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Ecological Economics 47 (2003) 71–78

ECOLOGICAL ECONOMICS

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ANALYSIS

# Team approaches in reducing nonpoint source pollution

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Received 4 December 2001; received in revised form 16 October 2002; accepted 30 October 2002

**Abstract**

It is technically difficult and costly to monitor nonpoint source pollution. Consequently, most economic instruments directed towards reducing this type of pollution have focused on circumventing the monitoring problem by focusing on readily observable factors. Such instruments include taxes or tradable permits on inputs or other incentives to induce changes in farming practices.

One difficulty with such approaches is that the incentives may not be consistent with the primary objectives of the policies—to reduce nutrient runoffs. This paper seeks to identify under what conditions it would be beneficial to apply more direct incentives for reduced nutrient runoffs. Monitoring and enforcement are core issues in this connection. It is still difficult to monitor individual farm field runoffs. Hence, the incentive problems associated with multiple agents emitting to the same recipient need to be resolved.


*Keywords:* Nonpoint source pollution; Game theory; Environmental economics; Incentives; Enforcement and monitoring

## 1. Introduction

The primary objective of environmental policies is to enhance social welfare. It is textbook environmental economics that optimal environmental quality is where the marginal costs of providing environmental quality equals the marginal benefits. Environmental economists stress cost efficiency as this implies least marginal costs of providing environmental quality.

A special feature of nonpoint source (NPS) pollution is that it is technically difficult and costly to measure individual farm field runoffs. Braden and Segerson (1993) denote this the *information problem* in NPS pollution. Conventional NPS policies have therefore focused on changing easily observable characteristics—like fertilization, manure spreading and tillage practices—that are assumed to form strong linkages to farm field runoffs. Several examples of such indirect policies exist like fertilizer taxes and manure spreading restrictions. For a survey, see Russell and Shogren (1993) or Romstad et al. (1997).

This paper asks if environmental quality is lost due to such a shift in the policy focus towards changing agricultural practices. For example, Vagstad (1990) was intrigued by the economists' strong focus on fertilizer taxes because the variability in the amount of N fertilizers applied only accounted for 30% of the measured Nitrogen runoffs. In addition to the intuitive *direct incentives* argument that prevails in the standard

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0921-8009/$ - see front matter 
doi:10.1016/j.ecolecon.2002.10.002

regulation literature, it may therefore be natural scientific reasons for having direct incentives providing on environmental quality.

The relative social costs of the various instruments and the possibilities of controlling the remaining 70% of nitrogen runoffs from Vagstad's (1990) study are some of the difficult issues related to controlling NPS pollution. Suppose that most of these runoffs are linked to the weather. It is virtually impossible to control the weather in rain fed agriculture. Consequently, farm management options in such agricultural systems tend to focus on spreading agronomic risk and robustness to meet stochastic variations in climate.

This paper takes a closer look at the potential benefits and costs of using more direct policies to control NPS pollution from agriculture. The following section briefly present past suggestions for ambient policies in the NPS setting. Next, I take a closer look at holding farmers jointly responsible for the environmental quality. A clear benefit of this team's approach is reduced monitoring costs compared schemes where individual farmers are monitored. Finally, I discuss extensions of the basic model developed.

## 2. Ambient NPS policies

Several papers have looked at ambient NPS policies before. Here, I list the most important contributions on ambient policies in NPS settings and some of the objections and problems regarding the suggested approaches.

Segerson (1988) is the seminal paper on ambient taxes in the NPS setting. She proposes and ambient tax for the single farmer case where each polluter pays a charge that varies with proportionally with the ambient concentration. The main problem is that when damage functions are convex, optimal tax rates vary among polluters. This makes the Segerson approach informationally demanding, and may also imply excessive fines at the aggregate. In addition, one may ask if her approach meets the *freedom of arbitrage opportunities* that is required for the scheme to be least cost.

