NONPOINT SOURCE POLLUTION REGULATION WHEN POLLUTERS MIGHT COOPERATE[1]

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Abstract

We analyse the regulation of nonpoint source pollution. In particular, we study the use of peer monitoring to sustain cooperative abatement by a group of polluters. Delegation to a group of polluters has sometimes been proposed under a policy of so called voluntary abatement accords. By solving the problem of a regulator who a priori does not know whether agents are cooperative or not, we explain some features of voluntary abatement accords. The analysis shows that the policy measure proposed in the literature for nonpoint source regulation - an ambient tax - may not be efficient.

Keywords: peer monitoring, cooperation, voluntary abatement accords, environmental regulation, ambient tax, incomplete information

JEL: D82, H41, Q25, Q28

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1. Introduction

Nonpoint source pollution is nowadays recognized as the main source of environmental damage. A well-known example is water pollution from agricultural

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[1] This paper presents preliminary results of ongoing research and was written while Katti Millock was visiting INRA-Toulouse - she thanks ERNA-INRA for its hospitality.

runoff of fertilizers and pesticides. This sort of problem seems complex, since one never knows which polluter must be made responsible for the environmental damage observed. Quite paradoxically, this difficulty is easily handled within theoretical models. The literature characterizes an efficient regulation, attaining the optimum; it is based on the use of what we call an ambient tax, which is nothing more than a collective variant of a Pigouvian tax. As in a single-agent moral hazard problem, one would like to sell the firm (here the environmental quality) to the agent. When pollution is nonpoint, efficiency is obtained when each agent is made responsible for global environmental quality.

The solution is based on Holmström's (1982) analysis of team production and imposes the full social marginal cost of an increase in pollution on each individual polluter (Segerson, 1988). This ambient tax, based on total observed concentration of a pollutant, obtains the first-best allocation when polluters are risk neutral and follow Cournot-Nash behaviour. McAfee and McMillan (1991) show how the use of a linear tax can be extended to the case of both moral hazard and adverse selection. The conclusion is that it is feasible to regulate nonpoint source pollution in an efficient manner although no information is available on individual emissions.

The main criticism of this policy is that it assumes risk-neutrality, though the transfers finally paid by the agents may be quite risky if the tax is based on a stochastic signal (a measure) that is imperfectly correlated with the polluters' decisions or environmental quality. Indeed, ambient taxes are not applied in actual policy on nonpoint source pollution. Three different policy approaches to nonpoint source pollution are typically used.

The most common approach is to regulate the polluting input, as done through taxation of fertilizers based on their content of nitrogen or phosphorus, or the sales taxes on pesticides that have been used in for instance Sweden and Denmark. Input taxation is however difficult to target to the actual pollution problem. In order to be efficient, the tax should ideally be differentiated according to site, time, and method of application, data that most often is private information of the polluter. But differentiated input taxes tend to lead to the organisation of a parallel market, which makes the policy ineffective.

The regulator could also try to circumvent the problem by imposing monitoring devices or creating incentives for monitoring of individual emissions. One example could be French water law's delegation of the investment in monitoring equipment to individual polluters. The polluter either pays pollution charges according to pre-calculated production-pollution coefficients for its production sector, or may opt for the installation of continuous monitoring equipment and payment of pollution charges based upon measured individual emissions (see Ministry of Environment, 1992). Millock, Zilberman and Sunding (1997) show how an incentive scheme could be developed to allocate monitoring equipment among polluters in a cost-efficient manner.

In addition to attempts to circumvent the problem by improving monitoring, or using second-best input taxation, a third approach has recently received attention. It delegates the regulation of the pollution problem to the group responsible for its creation through a negotiated agreement between the group and an environmental agency representing government. Our definition of a so called voluntary abatement accord is delimited to signed agreements under which a group of polluters commits to a quantified emission reduction target under a certain time frame. Such a "voluntary" emission reduction target is often coupled with the adjustment of previously announced abatement targets or emission tax rates and is sometimes accompanied by subsidies to the agents undertaking abatement (Potier, 1994; Solsbery and Wiederkehr, 1995; Kohlhaas and Praetorius, 1996). The use of voluntary abatement accords has been a prominent feature of the implementation of the Dutch National Environmental Policy Plan (Ministry of Housing, Spatial Planning, and the Environment, 1994). It is an approach that relies specifically upon group action, and it is not clear how free-riding problems are addressed in actual use of the policy. There are for example no explicit sanctions for breach of contract in the voluntary abatement accords implemented so far, and their effectiveness relies on the extent to which the group can discipline its members (Glasbergen, 1996).

