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THE ECONOMICS OF NONPOINT SOURCE POLLUTION

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The Economics of Nonpoint Source Pollution

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Abstract

Nonpoint source (NPS) pollution refers to the form of pollution where neither the source nor the size of specific emissions can be observed and identified with sufficient accuracy. In NPS pollution the ambient concentration of pollutants associated with the individually unobserved emissions is typically observed. NPS pollution due to agricultural run-off is a major source of water pollution, eutrophication and hypoxia. Due to informational asymmetries and stochastic effects, the use of traditional environmental policy instruments such as emission taxes or tradable quotas to regulate NPS pollution is very difficult. This chapter reviews the main theoretical approaches, up to the present, to the regulation of NPS pollution – input-based schemes, ambient schemes, and endogenous monitoring – and discusses issues associated with NPS pollution regulation and their relation to the theoretically proposed instruments.

Keywords: Diffused source pollution, input-based schemes, ambient schemes, endogenous monitoring, moral hazard, uncertainty.

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1. Introduction

Nonpoint source (NPS) pollution or diffused source pollution refers to the form of pollution where neither the source nor the size of specific emissions can be observed and identified with sufficient accuracy. Instead what is typically observed in NPS pollution is the ambient concentration of pollutants associated with the individually unobserved emissions in water bodies such as streams, lakes, estuaries, or aquifers, the ground or the air.

As described in EPA (2003 Chapter 1, p. 1-3), NPS pollution results in general "… from precipitation, land runoff, infiltration, drainage, seepage, hydrologic modification, or atmospheric deposition. As runoff from rainfall or snowmelt moves, it picks up and transports natural pollutants and pollutants resulting from human activity, ultimately depositing them into rivers, lakes, wetlands, coastal waters, and ground water."

Runoff creating NPS pollution is mainly associated with pollutants such as sediment, including silt and suspended particles; phosphorus (P) and nitrogen (N) found in fertilizers used in agriculture; and pathogens related to livestock and septic systems. The process of runoff creation and ultimate deposition in water bodies is a complex process depending on many diverse factors, both stochastic and deterministic, which is the reason why the contribution of each individual agent or potential polluter to the runoff creation and the ambient concentration of the pollutant (e.g. phosphorus in the water body) is both very difficult and also costly to measure with sufficient accuracy.

NPS pollution can be characterized by the following broad features:

- NPS discharges enter surface and/or ground waters in a diffuse manner at intermittent intervals related mostly to meteorological events.

- Pollutant generation arises over an extensive land area and moves overland before it reaches surface waters or infiltrates into ground waters.
- The extent of NPS pollution is related to uncontrollable climatic events and to geographic and geologic conditions and varies greatly from place to place and from year to year.
- The extent of NPS pollution is often more difficult or expensive to monitor at the point(s) of origin, as compared to monitoring of point source pollution.
- Abatement of NPS pollution in practice is focused on land and runoff management practices, rather than on effluent treatment.
- NPS pollutants may be transported and/or deposited as airborne contaminants.

The runoff creating NPS pollution is mainly attributed to agriculture, although other significant sources of runoff are hydromodification, which is the alteration of the hydrologic characteristics of coastal and non-coastal waters, which could in turn cause degradation of water resources (EPA 2003); and silviculture, which is associated with forest management (EPA 2005). NPS pollution is regarded as the main cause of water pollution in the United States (EPA 2007). In Europe, diffuse nutrient sources – mainly from agriculture – have adverse environmental effects in enclosed seas and sheltered marine waters across the pan-European region, creating eutrophication and hypoxia (EEA 2007).

In particular scientific research suggests that:

- NPS pollution is a major source of P and N in surface waters. The major sources of nonpoint pollution are agriculture and urban activity, including industry and transportation.
- In the US and many other nations, inputs of P and N to agriculture in the form of

fertilizers exceed outputs of those nutrients in the form of crops.

- High densities of livestock have created situations in which manure production exceeds the needs of the crops to which the manure is applied. The density of animals on the land is directly related to nutrient flows to aquatic ecosystems.
- Excess fertilization and manure production cause a P surplus, which accumulates in soil. Some of this surplus is transported in soil runoff to aquatic ecosystems.
- Excess fertilization and manure production create an N surplus on agricultural lands. Surplus N is mobile in many soils, and much leaches into surface waters or percolates into groundwater. Surplus N can also volatilize to the atmosphere and be re-deposited far downwind as acid rain or dry pollutants that may eventually reach distant aquatic ecosystems.

Eutrophication, the over-enrichment of water by nutrients such as nitrogen and phosphorus, and the resulting harmful algal blooms and hypoxia – the reduction in the concentration of dissolved oxygen in aquatic environments to levels which are detrimental to the aquatic ecosystem, is one of the major sources of pollution of coastal waters, oceans and closed seas, lakes, rivers and estuaries. Surveys by the International Lake Environment Committee Foundation (ILEC/Lake Biwa Research Institute 1988-1993) showed that 54 percent of the lakes in Asia are eutrophic; 53 percent in Europe; 48 percent in North America; 41 percent in South America; and 28 percent in Africa. The World Resources Institute (WRI n.d.) research suggests that of the 415 eutrophic and hypoxic coastal systems worldwide – which are mainly concentrated in coastal areas in Western Europe, the Eastern and Southern coasts of the US, and East Asia, particularly Japan – 169 are documented hypoxic areas, 233 are areas of concern and 13 are systems in recovery. Eutrophication has been recognized as a problem in the North Sea and the Baltic Sea, in parts of the Mediterranean, the Black Sea and the Azov Sea

(UNEP1999), the Great Lakes in North America, Lakes Dianchi and Taihu in China, Lake Victoria in Africa and in many lakes in central Europe (UNEP 2010).