Cabe and Herriges (1992) suggest an ambient tax framework where ambient concentrations are measured on selected sites. Using a Bayesian framework, they can reduce the number of monitoring points. This reduces overall monitoring costs. Their tax scheme is, however, basically the same as the Segerson tax. Consequently, the principal informational difficulties inherent in the Segerson approach also apply to Cabe and Herriges' paper.

Hansen (1998) and Horan et al. (1998) propose a damage based tax along the lines of Segerson (1988) that is less information-demanding. Both of these papers supplement the ambient tax with a lump-sum subsidy that corrects for the excessive total tax revenue collection resulting from the Segerson mechanism. Despite sorting out Segerson's problem of excessive tax collections, these papers do not address the informational difficulties.

Ambient taxes for NPS pollution have, so far, according to my knowledge, not been implemented in practice. There are several reasons for this. From a political economy perspective, the prime difficulty is that the ambient tax revenues raised in many cases would be far greater than farm revenues. Hence, implementation will be met with great resistance, and many of the schemes proposed in the past do not appear practically feasible.

## 3. A note on incentives

There is considerable variation in nutrient runoffs among farmers, even for farmers with quite similar

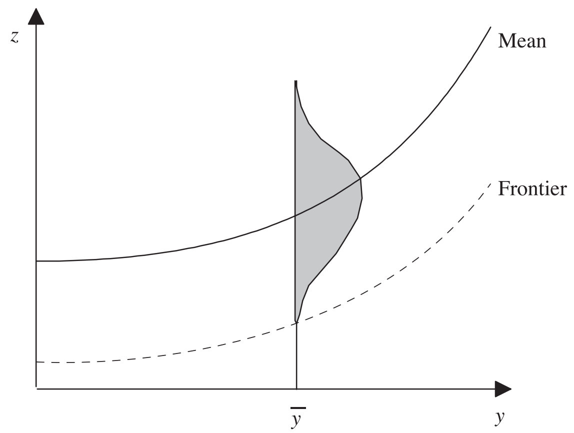


Fig. 1. Yield ($y$)–pollution ($z$) tradeoff (solid line: mean; dotted line: frontier).

operating conditions and production types. Fig. 1 provides an illustration of this.

Suppose that, for obtaining a given per hectare output level, $\bar{y}$, farmers' nutrient runoffs, $z$, vary as indicated by the distribution plot (the shaded area) in the figure. By varying the output level, two effects emerge. First, by reducing the output level, $y$, nutrient runoffs can be reduced. Reduced use of inputs like fertilizers, have this indirect impact on nutrient runoffs. Second, by moving farmers with high emission levels for a given output level closer to the frontier, emissions are also reduced. The primary difficulty with indirect regulations, like fertilizer taxes and requiring changes in agronomic practices, is that such measures are not likely to produce incentives for the second effect to take place. Ambient or emissions regulations, on the other hand, provide these incentives, thereby making such changes more likely.

## 4. Teams approaches for reducing ambient NPS pollution

An important feature of NPS pollution is that the problem usually has a strong local component through the pollution of local waterways. This may bind agents together. More important, however, is the *informational structure*. According to Seabright (1993) one of the most typical features of many local commons is that agents may possess information on the actions of the other agents. In the NPS setting this could include knowledge on farming practices, efforts to reduce NPS pollution, and accidents—like manure spillage when filling the manure spreader—that could increase nutrient loads. From a regulatory point of view, this could create some problems. It also opens for some interesting policy options. More specifically, can the regulator (the principal) exploit the relaxation of the *no mutual information assumption* when designing policies?

In this paper, I retain the conventional NPS assumption that the principal can monitor ambient quality in local recipient, but is unable to distinguish between individual agents' emissions. Assume that each agent has superior information relative to the principal regarding own emissions and the distribution of possible emissions of the other agents, but inferior information regarding actual performance of the team (recall that it is the principal who monitors). I claim that this additional and realistic assumption makes it possible to avoid some of the difficulties associated with input oriented policies or Segerson's approach. Now, consider a situation where the principal offers the agents to choose from the following alternatives:

(1) Some standard regulatory regime that reduces agent profits compared to a no-regulation setting.
(2) A contract that is favorable to the agents as a team relative to option (1) provided that the team of agents meet the targeted emission level (hereafter referred to as the target), but unfavorable to the team if the target is not met.