There are not many theoretical economic arguments for why the regulator may prefer to use a voluntary abatement accord instead of regulation by charges or standards. The few economic analyses that have been made of voluntary abatement accords focus on the advantages to polluters from being able to negotiate a different abatement target because of its private information on abatement costs (Carraro and Siniscalco, 1994; Schmelzer, 1996). Political scientists have emphasized the use of voluntary abatement accords as a social learning process, but also the fact that the use of voluntary abatement accords obviates the need to draft detailed environmental legislation that is costly to enforce and monitor (Glasbergen, 1996). We are aware of only one paper (Gårn Hansen, 1996) that analyses government's rationale for using voluntary abatement accords, and it focuses on the different actors involved in the policy process. Gårn Hansen interprets voluntary abatement accords as a means for government and industry to bypass congress when policy objectives differ.

Because of the basic team nature of nonpoint source pollution, it seems natural to rely upon a group solution for this type of pollution. For instance, a recent Swedish legislative proposal envisages the creation of agricultural abatement cooperatives regrouping all agents contributing to a pollution problem in a certain water basin (Ministry of Environment, 1996).

The purpose of this paper is to study how an ambient tax regulation must be modified for the case when polluters might cooperate. We set up a simple model with risk-neutral agents and moral hazard (but no adverse selection on costs), for which an ambient tax regulation is optimal (Section 2). We then compare the case of non-cooperation (Cournot-Nash behaviour) to the case of a cooperative group (joint profit maximisation).

Our first point is that taking into account cooperation between agents leads to a dramatic change in the level of the optimal ambient tax. With a cooperative group, it is sufficient to set the ambient tax at its Pigouvian level; that is, the regulator sells the environment to the group instead of selling it to each agent. Thus, when cooperation is possible the required level of an ambient tax may be quite low (Section 3). This is a feature one observes in voluntary abatement accords, for which the incentives given by the regulator may seem weak. It is also an argument for the use of an ambient tax when cooperation is possible or could be induced, since the risk associated with an ambient tax is now much lower.

We then analyse how cooperation between agents could emerge (Section 4). If individual actions are observable through peer monitoring, cooperation is likely to occur if agents have the power to punish a deviating agent: either through exclusion from a social group, or through exclusion from a cooperative offering access to services or capital stock, or by switching to the inefficient Cournot-Nash equilibrium if a deviation is observed, in the context of a repeated game (trigger strategies). Even if individual actions are not observable, some cooperation is feasible if agents observe interim signals correlated with the final official measure of environmental quality. In this case the problem exactly parallels the analysis of tacit collusion in an oligopoly due to Green and Porter (1984). To summarise, cooperation may emerge with different degrees, and for different reasons.

This conclusion also implies that the regulator may be unaware of which groups are cooperative, and which groups are not. It represents an important informational problem, because according to the former or the latter case the ambient tax must be set at very different levels. Section 5 considers the problem of obtaining revelation of this information. We show that revelation is very costly because it directly contradicts what the regulator would like to do by constraining the level of the tax for the non-cooperative group to be *less* than the tax level for the cooperative group. At equilibrium this constraint is likely to be binding, so that both types of groups get the same tax rate, but at an intermediate level. Therefore the desire to identify cooperative groups leads to a strong reduction in taxes for non-cooperative groups. It may also lead to an over-optimal level of taxes for the cooperative group.

To conclude, the fact that the regulator cannot identify cooperative groups constrains regulation severely and reduces its efficiency. It leads to over-optimal incentives to cooperative groups (though the penalties are apparently low, since they are computed by taking into account cooperative behaviour) and low incentives to non-cooperative groups. Consequently, voluntary abatement accords may well be interpreted as a practical form of ambient tax regulation.

2. The model

We use a simple model with n identical, risk-neutral agents, i=1,…,n. Each agent maximises profits π(e) by choosing an emission level e. The profit function is assumed to be concave in emissions, which could represent quantity of fertilizer applied on the field, for instance. Although the regulator cannot identify individual emissions, she has a measure of damage. Damage is assumed to be increasing and convex in emissions. For the sake of simplicity, damages are assumed to depend only on total emissions:

$$D = D(\sum e)$$

Agents' utility equals profits plus net transfers, NT:

$$U = \pi(e) + NT$$

The objective of the regulator is to maximise total surplus, taking into account the cost of public funds, λ>0, associated with net transfers:

$$W = nU - D(ne) - n(1+\lambda)NT$$

Using the expression for agents' utility, total social surplus can be rewritten as

$$W = -\frac{1}{n}\frac{D(ne)}{1+\lambda} + \pi(e) - \frac{\lambda}{1+\lambda}U$$

Although individual emissions are not observable, an ambient tax regulation can be introduced based on a verifiable measure m:

$$E(m|\sum e) = \sum e$$

Under an ambient tax regulation, each agent pays a tax tm when the measure is m.