NPS pollution and the associated agricultural runoff is one of the major causes of eutrophication and hypoxia, along with discharges from industries, homes, and urban and road surfaces that may also have NPS characteristics. NPS pollution is not, however, related to eutrophication and problems with water quality only. NPS airborne pollutants responsible for urban air pollution – such as carbon monoxide (CO), nitrogen oxides (NO_x), and volatile organic compounds, which are the major precursor for ozone – come from transportation, which consists of a large number of heterogeneous, with respect to fuel efficiency, and diffuse mobile sources (Roy 2004). Acidification is also related to pollutants with NPS characteristics, such as sulfur dioxide and nitrous oxides.

2. NPS Pollution Regulation and Informational Asymmetries

Although NPS pollution seems to be responsible for a large number of serious environmental problems, its regulation poses serious challenges. The main reasons are the underlying informational asymmetries between an environmental regulator and the agents who are contributing emissions to an NPS pollution problem, along with the coexisting uncertainty that can have quite a complex structure since it may be related to production technologies or natural conditions.

Informational asymmetries imply that the large number of potential sources and the diffuse character of pollution create a situation where it could be prohibitively costly for an environmental regulator, given the current state of the technology, to measure with sufficient accuracy the emissions of potential polluters as well as the polluters' abatement efforts. The regulator can only measure ambient pollutant concentration at pre-specified receptor points. It is not, however, possible to attribute any specified portion of the accumulation of the pollutant to a particular polluter when there are many polluters of the same pollutant. Furthermore, critical NPS-pollution-generating inputs or production practices may not be observable by the environmental regulator. Furthermore, even if they are partially observable at the point of application (e.g. the farm), weather uncertainty introduces stochastic shocks into the pollution dispersion process which makes the identification of the source of pollution and its individual contribution to the ambient concentration of the pollutants in the receiving environmental medium virtually impossible. Thus in NPS pollution, monitoring and measurement of individual emissions by a regulator break down and the regulator cannot attribute specific portions of the ambient concentration of the pollutant to individual sources. The actions of individual polluters are therefore hidden from the regulator and the NPS pollution problem can be regarded as a predominantly informational problem which is further exemplified by natural variability due to uncertainty (for surveys on the issue see, for example, Braden & Segerson 1993; Russel & Shogren 1993; Tomasi et al. 1994; Xepapadeas 1997a, 1997c, Chapter 4; Shortle et al. 1998; Segerson 1999; Shortle & Horan 2001).

In economic terms the informational asymmetries between the regulator and individual dischargers could be characterized as moral hazard with hidden actions and/or as adverse selection. Under moral hazard, monitoring and measurement of individual emissions, pollution abatement effort, or use of pollution generating inputs is not possible. In this case individual polluters can increase their profits by choosing lower emission levels since their actions are not observable. On the other hand, the inability to know the specific characteristics or type of each potential polluter – which is private information known only to the polluter and affects the polluters' emissions – is associated with adverse selection. Under adverse selection, individual polluters may have incentives not to reveal their types to the regulator if this is profitable.

In a situation which is characterized by these informational asymmetries, the environmental regulator cannot use the standard instruments of environmental policy such as emission taxes, tradable emission permits, deposit-refund systems (see, for example, Stavins 2003), or command and control instruments, since the successful application of these instruments requires sufficiently accurate measurement and monitoring of individual emissions. To put it differently, the standard environmental policy instruments mentioned above are applied on an emission-based principle which means charging or controlling per unit emissions discharged by the polluter into the ambient environment, according to damages generated by this unit of emissions. In this way external damages generated by pollution are internalized and a Pareto optimal outcome can in principle be attained.

These pollution problems are the so-called point source (PS) problems where the regulator has sufficient (in theory, perfect) information regarding the emissions generated by each potential polluter. That is, the source, the size and the distinctive characteristics of the emissions can be identified with sufficient accuracy at a non-prohibitive cost, which is a situation that can be identified with pollution associated with large industrial or municipal emissions.

In an NPS problem, since individual emissions cannot be observed, the standard environmental policy instruments cannot be used to internalize external damages and to obtain the Pareto optimal outcome. The potential polluters will choose higher than socially-desirable, or regulated, emission levels if by doing so they can increase their profits.

The inadequacy of the standard instruments of environmental policy to deal with

NPS problems has resulted, in recent years, in increasing effort to develop policy schemes appropriate for such problems. The environmental economics literature on NPS pollution has developed three main approaches for regulating NPS pollution problems. The general characteristic of all three is that they aim to link environmental policy instruments with observables of an NPS pollution problem.

