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# Nonpoint Source Pollution When Polluters Might Cooperate

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## Abstract

In a model of nonpoint source pollution, we extend the theory of ambient taxes to the case when polluters might cooperate. We show that regulation through ambient taxes is severely constrained when the degree of cooperation among polluters is unknown to the regulator. On the other hand, if the regulator can invest in costly monitoring of emissions, then the optimal regulation offers a low ambient tax to cooperative groups and an optimal but costly individual emission tax to non-cooperative groups. This mechanism also has attractive properties when risk-aversion is introduced.

**KEYWORDS:** ambient tax, cooperation, environmental regulation, group moral hazard, incomplete information

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## 1. Introduction

Nonpoint source pollution is nowadays recognized as an important source of environmental damage. Significant examples are water pollution from agricultural runoff of fertilizers and pesticides, and traffic emissions in big cities. For this form of pollution, designing an efficient regulation seems complex since it is difficult to identify each polluter's individual impact on environmental quality. Hence most practical proposals rely either on regulating a variable indirectly related to emissions, such as inputs, outputs or technological standards, or investing in monitoring devices aiming at making individual emissions observable.

Yet analyses that apply mechanism design show that a nonpoint source pollution problem can be handled using incentive-compatible schemes based on noisy observations of emissions. These theoretical models à la Holmström (1982) rely upon three assumptions. First, aggregate emissions are publicly observed, maybe with some measurement error. This makes it possible to compute and levy what is called an ambient tax: each polluter pays a fee that depends on the observed value of the measure. Second, polluters follow a Cournot-Nash behavior when choosing their emission level. Third, polluters are risk-neutral. Efficiency obtains when the tax is computed so that each agent bears the full social marginal cost of an increase in pollution (Meran and Schwalbe, 1987; Segerson, 1988). The conclusion is that it is feasible to regulate nonpoint source pollution in an efficient manner, although no information is available on individual emissions. In fact, such information would be valueless.[1]

Previous research has formulated two major objections to the efficiency result of an ambient tax. First, agents have to realize the impact of their emissions on the aggregate measure of pollution. In the context of nonpoint source pollution, which is characterized by a high number of polluters, this may be difficult (Cabe and Herriges, 1992). Second, ambient taxes generally apply to a noisy measurement of total emissions,[2] thus creating a risk for the polluters; this risk is socially costly if the polluters are risk-averse. In theory, the use of non-linear incentive schemes could mitigate this objection, but such schemes often lead to paradoxical outcomes such as the imposition of infinite penalties with zero probability (Mirrlees, 1974). Their design also relies on precise properties of the

[1] This result is also obtained in a more general, static model in Cabe and Herriges (1992); under adverse selection in McAfee and McMillan (1991) and Laffont (1994); and in a dynamic model by Xepapadeas (1992). Lewis (1996) surveys the use of mechanism design for environmental regulation. An early application of this method to agricultural pollution is Chambers and Quiggin (1996).

[2] In the absence of a measurement error, and even if polluters were risk averse, the regulator could create correct incentives by randomly fining one polluter if the objective is not met (Rasmusen, 1987; Xepapadeas, 1991; Herriges, Govindasamy and Shogren, 1994).

distribution of the measurement error; such a feature makes practical implementation difficult.

This paper analyses a third objection to the efficiency result of an ambient tax by introducing cooperation among polluters. We define cooperation as the ability to coordinate emissions in order to maximize joint profits, and we consider it as an exogenous characteristic of polluters. This assumption allows us to focus on one aspect of regulation with cooperative agents, namely, how the regulator should respond given the degree of cooperation among agents. The reciprocal aspect of causality, or how regulation may induce cooperation, is another important issue which we leave for future research. Still, analyzing the impact of cooperation is important for the following reason. Recall that the ambient tax applies to a measure of total emissions, and is paid by each polluter. In the absence of cooperation, each polluter chooses its emission level without taking into account the additional fee other agents will have to pay. Hence emission levels are collectively inefficient in the usual Cournot-Nash game. Conversely, cooperative polluters are able to coordinate their emission levels to lower levels. This observation motivates our study.

We set up a simple model with a group of identical polluters facing a benevolent regulator. We first show that the efficiency result of ambient taxes extends to the case of cooperation, and that a much smaller ambient tax is needed to obtain the same level of emissions. This reduction alleviates the aforementioned criticisms of ambient taxes based on risk-aversion. However we argue that for a number of reasons the level of cooperation in a group is normally difficult to observe for the regulator. We then solve for the optimal regulation in the case when the regulator is unaware of whether the group of polluters is cooperative or not. We show that this regulation is inefficient and strongly constrained by asymmetric information. In fact, because a cooperative group better manages an increase in the ambient tax, under incomplete information it must end up with a higher ambient tax; but as we have just seen this is exactly the opposite of what the regulator would like to do. Hence the regulator is bound to set too high a tax rate on cooperative groups, and too low a tax rate on non-cooperative groups. Therefore the efficiency result for ambient taxes does not extend to the case when polluters *might* cooperate.

This negative result calls for introducing additional instruments in order to screen groups better. We thus check whether cooperation modifies the regulator's choice between an ambient tax regulation and a more traditional emission tax requiring costly monitoring of each polluter's emissions. The optimal policy turns out to offer a choice between a traditional emission tax (with costly monitoring), which is chosen by non-cooperative groups; and a low ambient tax, for cooperative groups. This policy yields efficient emission levels, and does not require to leave any informational rents to polluters. It does not presuppose any knowledge of the distribution of the measurement error. The only departure from efficiency is that society has to incur the monitoring costs when the group is non-cooperative.

We also compare our proposal to other mechanisms advocated in the literature. An advantage of our proposal is that it does not require a precise knowledge of the distribution of the measurement error. Also, the risk borne by each agent is dramatically lower under cooperation. Consequently, a criticism often raised against ambient tax regulation, namely that due to the measurement error polluters would have to pay a highly variable collective charge,[3] appears less relevant. We check this by extending the model to the case of risk-averse agents. We show that the individual emissions of less cooperative groups should be monitored, while a low ambient tax should be chosen as soon as the group is cooperative enough.

