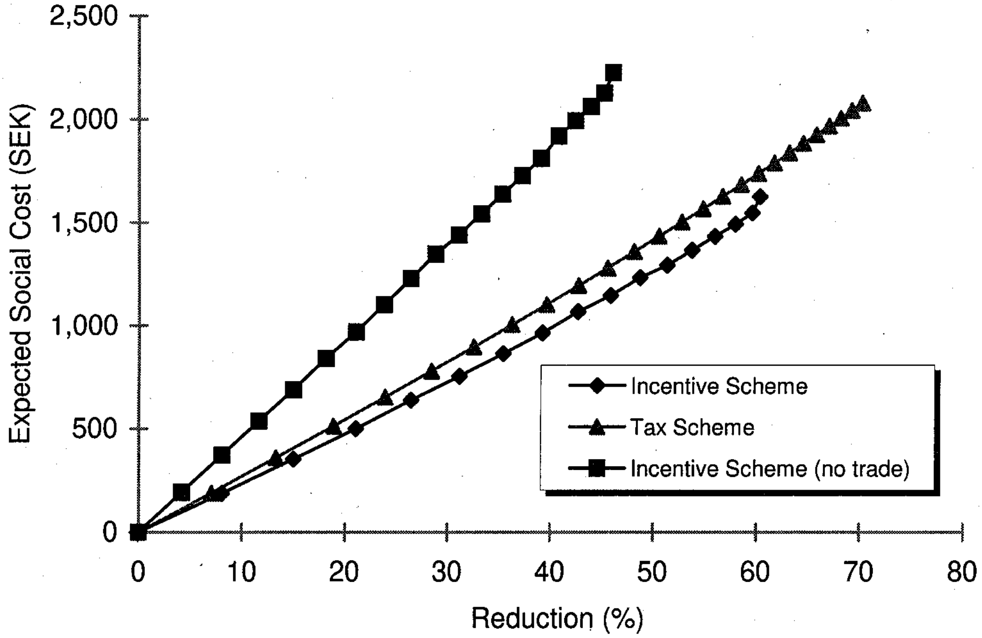

Figure 2. Social costs of three policies for reduction of nitrogen pollution

The expected penalty payment and the tax are solely transfers of wealth that reallocate resources from farmers to other individuals. The social cost of implementing a policy is then the reduction in farmers' profits due to reallocation of factor use. Figure 2 shows the social costs of three policies at different nitrogen abatement levels.

It is clear from figure 2 that the social cost of our incentive scheme is lower than the social cost of a tax policy. We also see that the costs for a noncooperative Nash equilibrium solution are considerably higher than costs under the incentive scheme. This result implies that a stable cooperative Nash equilibrium can be achieved under the incentive scheme.

It should be noted that costs and relative differences across policies are merely indicative. Exact differences are contingent on the shape of farmers' profit and utility functions, as well as on each farm's impact on water quality. Nevertheless, this example demonstrates the arguments made previously.

Implications

In the incentive scheme that we propose, there are a few points worth examining in more detail. We can formulate three questions: (*a*) Why would farmers engage in trade of pollution abatement? (*b*) If trade is desirable, how can contracts among farmers be enforced? and (*c*) What will be the equilibrium price of the "virtual permits," and how is this equilibrium reached?

Why Trade Abatement?

The motivation for trade in pollution abatement is simply that farmers' cost functions of abatement effort are different, and that farmers have different levels of risk aversion. If farmers can observe one another's efforts, they can buy and sell pollution among themselves and thus reduce total abatement costs compared with a situation where trade is not possible. If all farmers have the same risk aversion, the problem can be solved without allowing for trade simply by introducing a collective penalty that is constructed such that free riding is discouraged.

Solving the free-rider problem, however, may lead to an "overkill" effect if the difference in farmers' costs of effort is large. To solve the free-rider problem, a collective penalty must be set in such a way that the expected value of the penalty provides a private incentive to undertake abatement efforts for each farmer in the watershed. This requirement may lead to a penalty that forces farmers out of business and/or it may result in larger abatement efforts than the socially desirable level. In a dynamic context, this is a short-run problem—since as marginal costs are equalized among farmers, the level of penalty can be gradually decreased.

How to Achieve Enforceable Contracts?

The first and strong assumption that enables enforceability of contracts is that farmers can observe one another's efforts to reduce pollution. The realized pollution level is only observable ex post, and only on an aggregate level. Contracts among farmers thus have to be based on their abatement efforts rather than on actual reductions in pollution from a particular farm. We assume that there exists a common perception among farmers of how much pollution reduction can be expected from a certain abatement effort. There are (at least) three ways of achieving enforceable contracts among farmers, identified below.