Non-cooperative group

In our simple case of identical risk neutral agents, the regulator could use an ambient tax t to regulate agents. Assuming Cournot-Nash behaviour, agent i solves:

$$\underset{e_i}{Max}\; E[\pi(e_i) - tm]$$

For a risk neutral agent, this equals

$$\underset{e_i}{Max}\; \pi(e_i) - t\Big(\sum_{j \neq i} e_j + e_i\Big)$$

and the agent chooses an emission level such that

$$\pi'(e_i) = t$$

With a known profit function, the inverse function ε (t) can be defined as $\varepsilon(\cdot) = \pi'^{-1}$. The emission level chosen under an ambient tax will be denoted ε(t). Note that this choice is a dominant strategy for agent i. Individual profits under an ambient tax are defined as

$$\pi_0(t) = \pi(\varepsilon(t)) - nt\varepsilon(t)$$

In order to create the correct marginal incentive for each agent to choose the first-best level of emissions, the regulator has to levy the full social marginal cost on everyone, and individual tax payments are tnε(t). The optimal level of the tax is defined by

$$t^* = \frac{D'(n\varepsilon(t^*))}{1+\lambda}$$

Cooperative group

Joint profits are not maximised under this form of tax. If agents could cooperate, they would maximise joint profits $n[\pi(e) - nte]$. The solution to this problem is characterized by the first-order condition

$$\pi'(e) = nt$$

The chosen emission level under cooperation will be denoted ε(nt). Individual profits under a cooperative solution are defined by

$$\pi_1(t) = \pi(\varepsilon(nt)) - nt\varepsilon(nt)$$

3. First results and comparative statics

A comparison of the solution under cooperation versus non-cooperation shows that profits under cooperation are higher than profits under non-cooperative behaviour. If agents could cooperate, they would clearly gain from doing so.

An important consequence is that the incentive power of the tax under cooperation is n times t. In order to implement the same emission reduction, the regulator could use a much smaller tax under cooperation than under free-riding. Under cooperation, indeed the optimal tax is t*/n. If the regulator knew that the group can cooperate, she could obtain the desired result by a much smaller tax rate. This reduction in the necessary tax rate furthermore has the attractive feature that it reduces the risk imposed on agents facing an ambient tax. The risk borne by agents under an ambient tax scheme is directly proportional to the tax rate, and thus, when agents are risk averse, a second benefit from cooperation is a reduction in the necessary risk premium.

Furthermore, the gain from cooperation for a given number of agents increases with the tax rate. It seems an intuitive result, and we can show that concavity in tax revenues is a sufficient condition for $\pi_1(t)-\pi_0(t)$ to increase with t:

(A0): Tax revenues, tε(t), are a concave function of t.

Result: Under (A0), $\pi_1(t)-\pi_0(t)$ is an increasing function of t.

Proof: Computation shows that

$$(\pi_1-\pi_0)'(t) = (n-1)t\varepsilon'(t) - n\varepsilon(nt) + n\varepsilon(t) = 0 \text{ when } n=1.$$

It is enough to verify that the derivative with regard to n is positive:

$$\frac{\partial(\pi_1-\pi_0)'(t)}{\partial n} = (t\varepsilon'(t)+\varepsilon(t)) - (\varepsilon(nt)+nt\varepsilon'(nt))$$

This expression is always positive when tax revenues, tε(t) are concave in t. Q.E.D.

The assumption that tax revenues are concave in t is intuitive and is verified in many reasonable cases, in particular when the profit function is quadratic in emissions.