The criticism in Cabe and Herriges (1992) that ambient taxes are inefficient because polluters are unable to understand their individual impact on the ambient measurement and thus on their revenue is also alleviated. Our setting is flexible enough to encompass this possibility, and we show that such groups must end up with a traditional emission tax. Overall it seems that a low ambient tax might constitute an attractive policy for environmental problems due to agricultural runoff, such as local pollution problems around a watershed. Still one must keep in mind that this positive result only holds to the extent that the regulator offers a choice between a low ambient tax and an emission tax set at the Pigovian level; in the absence of the latter element it is impossible to screen groups satisfactorily.

There is little previous theoretical work on the implications of cooperation on environmental policy (some empirical studies are reviewed in the next Section). Hansen (1998) suggested to create a floor on the tax payment, and we shall show that this change indeed is welfare-improving. Nevertheless this proposal is not efficient when the measure of total emissions is noisy, and it relies on a very precise knowledge of the distribution function of the measurement error.[4]

Section 2 discusses actual use of cooperation in environmental regulation. Section 3 presents the model and the complete information benchmark. Section 4 examines the case when the degree of cooperation among polluters is unknown. Section 5 introduces a new type of regulation based on monitoring and the use of

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[3] This argument is used in Xepapadeas (1995) to justify the introduction of monitoring of (at least part of) individual emissions (see also Byström and Bromley (1998) for considerations related to risk-aversion). Millock, Sunding and Zilberman (2002) develop a model based on the circumvention of the problem by investment in monitoring of individual emissions.

[4] See also Romstad (1997), who discusses the problems of obtaining full cooperation when the approach of team incentives is used, and DeVuyst and Ipe (1999), who study the design of group incentive contracts for the adoption of best management practices in agriculture.

an emission tax for non-cooperative polluters and an ambient tax for cooperative groups. We show how such a regulation could work in a simple two-type model (Section 5.1) as well as in the more general case of continuous types (Section 5.2). Section 5.3 shows that the properties of this regulation are robust to risk aversion. Section 6 then compares our proposal with other schemes suggested in the literature. Proofs of propositions that do not follow immediately from the text are placed in an Appendix.

## 2. Cooperative Approaches in Reducing Pollution

The importance of relaxing the assumption of non-cooperative behavior is clearly linked to the team nature of nonpoint source pollution. In particular, many agricultural problems involve contamination of a local watershed for which cooperative approaches may be valuable. The construction and maintenance of wetlands and ponds to capture nitrate emissions are examples of activities where cooperation between farmers is indispensable. Furthermore, there is a trend in environmental policy in Europe and elsewhere to use voluntary agreements or covenants relying upon cooperation among polluters (Börkey, Glachant and Lévêque, 1998). The existence of cooperation between agents is now well-documented in different contexts, ranging from the workplace (Kandel and Lazear, 1992) and the organisation of micro-credit (Besley and Coate, 1995) to agri-environmental groups (Romstad, 1997).[5] This Section explains how cooperation could arise in environmental policy and gives real-world examples. Notice first that existing institutions often rely on cooperation among agents that are closely located geographically and may interact with each other, socially or in a professional context. Examples include water boards, and river basin commissions. In the Netherlands, agricultural cooperatives were formed in the early 1990s in order to coordinate measures against eutrophication resulting from excess fertilization (OECD, 1997).[6]

The economic literature on peer monitoring shows that side-contracting among agents only has a value when agents share information that the regulator cannot observe (see for example Varian, 1990, and Holmström and Milgrom, 1990). Agents may have superior information on emissions than the regulator. For example, much of the polluting industry in India is located in industrial districts, from which water pollution has a nonpoint source character. The regulator may be

[5] Kandel and Lazear (1992) show how peer pressure arising from social norms creates incentives for cooperation. de Janvry, McCarthy and Sadoulet (1998) study how the quality of cooperation in the appropriation of a common resource depends upon the costs of supervision and enforcement.

[6] An example of less formal cooperation (that does not include specific quantitative goals) is the Landcare Movement in Australia, that relies upon cooperation to combat dryland salinity, water logging and erosion.

able to observe common emissions from the borders of the estate, but firms sharing the location in the same industrial district have easier access and more legitimacy in monitoring individual plant emissions than geographically remote environmental agencies. Sterner (2003) analyses the monitoring efforts set up voluntarily by firms located in the Ankleshwar Industrial Estate in Gujarat. The estate comprises more than 400 chemical plants, and the Ankleshwar Industries Association has used several instruments to coerce its members to clean up emissions - including provision of information, small effluent fees and fines - all in an effort to improve the reputation of the entire industrial estate. This advantage of peer monitoring has been established in several empirical studies on common property resource management (Ostrom, 1990). Similar advantages of peer monitoring based on peer pressure from fellow members of an industrial association might be found in manufacturer initiatives, like the Responsible Care Program of the Chemical Manufacturers Association.

While geographical proximity facilitates the detection of possible deviations, cooperation also necessitates the ability to enforce sanctions. As to this point, the threat of exclusion from common projects (e.g. agricultural cooperative, professional associations, joint research) may deter deviations. As is well known, in repeated games, credible threats such as social seclusion help sustain cooperation if agents' discount factors are high enough. Cooperation may also emerge if agents interact simultaneously in another game, for example social cooperation, or the sharing of common production factors in a cooperative. By using a trigger strategy and threatening to revert to the non-cooperative equilibrium in the secondary game if agents stop cooperation on emissions abatement, the agents may sustain cooperation on both activities (Spagnolo, 1999). Notice that some cooperation is still sustainable even if deviations are not observed. In this case, sanctions must be collective and used when the measure $m$ is above a certain threshold. At equilibrium no one deviates from the prescribed emissions, but sanctions are inefficiently exerted with positive probability if the measure is stochastic.[7]

As we shall show below, cooperation has an important impact on behavior when an ambient tax is used. Still, few real-world examples of ambient taxes are known; a close example of U.S. regional regulation is the Everglades Forever Act, under which land taxes are automatically increased if an aggregate objective of phosphorus reduction is not met (Ribaudo and Caswell, 1999). We shall argue below that practical difficulties in using ambient taxes may originate in the fact that the regulator does not know whether the polluters are able to behave in cooperative manner. Indeed it is difficult for a regulator to observe the effectiveness of peer monitoring, the different games played by the agents, and the values of the associated threats.