The earliest of these approaches developed instruments that are linked to observable polluting inputs. This approach produced the so-called input-based instruments to regulate NPS pollution. Schemes based on observed ambient environmental quality or pollutant concentration were developed next and produced the so-called ambient schemes. The most recent approach focuses on the possibility of measuring, even partially, individual emissions in an NPS pollution problem by applying costly monitoring technologies. Increased observability of individual emissions in NPS pollution allows the use of standard PS pollution instruments to regulate NPS pollution to some, or even to a full, extent.

These schemes are reviewed in the remainder of this chapter. Furthermore, experimental evidence regarding the effectiveness of some of these schemes is provided, along with some evidence from application of these schemes in practice.

3. Input-Based Schemes

Input-based incentive schemes for NPS pollution were first introduced by Griffin & Bromley (1982). In the simplest possible case, when there is no uncertainty and unobservable individual emissions are perfectly correlated with a fully observed input use, then a first-best policy can be designed by appropriate taxation of the polluting input. If the ambient concentration of the pollutant is a known function of individual emissions, $X = X(E_1,\ldots,E_n)$ and individual emissions are known functions of the inputs used by each firm, or $E_i = E_i(r_{i1},\ldots,r_{im})$ where $r_i = (r_{i1},\ldots,r_{im}), i = 1,\ldots,n$ is the input vector of the *m* inputs used by the *i*th firm, and all firms are assumed identical, then the optimal input tax for the *j*th input will be $\tau_{ij} = D'(X^*)\frac{\partial X^*}{\partial E_i}\frac{E_i^*}{\partial r_{ij}}$, where $D'(X^*)$ are marginal damages at the desired ambient concentration level.

This simple case is not, however, very relevant in reality due to stochastic shocks, imperfect correlation between individual emissions and observed inputs, and other informational asymmetries. One approach to dealing with this problem was the development of combined economic-biophysical models which can be used to estimate individual emissions by relating observable inputs and measured ambient concentration of pollutants (e.g. Shortle & Dunn 1986; Dosi & Moretto 1993, 1994; Weaver 1996; Vatn 1997). If these models can be granted "political legitimacy," they can be used in principle to estimate individual contributions to ambient pollution and therefore provide the basis for designing emissions taxes or input-based taxes.

When stochastic shocks affect the transport and fate of pollutants and the polluting firms are heterogeneous with respect to productivity and their locations, implying that firms have differential impacts regarding the creation of NPS pollution (Shortle et al. 1998; see also Shortle & Abler 1994), the optimal firm specific and input specific marginal input tax in this case can be defined as:

$$\tau_{ij} = \mathrm{E}_0\left[D'\left(X^*\right)\right]\mathrm{E}_0\left[\frac{\partial X^*}{\partial E_i}\frac{E_i^*}{\partial r_{ij}}\right] + \mathrm{cov}\left[D'\left(X^*\right), \frac{\partial X^*}{\partial E_i}\frac{E^*}{\partial r_{ij}}\right], \forall i, j$$

where E_0 denotes expectation over all stochastic variables. The tax could be positive or negative (subsidy), while the covariance term acts as a risk premium or reward. The first best tax is exceptionally complex due to its firm and input specific characteristics, and potential problems due to arbitrage possibilities, so Shortle et al. provide a second-best uniform tax which economizes on transaction costs and reduces arbitrage possibilities. Schmutzler (1996) develops a mixed optimal policy scheme consisting of output and input taxes for the case where it is difficult to monitor individual emissions. Helfand and House (1995) compare uniform versus efficient input-based schemes when pollution functions vary across emission sources, while Kampas & White (2004) study the least-cost property of nitrogen taxes in an NPS pollution problem.

Input-based schemes can be extended to address NPS pollution problems under adverse selection, which is a situation where the regulator cannot observe the polluters characteristics. These characteristics are private information and by not revealing them the polluter may acquire benefits. Shortle & Abler (1994) study the case where the regulator cannot observe polluters' private characteristics such as management practices and suggest incentive mechanisms such as tax schemes and mixed schemes consisting of taxes, subsidies and permits. Laffont (1994) analyzes the problem of regulating NPS pollution under incomplete information, where both productivity characteristics (adverse selection) and cost reducing effort (moral hazard) are not observable, and characterizes optimal regulation.[2] Xepapadeas (1997b) analyzes an NPS pollution problem where the moral hazard variable is individual emissions and the adverse selection variable is polluters' (farmers') ability. Using the mechanism design approach to regulation, linear taxes on observable pollution inputs are derived and polluters choose their own tax from a menu of linear tax schedules.

[2] See also Chambers & Quiggin (1996) for the use of a principal-agent model to analyze NPS pollution regulation.

4. Ambient Schemes

Ambient schemes relate the policy instrument with the ambient concentration of the pollutant to be regulated. Segerson (1988) was the first to formulate such a scheme in the form of an ambient tax. An ambient tax is a tax imposed on all potential polluters whose individual emissions are not observed, but the outcome of their collective emissions – the ambient concentration of the pollutant – is observed either deterministically or stochastically. The ambient tax is linked with the deviation between the observed ambient concentration of the pollutant and some cut-off or desired level of ambient concentration. Once this deviation is positive then a tax per unit of deviation is paid by all potential polluters. Negative deviations may induce a subsidy.