Finally, can we make some comparative static conclusions on the number of agents? There are two effects from an increase in the number of agents: a scale effect (total profits increase, damage increases) and an effect linked to the number of autonomous decision-making units, which is more interesting. In order to separate these effects, we will impose a form of constant scale in emissions, similar to the “fissioning” procedure used in Hyde, Rausser and Simon (1997). For agricultural pollution, this seems a natural assumption. As an ambient tax applies to a regional problem, land is limited, and an increase in the number of decision-making agents implies that the scale of each agent’s operations is reduced. Hence, the scale of the aggregate pollution problem would be unchanged. Then, if the number of agents change from n to n’ (n’>n), given our assumption of constant scale, the individual profit function would become[2]:

(A1): $$\Pi(e) = \frac{n}{n'}\pi\left(\frac{n'}{n}e\right)$$

Consequently, emissions $E(t) = \Pi'^{-1}$ verifies $E(t) = \frac{n}{n'}\varepsilon(t)$

so that total emissions remain the same. Using this assumption, the optimal ambient tax under non-cooperative behaviour does not change as the number of agents vary, but remains t* as defined in section 2. Consequently, the optimal tax under cooperation is only affected by the direct increase in the number of agents: t*/n'. We can show that an increase in the number of agents facilitates cooperation, since it increases the gain from cooperation.

Proof: Let Π_0 denote individual profits with n' agents under non-cooperation and Π_1 individual profits under cooperation with n' agents:

$$\Pi_0 = \Pi(E(t)) - n't\,E(t) = \frac{n}{n'}\pi(\varepsilon(t)) - nt\,\varepsilon(t)$$

$$\Pi_1 = \Pi(E(n't)) - n'tE(n't) = \frac{n}{n'}\pi(\varepsilon(n't)) - nt\,\varepsilon(n't)$$

The derivative in the profit differential is indeed positive with respect to n:

$$\begin{aligned}\frac{\partial}{\partial n'}[\Pi_1 - \Pi_0] &= \frac{n}{n'^2}\pi(\varepsilon(t)) - \frac{n}{n'^2}\pi(\varepsilon(n't)) + \\ &+ \frac{n}{n'}n't^2\varepsilon'(n't) - nt^2\varepsilon'(n't) = \\ &= \frac{n}{n'^2}[\pi(\varepsilon(t)) - \pi(\varepsilon(n't))] > 0\end{aligned}$$

Q.E.D.

It is also interesting to note that by (A0) the impact of n is increasing in the tax rate, t:

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[2] Capital letters denoting the solution with n' agents.

$$\frac{\partial}{\partial t}\frac{\partial}{\partial n'}[\Pi_1 - \Pi_0] = \frac{n}{n'^2}[t\varepsilon'(t) - n'^2\, t\varepsilon'(n't)] > 0$$

4. The scope for cooperation

How could cooperation appear? First, note that financial links via cross ownership would induce agents to choose emission levels as under joint profit maximisation. This would amount to the case of a cooperative. However, agents may be able to cooperate also in other, less formal contexts.

Cooperation necessitates both detection of possible deviations as well as the ability to enforce sanctions. The easiest setting would be peer monitoring combined with the threat of exclusion from common services, which can be envisaged in an agricultural setting. Social seclusion could also work as a sanction. Kandel and Lazear (1992), for instance, show how peer pressure arising from social norms create incentives for cooperation. The existence of a social penalty function has been used in models of credit cooperatives, where it has been shown to increase repayment rates under group lending schemes (Besley and Coate, 1995). In the context of agricultural pollution, its interpretation may be one of exclusion from common means of production or the refusal of assistance during harvest. Possibilities to sanction deviating agents may also exist because of interaction in related markets. Assume that the agents that are subject to an ambient tax also interact repeatedly in a product market. If an agent deviates from the cooperative emission level, the sanction would be a switch to strategies leading to the “bad” equilibrium in the product market.

Our assumption of agents being either cooperative or non-cooperative could thus be interpreted as an assumption of an exogenous penalty that agents can impose on a deviating agent at no cost. A fully cooperative group assumes the existence of a very high penalty P>0, whereas P=0 for a non-cooperative group. The timing of the game is the following: first, agents choose their level of emissions e. Then, everyone observes the full vector e and any deviations from the cooperative solution are penalised. Thus, each agent will cooperate if the following condition holds:

$$\pi(\varepsilon(nt)) - nt\varepsilon(nt) \geq \pi(\varepsilon(t)) - ((n-1)\varepsilon(nt) + \varepsilon(t))t - P$$

$$\Leftrightarrow P \geq \pi(\varepsilon(t)) - t\varepsilon(t) - [\pi(\varepsilon(nt)) - t\varepsilon(nt)]$$

Note that the right-hand-side is positive, and defines a minimal penalty level. It can be verified that the right-hand-side expression increases with the tax rate, that is, the necessary penalty level is higher and cooperation is more difficult the higher is the ambient tax rate.