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

## 3. The Model and the Complete Information Benchmarks

Consider a group of $n$ identical, risk-neutral polluters, and a benevolent regulator aiming at reducing environmental damage due to polluting emissions through the use of monetary transfers based on observable variables. The games we study share the following timing: polluters $i=1,\ldots,n$ simultaneously choose emission levels $e_i$, and get profits $\pi(e_i)$, minus the transfers paid to the regulator. The profit function $\pi$ is assumed strictly concave, so that its derivative $\pi'$ is decreasing, and so is the inverse function $\varepsilon = (\pi')^{-1}$. Hence an agent facing an emission tax $t$ chooses an emission level $e = \varepsilon(t)$. We assume:

**(A)**: tax revenues, $t\,\varepsilon(t)$, are a concave function of the tax level $t$.

This assumption has a clear, Laffer-type intuitive content, and is not very demanding analytically (it is verified as soon as the third derivative of the profit function is non-positive). Environmental damage is a function $D\left(\sum_{i=1}^{n} e_i\right)$ of total emissions, where $D$ is a convex, increasing function. Since polluters do not take into account the environmental damage when choosing emissions, public intervention may be valuable. We therefore introduce a benevolent regulator that maximizes total surplus. In a symmetric case when each polluter emits $e$ and pays a total fee $F$, the payoff or rent of a polluter is

$$U = \pi(e) - F.$$

The fee $F$ could be an ambient tax or an emission tax. (In the latter case, the firm would pay $F = t\,\varepsilon(t)$, as in assumption A.) Then total social surplus is given by[8]

$$nU - D(ne) + (1+\lambda)nF$$

where $\lambda > 0$ is the multiplier associated with the regulator's budget constraint (or equivalently this multiplier plus one is the marginal cost of public funds). Substituting and dividing by $n(1+\lambda)$, one can rewrite the surplus as

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[8] For the sake of simplicity, we limit our analysis to the case of identical polluters that do not interact on a product market. For the same reason, we do not include any consumer surplus in social welfare computations. This last assumption could easily be relaxed. The assumption of a given set of identical polluters is more important, since as we shall see it allows for a simple definition of cooperative outcomes. Hence we consider neither entry nor exit.

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

Notice that leaving rents to agents is socially costly, due to the cost of public funds. Moreover, since polluters always can choose to close down or relocate, we impose that any regulation must satisfy a participation constraint: the net payoff *U* of agents must be higher than a lower bound *u*. Maximizing the above welfare under this constraint, we get that participation constraints are binding (*U*=*u*), and the individual emissions $e^*$ and individual tax $t^*$ are given by[9]

$$\pi'(e^*) = \frac{D'(ne^*)}{1+\lambda} \equiv t^*.$$

Thus this benchmark allocation can be implemented by imposing an individual emission tax equal to $t^*$, together with a lump-sum transfer aiming at satisfying participation constraints. Though this tax level is distorted due to the marginal cost of public funds, we nonetheless refer to it as a first-best level, in order to distinguish it from different, less efficient, rates that will obtain under additional constraints.

In practice emissions are costly to observe, because the regulator has to set up a monitoring system aiming at a precise measurement of individual emissions. The cost of monitoring should be understood as including not only measurement devices, but other costs such as the wages of controllers and the cost implied by collusion-proofness constraints. Such a system makes it possible to use emission taxes based on individual emissions. Compared to the previous benchmark, the only difference is that social welfare is reduced by the measurement cost.

Alternatively, if the regulator chooses not to incur the costs of the monitoring system, then individual emissions are not observable. In real world cases, information about global emissions is often available through some measurement of global damage *D* or of other variables such as pollutant concentrations in a watershed. Here we assume that the only variable the regulator can observe is a noisy, real-valued, unbiased measure *m* of total emissions, so that

[9] Participation constraints prevent the regulator from using lump-sum transfers to raise enough money, so other taxation devices must create distortions elsewhere in the economy. This explains why the marginal cost of public funds is above one, in the denominator of the optimal tax rate, as in Bovenberg and van der Ploeg (1994). Much of the literature deals with the case when public funds are not costly to raise, so that the distribution of rents becomes indifferent.

$$E(m \Big| \sum_i e_i) = \sum_i e_i \ .$$

($E$ is the expectation operator; the fact that the measure is noisy plays an important role in our analysis). In such a nonpoint source pollution problem, the only available regulatory instrument consists in fees based on the measure $m$. In the following, we first consider identical, linear fees, which we write:[10]

$$F(m) = \tau\, m + T$$

where $\tau$ is an ambient tax and $T$ is a lump-sum tax. To allow the system to satisfy the participation constraints, this is a payment to the firm ($T<0$). The firm pays $\tau$ times the measure of total emissions, $m$, but given the sum of all other firms' emissions, this $\tau$ is also the extra ambient tax associated with one more unit of this firm's own emissions. Thus, to this firm, it acts like an emission tax.