The theoretical foundation of ambient taxes is based on Holmstrom's (1988) results on moral hazard in teams which suggest that group penalties might be efficient in ensuring that agents follow the principal's rules although the principal cannot observe agents' actions. If the tax rate is set equal to marginal damages evaluated at the socially optimal level of ambient concentration, then the individual profit maximizing polluters equate marginal benefits from emissions with marginal damages at the socially optimum, and thus they choose the optimal individual emissions levels. This is done while individual emissions are not observed. Without the ambient tax moral hazard with hidden actions would emerge, and polluters would have incentives to emit more than socially desirable, since their actions are not observed. In contrast, if the pollution problem was a PS problem a tax on individual emissions equal to marginal damages at the socially optimum – a Pigouvian tax – would produce the social optimum. Thus the same Pigouvian tax can be applied in the two polar cases of NPS and PS, but on a different basis, on ambient deviations for NPS and on individual emissions for PS. This mechanism basically drives the proposed ambient taxes scheme as well as schemes that combine ambient and emission taxes.

This result can be shown using a simplified model, which will be also helpful for subsequent presentation of results. Let the net benefit of the *i*th firm $i = 1,\ldots,n$ at each instant of time be a function of its discharges into the environment, $B_i = B_i(E_i), B' \geq 0, B'' < 0$, where $E_i \geq 0$ denotes discharges of the *i*th firm into the ambient environment (Xepapadeas 1992). Thus E_i could be the phosphorus contribution to the runoff of an agricultural unit. Let *X* be the ambient concentration of the pollutant. In a static setting, $X = g(E_i,\ldots,E_n,\mathbf{b}), \frac{\partial X}{\partial E_i} > 0$, which could indicate for example the concentration of phosphorous in a lake due to agricultural runoff, and **b** is a vector of parameters (e.g. site characteristics). Damages from ambient pollution are described by a damage function, $D(X), D' > 0, D'' \geq 0$. An environmental regulator wants to attain the socially optimal level of ambient pollution X^* by imposing on each polluter an ambient tax α_i on deviations between observed and desired ambient pollution, $X - X^*$. Thus the tax rate α_i is state independent and the ambient tax is linear. To attain X^* the regulator should choose the ambient tax to maximize total benefits from emissions less total damages. At the same time each firm should choose individual emissions so that firm' profits are maximized, given the emissions policies of the rest of the firms. The regulator's problem is:

$$\begin{aligned} &\max_{\alpha} \sum_{i=1}^{n} B_i(E_i) - D(X) \\ &\text{subject to} \\ &X = g(E_1,\ldots,E_n\mathbf{b}) \\ &E_i \in \arg\max_{E_i} \left[B_i(E_i) - \alpha\left[g(E_i\overline{\mathbf{E}}_{-i},\mathbf{b}) - X^*\right]\right] \end{aligned} \tag{1}$$

where $\overline{\mathbf{E}}_{-i}$ is the vector of emissions of all other polluters except polluter *i.* Problem (1) is called an implicit programming problem (Feinstein & Luenberger 1981) since the constraint (3) is implicitly defined by the solution of the problem X^*. The solution to this problem (see Xepapadeas 1995 for a solution to a more general problem of NPS) implies that $\alpha_i = D'(X^*)\frac{\partial X^*}{\partial E_i}$.[3] Thus the ambient tax is a Pigouvian tax imposed on ambient deviations. When the ambient tax is imposed, firms equate marginal benefits from emissions with the full marginal damages of emissions, the socially optimal ambient concentration is attained and moral hazard is eliminated. Since no uncertainty has been assumed, in equilibrium $g(E_1^*,\ldots,E_n^*,\mathbf{b}) = X^*$ and no ambient tax is paid.

When uncertainty (e.g. weather conditions) affects the processes of ambient accumulation of pollutants then the regulator maximizes expected welfare defined as $\sum_{i=1}^{n} B_i(E_i) - \mathrm{E}[D(X)]$, where E is the expectation operator. Segerson (1988) introduces a linear ambient tax scheme where the expected tax is defined as:

$$\mathrm{E}[T_i(X)] = \begin{cases} \alpha_i\left[\mathrm{E}[X] - X^*\right] + k_i\left[1 - F(X^*, X)\right], & \mathrm{E}[X] > X^* \\ \alpha_i\left[\mathrm{E}[X] - X^*\right] & , \ \mathrm{E}[X] \le X^* \end{cases}$$

where α_i is the ambient tax rate, k_i is a fixed penalty which could be imposed when expected ambient concentrations exceed desired concentrations and $F(X^*, X) = \mathrm{Prob}[X \le X^*]$. The ambient scheme is then defined, where subscripts denote partial derivatives and (*) denote evaluation at the regulator's optimum, as:

[3] When ambient concentration is just the sum of individual emissions, then $\alpha_i = \alpha = D'(X^*)$ for all *i*.