- *Lawsuits.* If a farmer does not perform according to the contract, that farmer can be sued in court for not fulfilling the terms of the contract. This requires clear and commonly accepted rules of how and when a contract is fulfilled.
- *Pay on Deliverance.* A farmer does not pay for contracted abatement efforts until it is possible to verify that the agreed effort has been carried out.
- *A Subgame Perfect Nash Equilibrium.* We could easily formulate a strategy in a repeated game among farmers where cooperation achieves a subgame perfect Nash equilibrium (e.g., Gibbons).

The first two alternatives for achieving enforceable contracts require rather detailed information, and therefore may not be very credible for practical policy. The subgame perfect Nash equilibrium represents a third and more general approach that requires less of formal contracts by looking at the problem in a dynamic context. This third alternative means that we can find a strategy in which it is profitable for farmers to cooperate in the long run.

To illustrate, we can look at a two-stage game with two farmers: farmer *A* and farmer *B*. Assume that farmer *A* moves first and has higher abatement costs than farmer *B*. Farmer *A* is therefore interested in buying abatement effort from farmer *B* if the price of buying pollution is less than farmer *A*'s own marginal costs of pollution abatement, and if farmer *A* knows that farmer *B* will actually perform the abatement effort that farmer *A* pays for (and farmer *B* knows that farmer *A* has this information).

Assume now that farmer *B* receives a payment in period 1 in order to perform abatement in period 2. If there are no penalties *and* period 2 is the last stage of the game, then farmer *B*'s profits would be higher by not complying than by performing abatement efforts according to the contract with farmer *A*. This is because there is no third period in which farmer *B* can be penalized for not performing the abatement effort.

Let us now instead look at an infinite game between the farmers, and assume that farmer *A* adopts the following strategy: If farmer *B* in *any* period chooses not to perform the abatement effort that has been contracted with farmer *A*, then farmer *A* will never engage in trade again. Farmer *B*'s best response in this case is to cooperate. Under this simple "trigger" strategy, both farmers' profits will be lower over time if they do not cooperate since, by assumption, their total profit is higher under cooperation than under noncooperation.

Although the arguments presented above are set in a dynamic context, while our model is a static one, they nevertheless show that a cooperative and stable solution can be achieved quite easily. Moreover, the intuition behind our problem is not helped by presenting a dynamic model. The issue here is not to show ways of practical policy, but simply to point out the possibilities inherent in an incentive scheme such as the one proposed in this study. Therefore a static model, although simple, suffices to demonstrate the main points we wish to make.

Enforceability also depends on the legal opportunities that the authority has for enforcing collective penalties. Meran and Schwalbe offer an interesting note on the possibilities for legal enforcement of their suggested collective penalty system: ". . . our term 'collective penalty' may be somewhat misleading. To our knowledge there exists no criminal law which allows punishment without evidence of guilt. But precisely this proof of guilt is ruled out in our model by the assumed informational structure" (p. 628). This problem is equally valid in the incentive scheme we suggest here. If collective penalties cannot be enforced due to the legal structure, the problem could be solved by reversing the penalty to a contingent subsidy that will serve the same purpose, although it yields other distributional effects than a penalty system.

The Equilibrium Price of Permits

Finally, consider the equilibrium price of permits. The actual price of buying abatement effort from other farmers depends on each farmer's marginal costs of abatement effort as well as on each farmer's negotiation skills: a buying farmer will buy at a price that is not higher than the marginal costs of abatement effort; a selling farmer will sell only if compensation is at least as high as the marginal costs of effort. In practice, there may be a gap in marginal costs among farmers, and some of the farmers may make profits. The distribution of profits depends on the negotiating skills that each farmer possesses.

Conclusions

In this analysis, we suggest the use of nonindividual contracts, between farmers and a regulatory agency, to control agricultural NPS pollution. We show that for a domestic pollution problem, abatement efficiency can be attained even though contracts are not individual. The proposed incentive scheme generates a cost-effective reduction of emissions because it allows farmers to trade pollution abatement efforts among one another. This requires that farmers be able to observe the abatement efforts of at least a few other farmers. While it can be argued that this type of contracting requires farmers to hold extensive information, we think it is more plausible that farmers hold some information about one another than to assume that the regulating authority has sufficient information to formulate individual contracts with farmers. We also note that individual contracting may be prohibitively expensive for a regulating authority, and therefore the incentive scheme proposed in this study has policy implications that may be substantial.

The suggested incentive scheme rests on collective penalties for farmers. All farmers have to pay the penalty if water quality is less than an ambient standard. As pointed out by Meran and Schwalbe, a system of collective penalties has weak legal support, since criminal law generally requires that liability is established on an individual level. We note that if the suggested incentive scheme with collective penalties lacks legal support, it can be reversed to a scheme based on conditional subsidies, where a subsidy is paid only if the ambient water quality standard is not violated. Of course, these subsidies would then also reverse the distributional effects of the incentive that we have suggested here.