With only one principal, the problem of the non-existence of separating equilibria does not apply (see Rotchild and Stiglitz, 1976). Consequently, agents will only choose option (2) if all the agents believe that the team will be able to meet the ambient quality target. To increase the cohesiveness of the team, the principal adds the following incentives:

- If the team overachieves the target, all agents in the team receive a payment.
- An agent is given the possibility of self-reporting if the agent believes that the target will not to be met and this is the fault of this agent. Any agent that self-reports pays a fine that is smaller than the fine levied if the target is not met irrespective of whether the target is met or not. This fine needs to be larger than the costs associated with option (1), the "exit-the-team" alternative.

## 5. Model formulation

Consistent with the standard notion in environmental regulation it is costly for agents to reduce their emissions (or costs are reduced if emissions are increased), i.e.,

$$\frac{\partial C_n(y_n, z_n)}{\partial z_n} < 0 \qquad (1)$$

where $C_n(y_n,z_n)$ is twice differentiable in output, $y_n$, and emissions, $z_n$.

Let $\bar{Z}$ be the principal's target for aggregate emissions. Also assume that the principal is able to monitor aggregate emissions, $Z$, at a reasonable cost. The penalty given to a team for exceeding the ambient standard would then be a convex function in $Z$ of the form

$$B(Z - \bar{Z}) \tag{2}$$

A single agent's perception of this penalty function in a team setting then becomes

$$B_n(\hat{z}_n + \hat{Z}_{-n} - \bar{Z}) \tag{3}$$

where $\hat{z}_n$ denotes the $n$th agent's expected personal emissions, and $\hat{Z}_{-n}$ denotes this agent's expectations on the aggregate emissions caused by the other agents. Due to the local commons assumptions (cf. Seabright, 1993), these expectations are reasonably accurate under normal circumstances.

Accidents with regard to emissions occur. This may jeopardize such a scheme as individual agents' estimates of the other agents' emissions, $\hat{Z}_{-n}$, could be inaccurate. Intuitively, who would like to take responsibility of the accidents of other agents in the team? Allowing for self-reporting of accidents increases the likelihood that a team would hold together. To see this, consider the penalty function (3) perceived by agent $n$ when self-reporting of accidents is possible:

$$B_n^s[\hat{z}_n + (\hat{Z}_{-n} - \Sigma_{i\in\{N\backslash n\}} z_i^s) - \bar{Z}] \tag{4}$$

where $z_i^s$ is the amount of extra emissions reported by agent $i$ belonging to the set of the other agents in the team, $\{N\backslash n\}$. Both the penalty function and the costs of self-reporting an accident, $g(z_n^s)$, are increasing at an increasing rate, i.e.,

$$\frac{\partial B_n}{\partial z_n} > 0 \text{ and } \frac{\partial^2 B_n}{\partial z_n^2} > 0 \tag{5}$$

$$\frac{\partial g}{\partial z_n} > 0 \text{ and } \frac{\partial^2 g}{\partial z_n^2} > 0 \tag{6}$$

Agent $n$ **may** self-report if the cost of self-reporting is less than the agent's costs of the team being caught in noncompliance, i.e., $g(z_n^s) < B_n^s[\hat{z}_n + (\hat{Z}_{-n} + \Sigma_{i\in\{N\backslash n\}} z_i^s) - \bar{Z}]$. One problem with allowing for self-reporting is that if an agent believes that the team is not in compliance, this agent may choose to self-report emissions that did not take place to lower the fines he pays. To reduce the likelihood that this will happen repeatedly, it is necessary for dissatisfied team members to have the possibility of exiting the team. This implies that an agent still could choose to wrongfully overstate personal emissions (i.e., take the blame for someone else) to avoid paying the higher fine, $B_n^s[\ldots]$ in a single period. However, the agent would not do this repeatedly if exiting the team is less costly than taking the blame for someone else.