$$\alpha_i = \frac{\mathrm{E}\left[D_X^* X_{E_i}^*\right]}{\mathrm{E}\left[X_{E_i}^*\right]} \quad , \qquad k_i = 0$$

$$\alpha_i = 0 \quad , \qquad k_i = \frac{-\mathrm{E}\left[D_X^* X_{E_i}^*\right]}{\mathrm{E}\left[F_X^*\right]}$$

$$\alpha_i \text{ arbitrary} \quad , \qquad \frac{-\mathrm{E}\left[D_X^* X_{E_i}^*\right] + \alpha_i \mathrm{E}\left[X_{E_i}^*\right]}{\mathrm{E}\left[F_X^*\right]}$$

Horan et al. (1998) introduced damaged based ambient schemes and generalized Segerson's scheme to the case where firms choose inputs from a given choice set and these choices affect individual emissions and ambient concentrations. They show that the linear ambient tax is efficient in providing the correct incentives to attain the desired ambient pollution, when the choice set of firms is sufficiently small, or when marginal damages and the marginal effects of firms' choices on the distribution of the ambient pollutants are independent. They also derive for the general case: (i) efficient linear ambient taxes where the tax rate is conditional on the realization of the stochastic effects on ambient pollution, or $\alpha_i = \frac{\partial D(X^*, \eta)}{\partial X}, k_i = 0$, where η is a random variable, and (ii) efficient nonlinear state dependent ambient taxes with the tax rate depending on the ambient concentration of pollutants of the form $T_i(X) = D(X, \eta)$ for all *i*.

Damage-based ambient taxes under quite general assumptions about the damage function and the possibility of coalition formation among polluters have also been studied by Hansen (1998). Hansen (2002) introduced a variance-based ambient mechanism where the tax is a linear function of the estimated mean and standard deviation of ambient pollution.

A similar approach was adopted by Cabe & Herriges (1992) to introduce spatial considerations in the NPS problem by examining a multiple-zone system with stochastic transfers of pollutants across zones and with ambient measurements at specific zones. In this case the ambient tax is zone specific and is applied on the deviation of the ambient pollution level in a specific zone from the desired concentration at the same zone.

Static ambient tax model schemes have been extended to a dynamic setup where the stock of a pollutant accumulates in the ambient environment through a dynamic process (Xepapadeas 1992). The ambient concentration is described by a first-order differential equation of the form $\frac{dX(t)}{dt} = \sum_{i=1}^{n} E_i(t) - mX(t), X(0) = X_0$, where m reflects the environment's self cleaning capacity and the regulator seeks to choose time paths for individual emissions in order to maximize discounted benefits over an infinite time horizon, or $\int_0^{\infty} e^{-\rho t} \left[\sum_{i=1}^{n} B_i(E_i) - D(X) \right] dt$. The ambient tax rate is applied on the observed deviations between the observed and the desired pollutant stock and the scheme is defined as $\varphi(t) = \varphi\left(X(t) - X^*(t)\right)$. Individual polluters maximize discounted benefits by taking the ambient tax scheme and the decisions of the other polluters as given, subject to pollution dynamics, and by following stationary feedback or Markov perfect strategies which are defined as $E_i(X(t))$. The regulated polluter solves the problem:

$$\max_{\{E_i(t)\}} \int_0^{\infty} e^{-\rho t} \left[B_i(E_i(t)) - \phi\left[X(t) - X^*(t)\right]\right] dt$$

subject to .

$$\frac{dX(t)}{dt} = E_i(t) + \sum_{j \neq i}^{n} E_j(X(t)) - mX(t)$$

Xepapadeas (1992) shows that an efficient scheme defined as a scheme that attains the socially optimal steady state pollution accumulation X_{∞}^*, or $X(\varphi(t), t) \rightarrow X^*$ as $t \rightarrow \infty$, can be obtained by using an ambient tax rate at each point of time which is based on the shadow cost of the stock of pollution at the corresponding time. By the maximum principle this is the costate variable associated with the

Hamiltonian function of the regulator's problem. Xepapadeas (1992) extends these ambient schemes to stochastic environments where pollution accumulation is governed by an Itô stochastic differential equation.

There are two issues that need to be addressed in a dynamic setup. The first is how the desirable steady state is reached. If the target is to attain the steady state ambient pollution, the path for attaining the steady state might be different from the socially optimal and this implies welfare loss. The second is how the regulatory scheme accounts for nonconvexities in pollution dynamics, an issue which is drawing considerable attention since it provides a more realistic representation of the real world. Non-convexities imply the possibilities of multiple basins of attraction, hysteresis and irreversibilities (e.g., Mäler et al. 2003, Kossioris et al. 2008). In a recent paper Athanassoglou (2010) addresses these issues and proposes an ambient scheme which is a polynomial function of the difference between observed and desired ambient pollution that can attain the optimal path and converges at the socially optimal steady state. Under certainty no transfers in the form of taxes or subsidies are actually paid, but this result does hold in general under stochastic pollution accumulation.