Proof: Deriving with respect to t yields:

$$\begin{aligned}&-\varepsilon(t) - n^2 t\varepsilon'(nt) + \varepsilon(nt) + nt\varepsilon'(nt) = \\ &= \varepsilon(nt) - \varepsilon(t) + tn\varepsilon'(nt)(1-n)\end{aligned}$$

This expression equals zero when n=1. It is enough to verify that the derivative with respect to n is positive:

$$\begin{aligned}&-2nt\varepsilon'(nt) - n^2 t^2 \varepsilon''(nt) + 2t\varepsilon'(nt) + nt^2\varepsilon''(nt) = \\ &= [t - nt][2\varepsilon'(nt) + nt\varepsilon''(nt)]\end{aligned}$$

By (A0) the second term is negative, and the entire expression positive. Q.E.D.

Using (A1) above, the condition for cooperation when the number of agents increases from n to n’ translates into

$$P \geq \frac{n}{n'}[\pi(\varepsilon(t)) - t\varepsilon(t) - \pi(\varepsilon(n't)) + t\varepsilon(n't)]$$

and the minimal penalty level would go to zero as the number of agents increases. Cooperation is thus easier the larger is the number of agents. Note that this result depends crucially upon the assumption of a fixed penalty. If the penalty also was reduced proportionally to the number of agents (P/n’), cooperation would be more difficult as the number of agents increases.

If agents can use peer monitoring, but cannot implement sanctions, it can nevertheless be shown that cooperation can be supported as a subgame perfect Nash equilibrium in a repeated game. The equilibrium strategies are: each agent cooperates and chooses ε(nt). If an agent deviates, each agent chooses the non-cooperative level of emissions, ε(t). If agents' discount factor is denoted δ and it is assumed that a deviation from cooperative strategies is observed by other agents with some probability α, then cooperation is implementable as long as

$$\delta(1-\alpha+\frac{\alpha}{\varphi(n,t)})\geq 1$$

where $$\varphi(t,n)=\frac{1}{(n-1)t}\frac{[\pi(\varepsilon(t))-t\varepsilon(t)]-[\pi(\varepsilon(nt))-t\varepsilon(nt)]}{\varepsilon(t)-\varepsilon(nt)}.$$

Proof: The proof is an analogue of showing cooperation in a repeated prisoners dilemma game. For the trigger strategy to be a subgame Nash equilibrium, the following condition has to hold:

$$\pi_1(t)\frac{1}{1-\delta}\geq\pi(e^*)-t((n-1)\varepsilon(nt)+e^*)+\alpha\frac{\delta}{1-\delta}\pi_0(t)+(1-\alpha)\frac{\delta}{1-\delta}\pi_1(t)$$

Substituting in the agent's best strategy when deviating, $e^*=\varepsilon(t)$, and rearranging gives:

$$\pi_1(t)\geq\pi_0(t)(1-\delta)+(n-1)t[\varepsilon(t)-\varepsilon(nt)](1-\delta)+\alpha\delta\pi_0(t)+(1-\alpha)\delta\pi_1(t)$$

$$\Leftrightarrow\pi_1(t)-\pi(\varepsilon(t))+(n-1)t\varepsilon(nt)+t\varepsilon(t)\geq\delta[\alpha\pi_0(t)+(1-\alpha)\pi_1(t)-\pi(\varepsilon(t))+(n-1)t\varepsilon(nt)+t\varepsilon(t)]$$

$$\Leftrightarrow\pi(\varepsilon(nt))-t\varepsilon(nt)-[\pi(\varepsilon(t))-t\varepsilon(t)]\geq$$

$$\delta[\alpha[\pi(\varepsilon(t))-nt\varepsilon(t)-\pi(\varepsilon(nt))+nt\varepsilon(nt)]+\pi(\varepsilon(nt))-t\varepsilon(nt)-\pi(\varepsilon(t))+t\varepsilon(t)]$$

Define φ as above and the condition can be written as $\delta(1-\alpha+\frac{\alpha}{\varphi})\geq 1$ Q.E.D.

The interesting feature of φ is that it is always positive and less than 1 (by concavity of $e\mapsto\pi(e)-te$) and goes to zero when n goes to infinity. By our use of assumption (A1), an increase in the number of agents from n to n' yields proportionate increases in emissions and thus

$$j\ (n',t) = \frac{1}{(n'-1)}\frac{[p\ (e\ (t)) - te(t)] - [p\ (e\ (n't)) - te\ (n't)]}{e\ (t) - e\ (n't)}$$

By assumption (A0) above, this expression decreases with n. Therefore, when n is large the condition for cooperation will be satisfied even for small probabilities of detection of deviation and small δ.