### 3.1. The non-cooperative benchmark

When agents behave non-cooperatively, the impact of an ambient tax $\tau$ can be evaluated by solving a simple Cournot-Nash game. Facing the choices $(e_j)_{j \neq i}$ of other agents, agent $i$ chooses $e_i$ to maximize

$$E[\pi(e_i) - \tau\, m \ \ |\sum_{j=1}^{n} e_j] = \pi(e_i) - \tau \sum_{j=1}^{n} e_j$$

and thus chooses an emission level $e = \varepsilon(\tau)$. The first-best emission level can thus be implemented by setting the ambient tax $\tau$ equal to $t^*$. Consequently, information on individual emissions is valueless, an instance of the efficiency result for ambient taxes (Holmström, 1982; Meran and Schwalbe, 1987; Segerson, 1988; McAfee and McMillan, 1991). Notice however that joint profits are far from being maximized. This is because each agent chooses an emission level without internalizing the additional fee other agents will have to pay.

### 3.2. The cooperative benchmark

[10] Non-linear taxation may be helpful only if the regulator has exact knowledge of the cumulative distribution function of the measure $m$. Other practical reasons make linear taxes an important benchmark. The use of non-linear taxes is further discussed in Section 6.

Let us define cooperation as the ability of polluters to coordinate their emission choices, in order to reach a better internalization. We do not explain how cooperation appears, but consider it an exogenous characteristic that a given group may or may not possess. As discussed in section 2, cooperation relies on the ability of polluters to observe individual emission levels. Even if the regulator is unable to observe these levels, he could use sophisticated mechanisms aiming at learning the true levels from announcements by polluters. Nevertheless we shall stick to simple mechanisms, specifying an ambient tax $\tau$ and a lump-sum transfer $T$. We acknowledge that this is an important restriction, which we justify by robustness considerations.[11]

In order to model varying degrees of cooperation, assume that the group with $n$ polluters can be subdivided into $n/k$ fully cooperative subgroups of size $k$. Define an index of cooperation $x = \frac{k}{n}$, $x \in [\frac{1}{n}, 1]$. When facing an ambient tax $\tau$, members of each subgroup cooperatively choose their emission levels. Hence, with a subgroup of size $k$, and if $S$ denotes total emissions from other subgroups, total emissions equal $ke+S$. Each individual member of the subgroup obtains a profit equal to

$$\pi(e) - \tau(xne + S)$$

(before the payment of the lump-sum tax $T$). Profits are maximized when each member of the subgroup chooses an emission level $e=\varepsilon(xn\tau)$. Since all polluters behave this way, we can compute individual profits as

$$b(x,\tau) = \pi(\varepsilon(xn\tau)) - n\tau\varepsilon(xn\tau)\,. \tag{1}$$

It is easily verified that this profit is increasing with $x$, due to better internalization of cross effects. Also, the gain from being more cooperative should intuitively increase when the tax rate increases. This is indeed the case:

**Proposition 1**: $b(x,\tau)$ is increasing with $x$, and under (A) its cross-derivative with respect to $x$ and $\tau$ is positive.

The efficiency result of ambient taxes is readily extended to cooperative groups if the regulator knows the degree of cooperation (the value of $x$). Indeed:

[11] Under complete information on whether the group is cooperative or not, as is the case here, this restriction does not matter since efficiency obtains anyway. The restriction becomes relevant under incomplete information since the regulator could devise complex mechanisms aiming at learning whether a group is indeed cooperative or not.

**Proposition 2**: Under complete information on the degree of cooperation $x$, the first-best allocation is obtained by setting an ambient tax $\tau = t^*/xn$.

This result implies in particular that information on individual emissions is valueless. Interestingly the optimal ambient tax $\tau$ takes very different values, from $t^*$ for a non-cooperative group ($x$=1/$n$), to $t^*/n$ for a fully cooperative group ($x$=1). Indeed the incentive power of a given tax increases with the index of cooperation $x$, since $e=\varepsilon(xn\tau)$. This leads to qualifying some of the criticisms against an ambient tax system. For example, the difficulty associated with the practical feasibility of potentially large transfers is alleviated if the group is cooperative enough, thanks to the reduction in the necessary tax rate.[12] Notice also that the case in which polluters do not understand their impact on the measure (Cabe and Herriges, 1992) can be dealt with by letting $x$ go to zero (see the above formulas). In such a case, ambient taxes are clearly ineffective. We shall comment on this case later on.

## 4. Ambient Taxes are Inefficient under Incomplete Information

The previous Section underlined how the optimal regulation varies with the degree of cooperation in the group, under the assumption that this degree was public information. In reality, the different factors that explain cooperation are not likely to be observed by the regulator: vicinity and peer monitoring of effort, peer pressure arising from social norms, existence of another game with several equilibria (collusive or non-collusive), and so on (see Section 2). Thus, the regulator cannot *a priori* know which type agents are. This Section studies the problem of obtaining this information.

As usual in contract theory, the Revelation Principle allows us to focus on direct mechanisms. Here such a mechanism takes the form of an offer of a contract according to the degree of cooperation in the sector (as measured by the index $x$), specifying an ambient tax $\tau(x)$ and a lump-sum transfer $T(x)$. The mechanism has to satisfy the following incentive compatibility constraints (where $\tilde{x}$ denotes any other stated value other than the true value of $x$):

$$\forall x, \tilde{x} \qquad b(x, \tau(x)) + T(x) \geq b(x, \tau(\tilde{x})) + T(\tilde{x})\,.$$

The consequences for an ambient tax regulation are quite surprising:

[12] This criticism of the ambient tax is still debated. In fact, Karp (1998) has shown that the problem of excessive ambient tax payments may not arise if polluters know the tax adaptation rule and act strategically to minimize their tax payments.

**Proposition 3**: Under (**A**), any incentive-compatible ambient tax system $\tau(x)$ must be non-decreasing with respect to $x$.

Proposition 3 follows directly from the fact that the cross-derivative of $b(x,\tau)$ is positive (see Proposition 1). In economic terms, this means that more cooperative groups better manage an increase in the ambient tax, and thus must end up with a higher tax. However, from Proposition 2 we know that this is exactly the opposite of what the regulator would like to do,[13] since the optimal ambient tax, $\tau$, under complete information is $t^*/xn$. Consequently, an ambient tax regulation is severely constrained by incomplete information, and the efficiency result of an ambient tax does not extend to the case when polluters might cooperate.