Segerson & Wu (2006) developed a policy which combines a voluntary approach to control an NPS problem with the background threat of an ambient mandatory tax, which is triggered, possible retroactively, if the voluntary approach does not attain the desired ambient pollution levels.[4] If $\left(\alpha^{v},\alpha^{\alpha}\right)$ is the abatement vector of an individual polluter under the voluntary scheme and under the ambient tax scheme respectively, then the tax payments for this individual are defined as:

[4] See also Wu & Babcock (1999) where voluntary and mandatory schemes to control NPS pollution are examined as alternatives and not as a combined policy package.

$$TP = \begin{cases} 0 & \text{if } X\left(a^{v},\theta\right) \leq X^{*} \\ \alpha\left[X\left(a^{a},\theta\right)\right] & \text{if } X\left(a^{v},\theta\right) > X^{*} \end{cases}$$

where α is the ambient tax; $X(\cdot,\cdot)$ is the observed ambient pollution level under the voluntary or the ambient tax scheme; θ is a vector of the polluters' characteristics, such as farm characteristics; and $\left(X^{*},\overline{X}\right)$ are the desired and the cut-off ambient pollution level, which are not necessarily equal. It is shown that the combined voluntary-ambient scheme can obtain the desired ambient pollution level at a minimum abatement cost voluntarily. Furthermore, free riding and zero voluntary abatement can be eliminated by threatening to impose the ambient tax retroactively.

4.1 Ambient Schemes and Balance-Budgeting

One major characteristic of ambient taxes is that once the tax is triggered, when measured ambient pollution exceeds desired ambient pollution, then all potential polluters pay the tax irrespective of whether their actual, but unobserved, emissions were above or below the individually desired level. This means that when tax rates are chosen optimally, each polluter pays the full marginal damage of the difference between measured and desired ambient pollution and not just her/his share in this difference. In this way, however, total tax payments exceed pollution damages and this constitutes breaking of the balanced-budget relationship between total tax payments and total damages.[5]

The ambient tax in this case acts as a collective penalty. The collective penalty characteristics of the ambient tax are further amplified by the potential presence of a fixed penalty (Meran & Swalbe 1987, Segerson 1988). All potential polluters pay the fixed penalty if deviations between measured and desired ambient pollution are

[5] The need to break the balance in order to eliminate free riding in cases of moral hazard in teams was first shown by Holmstrom (1982).

observed and this further breaks any balanced-budget concepts.

The fact that when the ambient scheme is triggered – either in the form of tax or subsidy, total tax payments exceed the social damages of the pollution generated, or total subsidies given to individual polluters to abate pollution exceed the social benefits from abated pollution, constitutes an undesirable characteristic of the ambient schemes. Ambient taxes can be regarded as unfair while excess subsidies can induce excess entry of firms. The collective penalty and the breaking of balanced-budget property of ambient taxes, in particular, drastically reduce the political acceptability of ambient taxes and make their implementation difficult in practice.

Different types of solutions have been proposed. Following Rasmusen's (1987) development of balanced-budget contracts in cases of moral hazard in teams, Xepapadeas (1991) proposed balancing the budget by introducing an appropriately chosen fine when deviations between measured and desired ambient pollution are observed, which will be paid by a randomly selected subset of polluters. The fine will be redistributed among the rest of the polluters so that the budget is balanced. Under a balanced-budget scheme the aggregate subsidy for abating pollution will be equal to the social value of abatement and aggregate tax payments will be equal to the social damage of pollution. Herriges et al. (1994) show that if individual polluters are sufficiently risk-averse, the balanced-budget ambient scheme will provide the correct incentives for individual abatement or emissions for NPS pollution problems. Random punishments have recently been proposed (Roti Jones & Corona 2008) to supplement an ambient scheme to control invasive species emerging from the release of ballast water of ships. The punishment takes the form of randomly excluding ships from entering a port if damages exceed the cut-off level. Although the balanced-budget schemes can address the problem of unfairness or excess entry, the introduction of random penalties could undermine their acceptability as an environmental policy instrument. Alternatively the budget can be balanced with lump sum transfers or nonlinear taxes; however in this case there are tradeoffs between the size of transfers and the pollution control due to the cost of public funds (Hyde et al. 2000).

If firms recognize that their decisions affect aggregate emissions and the tax rate, then Karp (2005) shows that when strategic behavior is taken into account then firms have incentives to lower their emissions in order to lower the tax rate. This may result in a situation where the steady-state tax burden under the adjustable ambient tax is less than the burden when tax payments are based on firms' own emissions. Thus in the context of the problem analyzed by Karp (2005), firms might be better off with an ambient tax, since in this case firms are forced to behave to promote the industry's collective self-interest even though individual firms behave noncooperatively.

5. Nonpoint Source Pollution Instruments and Information Acquisition

The difficulty with the regulation of NPS pollution problems is created by the inability to acquire information about individual emissions and their actual contribution to ambient pollution as measured at specific receptor points. The ambient schemes described above provide a way to attain the desirable ambient pollution level without acquiring information about individual emissions.

Another way is to acquire information about individual emissions and in this way to transform the NPS pollution problem into a PS problem so that conventional environmental policy instruments can be applied.

Information can be acquired in general by polluters revealing information about their individual emissions or by using specific monitoring technologies. Xepapadeas (1994, 1995) analyzed an NPS pollution problem under uncertainty where risk averse polluting firms were liable for an ambient tax even if they had adjusted their emissions to the optimal level, because the actual pollution level could exceed the expected cut-off level due to random shocks. In this setup monitoring is endogenous in the sense that polluters can choose to reveal information about their own emissions, pay a traditional emission tax or effluent fee on the revealed emissions, and in exchange reduce their ambient tax liability if measured ambient levels exceed desired levels.