The incentive system also does not require that farmers "stay in business." If implementation of the incentive scheme means that some farmers go out of business, this does not affect the mechanism of the suggested system. Farmers may go out of business for various reasons. Some may be "too" risk averse relative to the other farmers, such that they undertake a large share of the abatement. Other reasons may be that some farmers are relatively less efficient in their production, or perhaps financially weaker, than other farmers in the region. Traditional agricultural policy tends to protect farmers from going out of business. If this is an issue, the suggested incentive scheme can easily be converted to a system of conditional subsidies, yielding the same financial incentives to farmers.

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Appendix

We intend to show that the incentive scheme yields a cost-effective allocation of abatement efforts among farmers in a watershed. Dividing text equation (3) by equation (4) and rearranging the result, we get:

$$\text{(A1)} \qquad \frac{py_{a^i}(a^i) - c_{a^i}(a^i) + \sum_j k^j_{a^i}(a^i)}{\int_0^{e^*} f_{a^i}(e;\mathbf{a})\,de} = \frac{-k^i_{a^j}(a^j)}{\int_0^{e^*} f_{a^j}(e;\mathbf{a})\,de}, \quad \forall i \neq j.$$

The interpretation of (A1) is that, in optimum, a farmer's expected marginal cost of abatement is equal between abatement at the individual farm and buying abatement from other farmers. To complete the proof, we need to show that given the incentive scheme, all farmers' marginal costs of abatement are equal in optimum. In order to simplify notation, let

$$Q^i = \frac{\left[V^i(WH^i) - V^i(WL^i)\right]}{\left(1 - \int_0^{e^*} f(e;\mathbf{a})\,de\right) V^{i\prime}(WH^i) + \int_0^{e^*} f(e;\mathbf{a})\,de\, V^{i\prime}(WL^i)}.$$

Text equations (3) and (4) are then rewritten as:

$$\text{(A2)} \qquad py_{a^i}(a^i) - c_{a^i}(a^i) + \sum_j k^j_{a^i}(a^i) = Q^i \int_0^{e^*} f_{a^i}(e;\mathbf{a})\,de, \quad \forall i \neq j,$$

and

$$\text{(A3)} \qquad -k^i_{a^j}(a^j) = Q^i \int_0^{e^*} f_{a^j}(e;\mathbf{a})\,de, \quad \forall i \neq j.$$

Equations (A2) and (A3) hold for all farmers in the watershed. Analogous to equations (A2) and (A3), the first-order conditions of farmer *j* are specified as:

$$\text{(A4)} \qquad py_{a^i}(a^j) - c_{a^j}(a^j) + \sum_i k^i_{a^j}(a^j) = Q^j \int_0^{e^*} f_{a^j}(e;\mathbf{a})\,de, \quad \forall j \neq i,$$

and

$$\text{(A5)} \qquad -k^j_{a^i}(a^i) = Q^j \int_0^{e^*} f_{a^i}(e;\mathbf{a})\,de, \quad \forall j \neq i.$$

The bribe, $k^i(a^j)$, that farmer *i* makes to farmer *j* has to be strictly equal to the payment that farmer *j* receives (given zero transactions costs). Hence, all marginal bribes must be equated among farms. Consequently, farmer *i*'s marginal payment to *j*, that is, $k^i_{a^j}(a^j)$ in (A3), is equal to the bribe that farmer *j* receives from *i* in (A4). Thus, (A3) is solved for $k^i_{a^j}(a^j)$ and the result is substituted into (A4) for all $i \neq j$, which then yields:

$$\text{(A6)} \qquad py_{a^j}(a^j) - c_{a^j}(a^j) = \int_0^{e^*} f_{a^j}(e;\mathbf{a})\,de \left(Q^j + \sum_i Q^i\right), \quad \forall j \neq i,$$

where $i = (1, 2, \ldots, j-1, j+1, \ldots, n)$. Following the arguments above, we also substitute (A5) into (A2) for all $j \neq i$:

$$\text{(A7)}\qquad py_{a^i}(a^i) - c_{a^i}(a^i) = \int_0^{e^*} f_{a^i}(e;\mathbf{a})\,de\left(Q^i + \sum_j Q^j\right), \quad \forall\, i \neq j,$$

where $j = (1, 2, \ldots, i-1,\ i+1, \ldots, n)$. Note that the terms within large parentheses in (A6) and (A7) both express the sum over all the n farms in the watershed. Dividing (A6) by (A7) and rearranging the terms then yields the following result:

$$\text{(A8)}\qquad \frac{py_{a^j}(a^j) - c_{a^j}(a^j)}{\int_0^{e^*} f_{a^j}(e;\mathbf{a})\,de} = \frac{py_{a^i}(a^i) - c_{a^i}(a^i)}{\int_0^{e^*} f_{a^i}(e;\mathbf{a})\,de}.$$

Equation (A8) shows that under the incentive scheme, the expected marginal costs of abatement are equal among farms. By (A1) and (A8), it is clear that a cost-effective reduction of nonpoint emissions is achieved under the incentive scheme.