This result has important consequences for the optimal regulation under incomplete information, which we now introduce informally. Because only increasing tax rates are feasible and the regulator wants the tax rates to decrease with the index of cooperation, it is likely that the optimal regulation involves some bunching: the same ambient tax is given to groups with different values of $x$, though efficiency would require differentiated values. The ambient tax must thus be set at some intermediate value, too low for non-cooperative groups and too high for cooperative ones. In other words, emissions are larger than optimal for some non-cooperative groups, and below optimal for more cooperative groups, compared to the first-best situation. This negative result calls for introducing an additional instrument, namely the costly monitoring system, in order to relax incentive compatibility constraints.

## 5. An Efficient Regulation with Ambient Tax and Monitoring

In general, the optimal regulation should propose a choice between the ambient tax or the monitoring of individual emissions together with a traditional Pigovian tax on individual emissions. Let $C$ denote the cost of a monitoring system to measure individual emissions of each firm. Because more cooperative groups better manage ambient taxes, it is likely (and we shall soon prove this result) that the less cooperative groups should opt for the emission tax, whereas more cooperative groups should opt for the ambient tax.

### 5.1. The two-type case of a non-cooperative or fully cooperative group

As an illustration, let us consider the case when the whole group can be either non-cooperative ($x$=1/$n$) or fully cooperative ($x$=1). When the monitoring cost $C$

[13] In terms of contract theory, this is a case in which the efficient allocations are not incentive compatible. This is sometimes called 'non-responsiveness'. See Guesnerie and Laffont (1984), Section 4, for a striking example.

is very high, the regulation proposes a choice between two ambient taxes, together with differentiated lump-sum transfers: $(\tau, T)$ and $(\tilde{\tau}, \tilde{T})$. Then the incentive compatibility constraints read:

$$U = b(\frac{1}{n}, \tau) + T \geq b(\frac{1}{n}, \tilde{\tau}) + \tilde{T} \quad \text{for a non-cooperative group}$$

$$\tilde{U} = b(1, \tilde{\tau}) + \tilde{T} \geq b(1, \tau) + T \quad \text{for a cooperative group}$$

where $U$ and $\tilde{U}$ are the payoffs of the non-cooperative and cooperative groups. Substracting we get

$$b(1, \tau) - b(\frac{1}{n}, \tau) \leq \tilde{U} - U \leq b(1, \tilde{\tau}) - b(\frac{1}{n}, \tilde{\tau})$$

The first inequality implies that a socially costly rent has to be left to the cooperative group, since the left-hand-side is positive from Proposition 1. The same Proposition showed that the left-hand-side is increasing with $\tau$. Therefore the regulator should react by distorting $\tau$ downwards. Also, the inequality between the profit differentials can be satisfied only if $\tau \leq \tilde{\tau}$, an additional reason for distorting $\tau$ below $t^*$; and if this constraint still binds, then $\tilde{\tau}$ should be distorted upwards (above $t^*/xn$). Overall, regulation is inefficient.

Now let us check what happens when $C$ is not too high, so that the regulator proposes a choice between monitoring of individual emissions - with an emission tax $t$ and a lump-sum transfer $T$ - and no monitoring, with an ambient tax $\tilde{\tau}$ and a lump-sum transfer $\tilde{T}$. Notice that whatever their type, groups behave in the same manner under an emission tax $t$: each member gets

$$\pi(\varepsilon(t)) - t\varepsilon(t),$$

which turns out to be equal to $b(1,t/xn)$. Therefore, the incentive compatibility constraints now read

$$U = b(1, \frac{t}{xn}) + T \geq b(\frac{1}{n}, \tilde{\tau}) + \tilde{T} \quad \text{for a non-cooperative group}$$

$$\tilde{U} = b(1, \tilde{\tau}) + \tilde{T} \geq b(1, \frac{t}{xn}) + T \quad \text{for a cooperative group}$$

The regulation also has to satisfy participation constraints. Reservation utilities $u$ are assumed to be identical for both types, which is the case if the initial situation entails no ambient tax regulation. A striking result is that the first-best allocation now can be obtained, without leaving any rent to the agents. Indeed it is easy to check that by setting $t = xn\tilde{\tau} = t^*$ and $T = \tilde{T}$, both incentive-compatible constraints are verified. Moreover we get $U = \tilde{U} = u$ by choosing a lump-sum transfer equal to $u$-$b(1,t^*/xn)$.

**Proposition 4**: When a group is either cooperative or non-cooperative, the optimal regulation offers a choice between an individual emission tax $t^*$ and an ambient tax $\tau = t^*/xn$, with the same lump-sum transfers in both cases. It is efficient, apart from the monitoring costs which are incurred when the group is non-cooperative.

To our knowledge, this type of regulation has not been derived earlier in the literature. It is quite simple, and allows the regulator to economize on monitoring costs when the group is cooperative. It is important to stress that no informational rents are left to the agents, a worthwhile consideration for a budget-constrained regulator. Notice moreover that, in this setting, polluters unable to understand their individual impact on the measure $m$ have a cooperation index $x$ equal to zero, and thus must end up with a traditional emission tax (if the cost of monitoring does not exceed the entire social surplus).

### 5.2. An extension to multiple levels of cooperation

One may wonder whether these results extend to the case when the cooperation index $x$ may take more than two values. This sub-section is devoted to the general study of the optimal regulation, when $x$ can take arbitrary values between 0 and 1. Without loss of generality, groups with $x$ belonging to some set $X$ (maybe empty) opt for monitoring of their individual emissions, with an emission tax $t$ and a lump-sum transfer $T$ (the same for all such groups, since all types behave in the same manner when facing an emission tax). Other groups should choose from a menu of ambient taxes $(\tau(x),T(x))$.