To connect this idea with the models in the previous sections, let the ambient concentration of pollution be a stochastic variable $\tilde{X} = X + \varepsilon$, $\mathrm{E}\varepsilon = 0, \mathrm{var}(\varepsilon) = \sigma^2$, let also $f_i(\theta_i)$ denote the amount of individual emissions revealed when monitoring effort θ_i is undertaken by agent i with $f_i(0) = 0$; τ_i an effluent fee imposed per unit of emissions; $\alpha_i(\theta_i)$ an ambient tax which takes its maximum value when $\theta_i = 0$; and $\phi_i\left(\tilde{X} - X_m^*\right), \phi(0) = 0, \phi', \phi'', \phi''' > 0$ a function of the deviation between the observed ambient pollution and the expected desired ambient pollution. When monitoring is endogenous and regulation could include both ambient and effluent fees, then firms choose individual emissions E_i and monitoring effort θ_i to maximize expected profits defined as:

$B(E_i) - \alpha_i(\theta_i)\left[\phi_i + \frac{\sigma^2}{2}\phi_i''\right] - \tau_i f_i(\theta_i)$. Then under certain condition the optimal choice for monitoring effort θ_i is positive, indicating that firms have incentive to reveal own emissions and pay an effluent fee in order to avoid being fully liable for the ambient tax.

The optimal level of individual emissions revealed is such that the extra cost that firms pay for the effluent fee equals the ambient tax liability savings. In other words, by revealing information about their own emissions by using monitoring and self-reporting, the firms are insured against the possibility of paying high ambient taxes due to random shocks.

Millock et al. (2002) follow the same line of approach and show that if monitoring technology is not regarded as infinitely costly as in the traditional NPS pollution approaches, but it is endogenized so that it becomes a choice variable for individual polluters, then as monitoring technology improves many NPS pollution problems could become PS problems. Depending on factors such as direct monitoring costs, environmental quality and the sensitivity of private profits to changes in polluting inputs, three possible regulatory approaches are analyzed: mandatory monitoring; no monitoring; and a scheme that induces agents to invest in monitoring, implying partial adoption of monitoring.

Information acquisition and learning in a budget constrained NPS pollution problem are analyzed by Kaplan et al. (2003) and applied to the Redwood Creek sediment load management program, along with a statistical analysis using a sequential entropy filter to overcome problems associated with NPS pollution data. It is shown that resources diverted from abatement to information acquisition may increase the overall abatement effectiveness. In the same context Farzin & Kaplan (2004) show that acquiring and exploiting information on heterogeneity of sediment loading distributions across polluting sources leads to a more efficient budget allocation and hence a greater reduction in pollution damage than would be the case without such information. Franckx (2002) proposes that ambient inspections can be used prior to inspecting individual firms, so that ambient levels can be used as prior information to guide the monitoring efforts of the regulator. Dinar & Xepapadeas (1998) study a dynamic NPS pollution problem associated with the regulation of water quality and quantity in irrigated agriculture where the regulatory agency acquires information through monitoring, and they conclude that the optimal path for investment in monitoring equipment suggests that investment in monitoring should be undertaken as early as possible. Romstad (2003) suggests combined ambient and individual emission based policies, which are supported by monitoring schemes as a better way to address NPS pollution problems, especially when technological progress reduces the cost of monitoring individual emissions, while Hansen & Romstad (2007) propose a self-reporting mechanism which is robust to cooperation among polluters and provides correct abatement incentives.

When firms behave strategically, in the sense that they recognize that their behavior can affect the ambient tax rate, then Karp (2005) shows that the industry's tax burden is minimized if no firm installs the equipment, or if every firm installs it.

The introduction of monitoring possibilities, which is a realistic alternative in many NPS pollution problems, puts the regulation of these problems in a different perspective since it does not have the implementation constraints of the ambient schemes, and in addition it can be used in cases where outputs or input cannot be used as proxies for regulation.

6. NPS Pollution Regulation Schemes and Experimental Evidence

The use of ambient schemes raises the issue of determining their efficiency, because of their collective fine or subsidy characteristics, and the fact that they have not been used to a large extent in practice so that empirical evidence could be analyzed. During the last decade this question was addressed by using methods of experimental economics (e.g., Spraggon 2002, 2004 ; Alpízar et al. 2004 ; Cochard et al. 2005 ; Vossler et al. 2006;

Suter et al. 2008, 2009).

Spraggon (2002) analyzed in a controlled laboratory environment the ambient schemes proposed by Segerson (1988), namely Tax-Subsidy, Tax, Subsidy, and Group Fine. He found that the instruments Tax-Subsidy and Tax are effective in attaining the environmental target without the need for costly individual monitoring, while the other two instruments, Subsidy and Group Fine, lead to multiple equilibria and cannot enforce the standard. When the study was extended to heterogeneous agents (Spraggon 2004) the results suggested inequalities among the firms' outcomes and inefficiencies. Alpízar et al. (2004) studied collective vs random fines in controlling NPS pollution and concluded that both approaches lead to efficient outcomes but the observed frequency of Nash play is lower than the theoretical predictions. Cochard et al. (2005) compared the efficiency of input-based taxes with ambient tax/subsidy, ambient tax and group fines, in an NPS pollution problem where the polluters themselves are affected by the externality. Their results show that the input tax and the ambient tax are efficient and reliable instruments. Suter et al. (2009), using ambient schemes without subsidies, suggest that the distribution of firms (polluters sizes) has an impact on group decisions and heterogeneity seems to generate desirable or undesirable outcomes depending on specific conditions.