Suppose a menu is constructed so that the cost of being member of a complaint team is less than the costs of facing an "exit option" (which could involve being subject to some other costly regulations). These costs are then less than the costs of self-reporting, which again are less than the costs of being member of a non-compliant team. In mathematical terms for agent $n$:

$$\begin{aligned} C_n(y_n, \bar{z}_n) < C_n(y_n, z_n) + h(r) < C_n(y_n, \bar{z}_n) + s(z_n^s) \\ < C_n(y_n, z_n) + B[\ldots z_n \ldots] \end{aligned} \tag{7}$$

For a given level of output, profits would the have the reverse order, i.e.,

$$\begin{aligned} \pi_n(y_n, \bar{z}_n) > \pi_n(y_n, z_n) + h(r) > \pi_n(y_n, \bar{z}_n) + s(z_n^s) \\ > \pi_n(y_n, z_n) + B[\ldots z_n \ldots] \end{aligned} \tag{8}$$

Using a more compact notation and adding a term for the profits of cheating without being caught, Eq. (8) can be written as:

$$\pi_n(z_u) > \pi_n(\bar{z}) > \pi_n(a) > \pi_n(s_n) > \pi_n(z_c) \tag{9}$$

where $\pi_n(z_u)$ denotes profits when not in compliance and not being caught, $\pi_n(\bar{z})$ denotes the profits of agent $n$ when the team reaches the target value, $\pi_n(a)$ denotes agent $n$'s profits obtainable at the standard (non-emission based) alternate regulation, $\pi_n(s_n)$ denotes the profits to agent n from self-reporting, and $\pi_n(z_c)$ denotes the profits when the team is not in compliance and caught. Graphically, the profits of the various actions can be illustrated as follows for agent $n$, with possible equilibria marked by solid dots (and marked by the terms inside the parenthesis in Eq. (10)).

## 6. Model insights

The most desirable position for any agent is to have other agents self-report. From Eq. (8) and Fig. 2 this yields the highest potential profits, $\pi_n(z_u)$. This allocation is, however, not achievable for multiple time periods. The reason for this is that in a repeated game situation compliant agents would choose the "exit option" if some agents decided to play a "free riding" strategy on other agents' self-reporting.

For the team to hold together, i.e., the "exit option" not to be chosen, the expected net profits from belonging to the team must exceed the expected net benefits from leaving the team for each agent. This condition has two parts, as follows.

(1) The expected profits of self-reporting in period zero plus the expected discounted profits of a compliant team must exceed the expected profits of cheating in period zero and the subsequent expected discounted profits of the team breaking apart for all agents. Symbolically:

$$\hat{\pi}_n(s_n) + \sum_{t=1}^{T} \beta^t \hat{\pi}_n(\bar{z}) > \hat{\pi}_n(z_u) + \sum_{t=1}^{T} \beta^t \hat{\pi}_n(a) \qquad (10)$$

where $\beta=(1+\delta)^{-1}$ denotes the discount factor. Simplifying Eq. (10) to the two-period game gives:

$$\hat{\pi}_n(s_n) + \beta\hat{\pi}_n(\bar{z}) > \hat{\pi}_n(z_u) + \beta^t \hat{\pi}_n(a) \qquad (11)$$

which yields the sub-game perfectness condition for holding the team together. After some transformation, this gives the Folk theorem condition for supporting compliance:

$$\beta > \frac{\hat{\pi}_n(z_u) - \hat{\pi}_n(s_n)}{\hat{\pi}_n(\bar{z}) - \hat{\pi}_n(a)} \qquad (12)$$

This condition must hold for all agents who are members of the team.