Suppose first that agent $i$ does not belong to $X$. Then $i$ must prefer the ambient tax $(\tau(x),T(x))$ to the emission tax $(t,T)$:

$$b(x,\tau(x)) + T(x) \geq b(1,t/xn) + T.$$

Now consider some $\tilde{x}$ with more cooperation: $\tilde{x} > x$. Because $b(x,t)$ is increasing with $x$, one gets

$$b(\tilde{x},\tau(x)) + T(x) > b(1,t/xn) + T.$$

Therefore any $\tilde{x} > x$ must also opt for an ambient tax. We thus have shown that the set *X* preferring the emission tax is an interval [0,x*]. All types below *x** opt for the monitoring system, and all other types opt for an ambient tax system. Consider the latter types. As above, the incentive compatibility constraint reads

$$\forall x, \tilde{x} > x^* \qquad U(x) = b(x, \tau(x)) + T(x) \geq b(x, \tau(\tilde{x})) + T(\tilde{x})$$

where *U(x)* is the payoff of each agent. Applying the envelope theorem shows that

$$\frac{dU}{dx} = b_x(x, \tau(x)) > 0 .$$

Consequently, all types above *x** get a positive rent. By reducing the lump-sum transfer *T*, one can make the participation constraint of types below *x** bind. Therefore one must have

$$b(x^*, t / nx^*) + T = u$$

and the rent of an agent with *x*>*x** is

$$U(x) = u + \int_{x^*}^{x} b_x(r, t(r)) dr .$$

Now recall that the expected surplus is

$$W = \int_0^{x^*} \left[ \pi(\varepsilon(t)) - \frac{\lambda}{1+\lambda} u - \frac{1}{n} \frac{D(n\varepsilon(t))}{1+\lambda} - C \right] dH(x)$$
$$+ \int_{x^*}^{1} \left[ \pi(\varepsilon(xn\tau(x))) - \frac{\lambda}{1+\lambda} U(x) - \frac{1}{n} \frac{D(n\varepsilon(xn\tau(x)))}{1+\lambda} \right] dH(x)$$

where *H* is the c.d.f. associated to the distribution of *x*; denote *h* the density function. Integrating by parts, we get

$$W = \int_0^{x^*} \left[ \pi(\varepsilon(t)) - \frac{1}{n}\frac{D(n\varepsilon(t))}{1+\lambda} - C \right] dH(x) - u$$
$$+ \int_{x^*}^{1} \left[ \pi(\varepsilon(xn\tau(x))) - \frac{1}{n}\frac{D(n\varepsilon(xn\tau(x)))}{1+\lambda} - \frac{\lambda}{1+\lambda}\frac{1-H(x)}{h(x)} b_x(x,\tau(x)) \right] dH(x)$$

which must be maximized with respect to $t$, $\tau(x)$, and $x^*$, under the constraint that $\tau(x)$ be non-decreasing. Now it is clear that $t$ can be set to its optimal value $t^*$. The Appendix shows additional features of the solution:

**Proposition 5:** Under incomplete information, the optimal regulation offers a choice between a monitoring system with the optimal emission tax $t^*$, and a menu of ambient taxes $\tau(x)$. The less cooperative groups choose the former, and get no rents. The more cooperative groups choose the latter. Under **(A)**, the ambient taxes are less than $t^*$; and if $\lambda$ is low enough, only one ambient tax is proposed.

This proposition extends Proposition 4 to the general case. A common feature is that monitoring costs are saved if the group is cooperative enough. This positive effect must be weighed against informational rents and the monitoring cost in order to set the right value for the threshold $x^*$. Even if the outcome is not first-best anymore (because of rents, because ambient taxes are distorted, and because of the monitoring costs), this policy remains simple and may have some practical interest.

### 5.3. An extension to the case of risk aversion

A common criticism of the ambient tax argues that the risk borne by the polluters is high due to the measurement error, and thus supports the building-up of a costly monitoring system. Indeed, with a perfect monitoring system, neither risk nor cooperation has any impact, since it is individual emissions that are taxed. To get additional insights, let us extend our setting to the case when polluters are risk-averse. As seen above, the necessary ambient tax rate is much lower under cooperation. Intuitively, the risk associated with measurement errors should be dramatically reduced. Therefore the use of a linear ambient tax can be envisioned even if agents are risk averse, under the condition that the group is cooperative enough. Indeed the following result proves this point formally:

**Proposition 6**: Assume that measurement errors are additive. If agents are risk-averse, the welfare level reached by an ambient tax system increases with the cooperation index $x$. As a consequence, an ambient tax system is used as soon as $x$ is high enough, and a monitoring system is preferred otherwise.

Consequently a typical criticism against the use of an ambient tax, that is risk-aversion, is less persuasive under cooperation. Also, the cost of a monitoring system can be avoided if cooperation is known to exist. These conclusions are reminiscent of the results in Xepapadeas (1995), but there are important differences. Xepapadeas (1995) studies a non-coooperative case, and proposes a ‘mix’ between an individual emission tax and an ambient tax, justified by the fact that agents are risk-averse, so that they are ready to pay for the monitoring of part of their individual emissions. Our conclusion differs since we show that risk-averse agents may be efficiently regulated either without any monitoring system, due to cooperative effects, or with complete monitoring of individual emissions.

## 6. A Welfare Comparison with Other Mechanisms

The mechanism we propose avoids some monitoring costs, and therefore dominates the imposition of a Pigovian tax on all groups if the monitoring cost is large enough. As we have seen in Proposition 4, our mechanism also dominates the imposition of linear ambient taxes to all groups. One may however wonder if the use of non-linear ambient taxes may restore efficiency anyway. To study this question, let us generalize the model somewhat.