Even in cases where the probability of observing other’s effort levels is zero, and there are no sanctions, it may still be possible to implement cooperation through the use of an interim measure of ambient quality.[3] Consider the following dynamic game structure: polluters determine effort choice in the first period. After the realisation of first period effort choice, every agent is able to observe an intermediate measure of ambient quality, upon which they can condition the decision on second period effort. At the end of the second period, the regulator takes an official measure of ambient quality and calculates an ambient tax accordingly. Just like for a self-policing cartel, it can be shown that cooperative effort levels can be sustained based upon the existence of the intermediate measure. The intermediate measure serves as an indirect signal to agents of whether effort levels in the first period already have compromised the possibilities of obtaining a good measure, and hence, a low fee in the second period. It is possible to find examples in which total emissions are reduced when an interim measure is introduced, given a tax t. In particular, this is the case if a bad measurement in the first period reduces the chance of a favourable measure at the end of the game, so that deviations in the first period would lead the other agents to increase their emissions, thereby punishing the agent who deviated.

5. Identifying cooperative groups

We have argued for some reasons why cooperative abatement by polluters may be feasible. The most transparent reason is the case of financial links via cross ownership. However, financial cross ownership is observable to the regulator, who can choose the appropriate ambient tax accordingly. In the previous section we presented some other arguments for why agents may be able to cooperate, all of which are more difficult to observe for an outsider. For example, agents may be able to cooperate simply because of vicinity and peer monitoring of effort, and by imposing penalties on deviating agents through the use of trigger strategies in other markets in which they interact repeatedly. There may exist several reasons for why a certain group of agents can cooperate or not, but these factors are not easily observable to the regulator. Thus, the regulator cannot a priori know which type agents are. The sector may be one in which agents can monitor each other and will observe each other's effort level, or it may be that agents cannot cooperate and a high ambient tax is called for.

A revelation mechanism could be developped in order to determine what form of taxation should be used. The revelation mechanism would take the form of an offer of two contracts, one for agents that cannot cooperate, (t_0,T_0), and one for agents that can cooperate (t_1,T_1), where T_0 and T_1 are lump sum taxes. The contracts have to satisfy incentive compatibility constraints:

$$U_1 = \pi_1(t_1) + T_1 \geq \pi_1(t_0) + T_0 \qquad \textit{for a group that can cooperate}$$
$$U_0 = \pi_0(t_0) + T_0 \geq \pi_0(t_1) + T_1 \qquad \textit{for a group that cannot cooperate}$$

Note that we assume that collective lying is possible, an assumption that is addressed at the end of the paper. From the incentive-compatibility constraints, the following condition has to hold:

$$\pi_1(t_0) - \pi_0(t_0) \leq U_1 - U_0 \leq \pi_1(t_1) - \pi_0(t_1)$$

The first inequality implies that a rent has to be left to cooperative agents, since π_1 is always greater than π_0. More interesting is the second-order condition expressed by the inequality between the profit differentials. It is intuitive that when t increases, the gains from cooperation get larger, and a sufficient condition for this to hold was given by (A0).

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[3] This parallels the work on implicit cartels by Green and Porter (1984).

The consequence is dramatic: t_0 has to be smaller than t_1, which goes directly contrary to what the regulator would like to do. This constraint reduces the efficiency of using an ambient tax.

Let us now turn to the regulator's problem. Assume the regulator has a prior probability on the proportion of groups that can cooperate, and that it is v. The prior on the proportion of agents that cannot cooperate is (1-v). The regulator's objective is then:

$$\underset{t_0,t_1,U_0,U_1}{Max} \quad v[\mathrm{p}(\mathrm{e}(nt_1)) - \frac{1}{n}\frac{D(n\mathrm{e}(nt_1))}{1+\mathrm{l}} - \frac{\mathrm{l}}{1+\mathrm{l}}U_1] + $$
$$+(1-v)[\mathrm{p}(\mathrm{e}(t_0)) - \frac{1}{n}\frac{D(n\mathrm{e}(t_0))}{1+\mathrm{l}} - \frac{\mathrm{l}}{1+\mathrm{l}}U_0]$$

s.t $\quad U_0 \geq \underline{U}$

$U_1 \geq \underline{U}$

$\mathrm{p}_1(t_0) - \mathrm{p}_0(t_0) \leq U_1 - U_0 \leq \mathrm{p}_1(t_1) - \mathrm{p}_0(t_1)$

The agents' reservation utility equals $\underline{U}$, and the contracts have to satisfy individual rationality constraints. The reservation utilities are assumed to be the same for both types, which is the case if the initial situation entails no regulation (t=0).