(2) The expected profits from occasionally having to self-report accidents, ending up with a mix of the

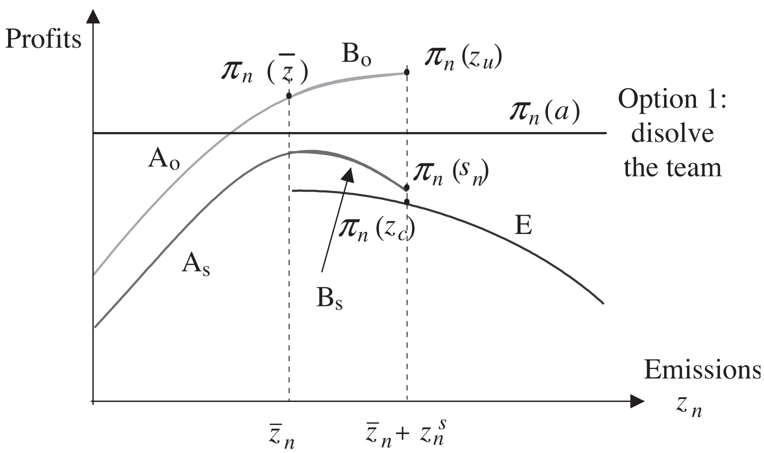


Fig. 2. Profits for agent $n$ under various actions and possible equilibria. $A_o$: team is in compliance, $A_s$: the team is in compliance and self-reports (a fake violation), $B_o$: the team is not in compliance and but someone else has self-reported, $B_s$: the team is not in compliance and some team members including this one has reported a violation, E: the team is not in compliance and has been caught. $\pi_n(z_u)$: profits when the agent "free rides" on other agents' self-reporting, $\pi_n(\bar{z})$: profits when the team is in compliance, $\pi_n(a)$: profits under the alternate (exit option) regulation, $\pi_n(s_n)$: profits when self-reporting, and $\pi_n(z_c)$: profits when the team is not in compliance and caught. $\pi_n(z_c)$ could be located anywhere on the line E.

expected payoffs $\hat{\pi}(s)$ and $\hat{\pi}(\bar{z})$ must exceed the expected payoffs of staying outside the team, $\hat{\pi}(a)$. Let $\rho$ denote the share of situations where agent $n$ needs to self-report, and assume that $\rho$ is identically independently distributed.[1] Symbolically:

$$\rho\hat{\pi}_n(s_n) + (1-\rho)\hat{\pi}_n(\bar{z}) > \hat{\pi}_n(a) \tag{13}$$

which, after a simple transformation, becomes

$$\rho < \frac{\hat{\pi}_n(\bar{z}) - \hat{\pi}_n(a)}{\hat{\pi}_n(\bar{z}) - \hat{\pi}_n(s_n)} \tag{14}$$

If agent $n$'s knowledge about the emissions of the other agents, $Z_{-n}$, is imperfect outcomes (12) and (14) are not guaranteed.[2] Still, the "exit option" plays an important role as it provides a "safety net". Without the possibility to dissolve the team, some agents could be tempted to seek the "free riding" profits, $\hat{\pi}_n(z_u)$, which would leave some members of the team at a considerable disadvantage. It is instrumental for the "exit option" to work that the following part of the ranking, $\pi_n(\bar{z})>\pi_n(a)>\pi_n(s_n)$ from Eq. (9) holds. The primary purpose of the "exit option" is not to reduce emissions per se. Its important role is rather to introduce an equilibrium alternative that makes it undesirable to self-report to cover for other agents' failure to comply. In brief, the existence of the "exit option" helps support team compliance.

The second effect of the "exit option" is that it creates a separating equilibrium with (i) compliant teams with aggregate emissions meeting the watershed target, $\bar{Z}$, and (ii) farmers who choose not to join a team, and who are subject to the standard regulatory regime. Other factors like the social relationships among agents, the existence of "difficult individuals", etc., will also influence which of the two equilibria that will emerge.