Suppose that the measurement is a real-variable $m$, and that its distribution is only conditioned by the sum of emissions $Z \equiv \sum_{i=1}^{n} e_i$ . Denote $G(m;Z)$ the conditional c.d.f. of $m$ given $Z$, and assume that $G$ is smooth, with the usual dominance condition that $G$ decreases with $Z$, so that its partial derivative $G_Z \equiv \frac{\partial G(m;Z)}{\partial Z}$ is negative. A non-linear ambient tax is thus a fee paid as a function of the measure $m$, and each polluter must pay $F(m)$ when $m$ is observed. We shall assume that the function $F(m)$ is non-decreasing and bounded (but not necessarily continuous). One can then define the expected ambient tax payment conditional on $Z$ as

$$f(Z) = E[F(m)|Z].$$

Under weak regularity assumptions on the distribution $G$, a key point is that the expected payment $f(Z)$ is everywhere differentiable. This is because the measurement error smoothes the discontinuities in $F(m)$. The tax $f(Z)$ is also increasing as soon as $F(m)$ is not a constant. Now consider a fully cooperative group.[14] It chooses a common emission level $e_1$ to maximize its joint profit $n\left[\pi(e) - f(ne)\right]$, so that the necessary first-order condition yields

$$\pi'(e_1) = nf'(ne_1).$$

Concerning a non-cooperative group, the symmetric emission level $e_0$ is obtained as a Nash equilibrium: $e_0$ must maximize the individual payoff

$$\pi(e) - f((n-1)e_0 + e)$$

yielding the first-order condition

$$\pi'(e_0) = f'(ne_0).$$

Clearly these two solutions must differ. In the Appendix we show that

**Proposition 7:** Under any non-linear ambient tax, cooperative groups choose a strictly lower level of emissions than non-cooperative groups ($e_1 < e_0$).

Hence, with a non-linear ambient tax, efficiency never obtains, because emission levels are different.[15] To make these emission levels closer, one would like to increase $f'(ne_0)$ and decrease $f'(ne_1)$. This is the intuition of the scheme proposed in Hansen (1998), who advocates the introduction of a minimal payment (a floor). Such a mechanism consists in getting *f(Z)* as flat as possible for *Z* below *ne**, and as steep as possible otherwise. Clearly such a change goes in the right direction, though once more efficiency never obtains (apart from when the measurement error vanishes).

We conclude by providing a bound on the efficiency of any non-linear mechanism. The above first-order conditions are

$$\pi'(e_0) = f'(ne_0) = \int F'(m)[-G_Z(m;ne_0)]dm$$

for a non-cooperative group, and

[14] This analysis only considers the two alternative cases with all non-cooperative firms or all cooperative firms, but it could be generalized to arbitrary values for the index of cooperation.

[15] Another inefficiency is that the cooperative groups enjoy some rents which are socially costly. We do not discuss this point here.

$$\pi'(e_1) = nf'(ne_1) = n\int F'(m)[-G_Z(m;ne_1)]dm$$

for a cooperative group. Now define

$$K(Z_0, Z_1) = Inf_m \frac{G_Z(m;Z_1)}{G_Z(m;Z_0)} \geq 0.$$

Because F is non-decreasing, by choosing $Z_0 = ne_0$ and $Z_1 = ne_1$ one may apply this definition in the formulas above to get

$$\pi'(\frac{Z_1}{n}) \geq nK(Z_0, Z_1)\pi'(\frac{Z_0}{n}).$$

This formula confirms that efficiency cannot obtain as soon as $n \geq 2$, since it requires $Z_0 = Z_1 = ne^*$ which implies $K$=1. When $Z_0$ and $Z_1$ are allowed to differ, we have two cases. If $K(Z_0, Z_1)$ remains close to 1 when $Z_0$ is close to $Z_1$, then the constraint cannot hold for $Z_0$ close to $Z_1$, so that even with arbitrary non-linear taxes one can only implement emission levels which are different, in contradiction to efficiency. The case when $K(Z_0, Z_1)$ is small for $Z_0$ close to $Z_1$ is more complex and was discussed in Mirrlees (1974). It turns out that the ratio in the definition of $K$ goes to zero as $m$ goes to infinity, for most usual specifications of the error term. In this case, the best ambient tax consists in offering an arbitrarily large punishment with a probability that goes to zero; and only in this case does the above constraint vanish in the limit. Therefore it is possible to approximate efficiency. But this comes at the price of using unbounded transfers, a feature that makes the mechanism practically infeasible. Our mechanism does not rely on such features, and is practically feasible even if the distribution of the measurement error is not precisely known. This is why we shall not investigate whether a *menu* of non-linear taxes may dominate our proposal. Given the high dimensionality of such a menu, we conjecture it is the case; nevertheless the design of the menu would very much rely on the assumption that the distribution of the noise is precisely known.

## 7. Conclusion

This paper has studied the impact of cooperation on an ambient tax regulation. We have argued that for various reasons it is difficult for the regulator to observe the degree of cooperation within a group. Accordingly we have solved for the optimal regulation when the regulator is not aware of the group's type (cooperative or non-cooperative), and we have shown that it is inefficient and strongly constrained by asymmetric information. Therefore the efficiency result for ambient taxes does not extend to the case when polluters *might* cooperate. We have then introduced the possibility to monitor individual emissions at some cost. We showed that an optimal allocation of emissions is achieved by using an emission tax on non-cooperative groups and a low ambient tax on cooperative groups. Such a policy attains the first-best emission allocation and leaves no rents to the agents, but society has to incur the measurement costs borne when the group is non-cooperative. The paper thus proposes a new regulatory scheme for nonpoint source pollution that is robust to the degree of cooperation among polluters. This proposal makes it easier to counter some of the criticisms against an ambient tax: notably its effect on risk-averse agents, since the ambient tax would be lower for cooperative agents.

Finally, in order to capture the main impact of cooperation on using an ambient tax for environmental regulation, the analysis considered cooperation to be an exogenous characteristic of polluters. Two important issues left for future research are to explain the existence of cooperation, and endogenize it in a model of environmental regulation. The research on common property regimes has already made significant inroads in explaining the existence of cooperation among agents.[16] The extent to which an ambient tax might induce cooperation among polluters would be a worthwhile field to investigate by methods of experimental economics.