Since rents are costly, the regulator will set $U_0 = \underline{U}$ and the problem can be rewritten as follows:

$$\underset{t_0,t_1,U_0,U_1}{Max} \quad v[\mathrm{p}(\mathrm{e}(nt_1)) - \frac{1}{n}\frac{D(n\mathrm{e}(nt_1))}{1+\mathrm{l}}] + $$
$$+(1-v)[\mathrm{p}(\mathrm{e}(t_0)) - \frac{1}{n}\frac{D(n\mathrm{e}(t_0))}{1+\mathrm{l}}] - $$
$$-v\frac{\mathrm{l}}{1+\mathrm{l}}[\mathrm{p}_1(t_0) - \mathrm{p}_0(t_0)]$$

s.t. $t_1 \geq t_0$

We shall assume that the objective function is concave in t_0 and t_1.

Proposition: When the last constraint is not binding, the regulator sets t_1 at its optimal level t*/n, but distorts t_0 downwards to avoid to leave costly rents. This case corresponds to a high level of v and λ. When the constraint does bind, the regulator sets t_1=t_0=t,at an intermediate value between t*/n and t*.

<u>Proof</u>: Consider first the case when the constraint is not binding. In this case, the regulator's optimisation problem yields two first order conditions:

For t_1:

$$\pi'(\varepsilon(nt_1)) = \frac{D'(n\varepsilon(nt_1))}{(1+\lambda)} = nt_1$$

For t_0:

$$\pi'(\varepsilon(t_0)) = \frac{D'(n\,\varepsilon(t_0))}{(1+\lambda)} + \frac{\lambda}{1+\lambda}\frac{v}{1-v}[\pi_1'(t_0) - \pi_0'(t_0)]/\varepsilon'(t_0) = t_0$$

The level of t_1 equals the standard ambient tax divided by n, that is, t*/n. The condition for setting t_0 adds a second negative term to the derivative of the damage function. When v or λ increase, the second term is more important, which makes t_0 decrease. Q.E.D.

When the regulator has a high a priori probability of agents being able to cooperate, the emission tax offered agents that can cooperate is set at the optimal level, whereas the tax on agents that cannot cooperate is set below the optimal level. As t_0 is less than t_1, equal to t*/n, the actual level of the tax on agents that cannot cooperate will be very low. Since v is close to one, the welfare loss from not regulating the non-cooperative group is small. The practically inexisting tax on agents that cannot cooperate can be explained by the fact that higher levels of t_0 require larger rents to be paid to that type of agents. This case has some features in common with observed practices under voluntary abatement accords. Regulation in the form of emission taxes and reduction goals are only imposed on one group, agents that cooperate.

When the regulator a priori considers the probability of cooperation among agents to be low, it would be costly to try and implement the cooperative solution. Nor in this case, however, is the regulator's optimal solution the standard ambient tax. Instead, the identical emission tax that is offered both types of agents is set at a lower level than the optimal ambient tax, but higher than the tax under a fully cooperative solution. Cooperative agents in this case limit their emissions more than optimally, whereas emissions of noncooperative agents exceed the optimal solution.

An interesting question is how the solution varies with n. In a simple example with a linear damage function and a quadratic profit function, we show that the tax on the non-cooperative group decreases with both v, λ, and n. Specify $\pi(e) = e - \frac{be^2}{2}$ and D(e)=de. Calculations then show that $\pi_1 - \pi_0 = \frac{1}{2b}(n-1)^2 t^2$, and the regulator's objective function is thus concave in t. The solution to the regulator's problem when $t_0<t_1$ is[4]:

$$t_0 = t^* - \frac{\lambda}{1+\lambda}\frac{v}{1-v}(n-1)^2 t_0$$

$$\Leftrightarrow t_0 = \frac{t^*}{1+\frac{\lambda}{1+\lambda}\frac{v}{1-v}(n-1)^2}$$

and t_0 thus decreases with v, λ, and n. For the case when $t_0=t_1$, we obtain:

$$t = \frac{t^*}{n}\left[\frac{1+\frac{v}{1-v}n}{1+\frac{v}{1-v}n+\frac{\lambda}{1+\lambda}\frac{v}{1-v}(n-1)^2}\right]$$

which is always in $[\frac{t^*}{n},\ t^*]$.