[1] Relaxing this assumption about the distribution of $\rho$ makes the derivations more complex, but the same principal insights emerge.

[2] This follows from the literature on *approximate implementation*. For an overview, see Abreu and Matsushima (1990) or Abreu and Sen (1991).

## 7. Extensions of the model

One difficulty with the proposed model is that it does not account for the fact that there will be a larger variability in the teams approach compared to the standard regulatory setting. This implies that risk averse decision makers are more likely to choose a standard regulation with more predictable payoffs over time.

One may ask if the aggregate emission target for the team's approach should be relaxed somewhat to allow for some of this stochastic variability. As long as the cost-environmental performance of the proposed model is better than what follows from the standard approach, this is probably all right. This will create incentives for team participants to control the stochastic part of their emissions, thereby reducing the need for having additional regulations on the rates of discharges.

The primary argument against "forgiveness" regarding variability in emissions is that if variability is important in terms of environmental damages, incentives to improved process control would be desirable. Keeping the emission target the same irrespective of the "type of year" produces incentives for farmers to gain better control, i.e., to shrink the width of the density function of emissions. Farmers with good process control are then able to emit more.

This would increase their profits at the same time as variability in emissions is reduced. In this connection, note that when the marginal environmental damages are convex, reduced variability in emissions may include sizable gains in environmental quality (Romstad and Vatn, 1995). The other counter argument against "forgiveness" pertaining to variability in emissions is based on a natural science perspective: The number of extreme years is rather small. Hence, calibration may be difficult to undertake for the extreme years.

In situations where discharge rates are important from an environmental perspective (and the additional costs can be justified), a similar model for discharge rates can be introduced.

The stochasticity in emissions and the relation to process control accentuates another issue: the setting of emission targets under uncertainty. To avoid excessive emissions, the target must be set a little higher to allow for minor variations in emissions without the team being penalized.

The stochastic nature of emissions also reduces the quality of the reciprocal information among agents. This could reduce the cohesiveness of the team. However, coupled with a variability adjusted emission target, the effect on the team could also be the opposite—the team is "forced" to jointly focus on the emission generating processes. As such, this paper also makes other issues resurface. This includes the effects of risk aversion among farmers, the setting of standards, and the choice of monitoring rules in stochastic environments.

## 8. Concluding remarks

From an intuitive perspective, this paper argues that one should keep an open mind towards ambient and emission policies to control NPS pollution. These policies are better suited than conventional NPS policies to deal with variation between locations and over time. With technological progress, the cost of monitoring is likely to decline. One implication of this is that such policies become practically more feasible. The team approach suggests how one, through exploiting the reciprocal information among agents, can considerably lower monitoring costs.

The main benefits of ambient and emission based policies are as follows:

(1) They make it easier to achieve precision in NPS regulations. This is of particular importance in environmentally sensitive watersheds.
(2) They provide incentives that are targeted at the purpose of the regulations—to improve ambient quality. This way, they open up for new solutions to reduce the costs of NPS controls.
(3) Teams approaches are particularly important with respect to efficiency. To lower overall compliance costs one may envision trading or compensation schemes within teams to make expected marginal abatement costs equal among agents.

The main disadvantage of such policies is that they entail increased monitoring costs, and that they entail excessive tax collection. Collecting taxes that, in many cases, exceed farm revenues implies that the participation constraint is not met. Which policy to choose is then a question of weighting costs versus environmental performance. As environmental damages from NPS pollution are likely to vary across locations, one may expect to see conventional and ambient or emission policies coexist.

To conclude, there exists many intuitively valid reasons for a shift away from the conventional NPS policies that focus on agricultural practices towards more direct incentive for reducing emissions or improving ambient quality. The suggested team's approach is one way of reducing the monitoring costs of these more direct policies, and making incentives more direct. An important feature of the suggested approach is that it opens for the shifting of abatement burdens among agents, thereby increasing the likelihood of the "absence of arbitrage" condition being met.

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