## APPENDIX - *Proofs*

**Proposition 1**: Compute

$$\frac{\partial b(x,\tau)}{\partial x} = (x-1)n^2\tau^2\varepsilon'(xn\tau) \quad > 0. \tag{A1}$$

$$\frac{\partial^2 b(x,\tau)}{\partial x \partial \tau} = (x-1)n^2 2\tau\,\varepsilon'(xn\tau) + x(x-1)n^3\tau^2\varepsilon''(xn\tau)$$

$$= \frac{n\tau(x-1)}{x}\left[2\varepsilon'(xn\tau)nx + \varepsilon''(xn\tau)n^2x^2\tau\right] > 0.$$

[16] See, for an introduction, the recent survey articles by Ostrom (2000) and Fehr and Gächter (2000).

since $x \in \left[\frac{1}{n},1\right]$ and the expression in brackets is negative under (A).

Q.E.D.

**Proposition 3**: If $x$ prefers $(\tau(x),T(x))$ to $(\tau(\tilde{x}),T(\tilde{x}))$, and if the opposite holds for $\tilde{x}$, then we must have

$$b(x,\tau(x))+T(x)\geq b(x,\tau(\tilde{x}))+T(\tilde{x})$$
$$b(\tilde{x},\tau(\tilde{x}))+T(\tilde{x})\geq b(\tilde{x},\tau(x))+T(x)$$

Subtracting yields

$$b(\tilde{x},\tau(x))-b(x,\tau(x))\leq b(\tilde{x},\tau(\tilde{x}))-b(x,\tau(\tilde{x})).$$

Hence the conclusion, since the cross-derivative of $b(x,\tau)$ is positive from Proposition 1. Q.E.D.

**Proposition 5**: Let us first ignore the constraint. Then the optimal ambient tax $\tau(x)$ must verify

$$\tau(x)=\frac{D'(n\varepsilon(xn\tau(x)))}{xn(1+\lambda)}+\frac{\lambda}{1+\lambda}\frac{1-H(x)}{h(x)}\frac{b_{x\tau}(x,\tau(x))}{x^2n^2\varepsilon'(xn\tau(x))}.$$

The second term is due to incomplete information. Under Proposition 1 it is negative, and thus distorts the tax below its optimal level $t^*/xn$. Notice nevertheless that if this second term does not vary too much with $x$ (and this is the case if $\lambda$ is not too high), the derivative of $\tau(x)$ is given by the derivative with respect to $x$ of the damage term, and this derivative is negative. Then there is bunching for each value of $x$, so that a single ambient tax level is proposed. It is easily seen that each term in the second integral of the surplus is decreasing with $\tau$ for $\tau$ higher than $t^*$ (and even for $\tau$ higher than $t^*/x^*n$). Therefore the value of the ambient tax is set at a lower level. Q.E.D.

**Proposition 6**: By assumption we have

$$m=\sum_i e_i+y \qquad\qquad Ey=0$$

where the distribution of the noise $y$ does not depend on emissions. In this case, the emission level chosen by an agent does not depend on its attitude towards risk, summarized by the Von Neumann-Morgenstern function $V$. Given a reservation utility $u$, the regulator's problem is

$$Max_{\tau,T} \qquad n\tau\varepsilon(xn\tau)+T-\frac{1}{n}\frac{D(n\varepsilon(xn\tau))}{1+\lambda}$$

under the participation constraint

$$EV(b(x,\tau)-T-\tau\, y)\geq u\,.$$

This constraint binds, so that $T$ is implicitly given by $EV$=$u$. Since $Ey$=0, we get

$$\frac{\partial T}{\partial\tau}=b_{\tau}-\frac{\mathrm{cov}(y,V')}{EV'} \qquad \frac{\partial T}{\partial x}=b_{x}$$

We can now derive the objective with respect to $\tau$ to get the first-order condition:

$$n\varepsilon(xn\tau)+n^{2}\tau x\varepsilon'+b_{\tau}-\frac{\mathrm{cov}(y,V')}{EV'}-\frac{D'(n\varepsilon(xn\tau))}{1+\lambda}xn\varepsilon'=0$$

Notice that from the definition (Equation 1) of $b(x,\tau)$ we have

$$b_{\tau}=\tau x^{2}n^{2}\varepsilon'-n\varepsilon-n^{2}\tau x\varepsilon'$$

so that the first-order condition reduces to

$$\tau=\frac{1}{nx}\frac{D'(n\varepsilon(x\tau))}{1+\lambda}+\frac{1}{x^{2}n^{2}\varepsilon'(x\tau)}\frac{\mathrm{cov}(y,V')}{EV'}$$

Notice that the covariance is positive if agents are risk-averse: the optimal tax is reduced by risk-aversion.

To find how the objective varies with $x$, simply use the envelope theorem and derive the objective with respect to $x$ to obtain

$$Y\equiv-\frac{D'}{1+\lambda}n\tau\varepsilon'+n^{2}\tau^{2}\varepsilon'+b_{x}\,.$$

Using (A1) to replace for $b_x$ we get

$$Y = \varepsilon' n\tau \left( xn\tau - \frac{D'}{(1+\lambda)} \right).$$

Using the value of $\tau$ found above, we finally obtain

$$Y = \frac{\tau}{x} \frac{\operatorname{cov}(y, V')}{EV'}$$

which is positive. Therefore the ambient tax dominates the emission tax for $x$ high enough. Q.E.D.

**Proposition 7**: By definition of $e_1$ we have

$$\pi(e_1) - f(ne_1) \geq \pi(e_0) - f(ne_0)$$

and by definition of $e_0$ we have

$$\pi(e_0) - f(ne_0) \geq \pi(e_1) - f((n-1)e_0 + e_1).$$

Together these inequalities yield $f((n-1)e_0 + e_1) \geq f(ne_1)$, which shows that $e_0 \geq e_1$ since $f$ is increasing by assumption. The fact that these levels are different follows from inspection of the first-order conditions. Q.E.D.

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