Here, as $n \to \infty$, $t \to \frac{t^*}{n}\frac{1+\lambda}{\lambda}$ and there will at the limit be a zero tax rate. This result may seem counterintuitive, since as the number of polluters increases, marginal damage increases, and the regulator would want to raise the optimal tax. However, raising t

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[4] $t^*=d/(1+\lambda)$

leads to a large loss in distorting the abatement done by the cooperative group, for which the single tax rate t is set at too high a level (see above).

The previous use of a direct revelation mechanism to determine whether agents can cooperate or not relied upon a restrictive assumption: agents can lie cooperatively. At first examination, it may not seem too restrictive an assumption. There is a difference in being able to coordinate effort levels to implement cooperative strategies, and tacitly colluding by lying collectively. However, it would seem that the regulator may be able to reveal what type agents are simply by offering a reward to an individual agent that breaks the collusive agreement. The fact that agents are cooperative or cannot cooperate is private knowledge belonging to the entire group, and inducing one agent to reveal this information could reduce the information rents paid by the regulator. Such message games, proposed by Ma (1988) and Ma, Moore and Turnbull (1988) amongst others, could overcome the regulator’s problem of separating cooperative agents from non-cooperative. Arya and Glover (1995) show how the principal can approximately implement the second-best solution with a small message space when agents cannot observe each other’s efforts. Ma, Moore and Turnbull (1988) proposed a message game for exact implementation of the second-best solution when agents can observe each other’s efforts, as would be the case with peer monitoring. Whether the features of optimal policy remain similar to those of voluntary abatement accords when more complex revelation mechanisms are accounted for is an open question that we intend to explore further.

6. Relation to the literature on peer monitoring

In Section 4, we proposed some explanations for why agents can cooperate, one of which is peer monitoring. The use of peer monitoring as a means of controlling free-riding incentives was first applied to the modelling of credit cooperatives in developing economies (Stiglitz, 1990; Varian, 1990; Arnott and Stiglitz, 1991). For such cooperatives, self-formed groups offer advantages in three regards: selection, monitoring, and enforcement. In the context of agricultural pollution, the group of polluters is already fixed, and so the advantage of peer selection in influencing the composition of the group (Ghatak, 1995) does not apply. The use of mutual monitoring of effort can however sustain cooperative strategies of agents. Itoh (1993) proves that the principal can implement a given effort level at lower cost when agents can collude to coordinate their effort levels. With the assumption of transferable utility, the result is robust to the message revelation games proposed for instance in Ma (1988). Laffont and Meleu (1996), however, show how peer monitoring may lower the principal's utility in a model of exchange of reciprocal favours. Other work on peer monitoring shows that the possibility of agents to observe states unknown to the regulator yields benefits from collusion, as compared to mutual monitoring per se (Holmström and Milgrom, 1990; Varian, 1990).

7. Conclusions

The economic literature on the regulation of nonpoint source pollution has proposed the theoretically attractive idea of using ambient taxes to implement the optimal abatement allocation. Actual policy on nonpoint source pollution is very much different, relying on second-best input taxation, or circumvention of the problem by installation of monitoring equipment. Recent policy emphasizes the team nature of nonpoint source pollution by proposing delegation of the abatement target to a group of polluters. Whether such delegation constitutes efficient policy depends very much on monitoring and enforcement to contain free-riding incentives. In the paper we analyse a simple moral hazard model with identical risk neutral agents. These are conditions under which an ambient tax would be an efficient instrument to implement optimal abatement levels. However, taking into account the possibility that agents might be able to cooperate changes the results for optimal policy. Policy now consists of regulating only cooperative agents, for which the emission tax level will be set below the typical ambient tax level. The fact that the regulator a priori does not know whether a group of agents can cooperate or not in implementing abatement then explains a policy that otherwise may be considered suboptimal.

Our main result is thus to show a previously unconsidered limitation in the practical application of ambient taxes. The optimal ambient tax rate varies significantly depending on the degree of cooperation among agents in the regulated sector. Cooperation depends on factors that to a large extent are unobservable to the regulator, and so, optimal policy changes according to the regulator's expectation of cooperation in the sector, and the number of agents in the sector. It may be that the recent surge in the application of so called voluntary abatement accords in fact constitutes the only means of implementing the theoretical notion of an ambient tax. Such a conclusion is compatible with the results of our theoretical model of an ambient tax when polluters might cooperate. That is, cooperative groups would be regulated by a voluntary abatement agreement, whereas the tax rate for noncooperative agents in practice would be insignificant.

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