It seems that the use of laboratory behavior to study the actual implications, acceptability and efficiency of NPS pollution instruments requires further research to capture the full extent of strategic interactions involved in NPS pollution problems. A interesting observation however in this context is that ambient tax/subsidy schemes seem to be inefficient because polluters tend to collude and use less input than the efficient level and thus overabate, because by doing so the ambient pollution tends to be below the cut-off level and in this way they can secure the subsidy. An ambient scheme without the subsidy provision seems to eliminate this problem and this could be a useful point for policy design.

Cason et al. (2003) and Cason and Gangadharan (2005) conducted laboratory experiments where landholders and potential NPS polluters compete in sealed-offer auctions to obtain part of a fixed budget allocated by a regulator to subsidize pollution abatement. They found that due to cost misrepresentation total abatement is lower when landholders know the environmental benefits of their projects, and that discriminative price auctions have superior overall market performance.

7. Applied Issues in NPS Pollution Control

The major NPS pollution problems are related to agricultural sources and contribute to environmental problems such as deterioration of applied water quality, groundwater pollution, acidification, biological oxygen demand (BOD), and eutrophication. Therefore applied regulatory policies for NPS pollution problems relate mainly to the regulation of water pollution from agricultural or other sources.

Looking at the instruments used to regulate water pollution and agricultural pollution, associations with the theoretical instruments proposed in order to control NPS pollution can be established. Although the applied instruments do not conform to the stylized characteristics of the NPS pollution instruments, some characteristics of the instruments used address observability and incentives associated with NPS pollution.

Water effluent charges, user charges for sewage and sewage treatment are used to varying degrees in many countries (OECD 1994, OECD/EEA 2010). When sewage charges are based on water used by individual agents, which provides an indirect indication of wastewater generation, then this policy can be regarded as an input-based intensive scheme, where water use is the input. In 18 countries surveyed by the OECD (1994), only nine of them charged firms on the basis of metered pollution load generated, while all households were charged on water use.

OECD (2007) reviews the use of policy instruments to regulate NPS pollution related to water pollution in OECD member countries with the main focus on agricultural nitrogen and phosphorus run-off as well as pesticides use in agriculture. In the EU, water pollution from NPS pollution sources is addressed mainly by the EU Nitrates Directive, the EU Water Framework Directive and the cross-compliance provision introduced with the 2003 CAP reform. Policy instruments used in the OECD member countries to address NPS pollution problems associated with nutrients and pesticides are mainly regulatory instruments, taxes, subsidies and informational instruments on the use of nutrients and pesticides.[6] All these are a form of input-based instruments in the terminology of the previous sections.

Cross compliance by the farmers requires ‘good agricultural and environmental conditions’ and respect for ‘statutory management requirements’. Failure of the farmers to respect these conditions can result in deductions from, or complete cancellation of, direct payments received by farmers in the context of the CAP. Cross-compliance is compulsory and all farmers receiving direct payments are subject to cross compliance.

Particular examples of NPS pollution regulation in Europe are the introduction of Nitrate Vulnerable Zones, and the Plant Protection Products Regulation and Groundwater Regulations to address pesticides use in the UK; the manure policy and the trading in manure quotas in the Netherlands; the Action Plans for Aquatic Environments aiming at reducing nitrogen leaching from agriculture in Denmark by

[6] Regulatory instruments refer to instruments which are not economic and can be associated with command and control regulation. Informational instruments like labeling schemes or other information provision schemes can enhance the effectiveness of environmental taxes, fees and charges.

introducing nitrogen quotas and subsidies for wetland and forest creation as well as phosphorus and pesticides taxes; fertilizer taxes in Sweden; pesticide taxes in the Nordic countries (OECD 2007, Hanley 2001).

Regarding the NPS pollution control policy in the USA, Ribaudo (2001) points out that NPS pollution started receiving attention by the mid-1980's as an important cause of water pollution, with the responsibility of developing NPS pollution programs given to the states. States are using enforceable best management practices (BMPs) with different levels and structures of enforceability. The mechanisms focus on design based BMPs and not on water quality or discharges because of the NPS pollution characteristics of pollutions. According to Ribaudo (2001), some states are trying to link the BMPs with observed environmental quality, by employing 'triggers' which are linked to observed conditions, or to adopt measures which are more performance-based when the relationships between the production activities and the water quality are better understood. Triggers and relation of regulation with observables of the production-pollution processes can be interpreted as structuring the regulation close to the structures implied by the theoretical models.

NPS pollution regulation is also associated with a number of off-farm management methods such as vegetation buffer strips, riparian zones or dredging of lake sediments. Ribaudo et al. (2001) proposes two strategies for controlling nitrogen loss in the Mississippi basin: reduction of the fertilizer application rates using standard methods such as taxation of inputs or subsidies for using nutrient management practices, or filtering of nutrients coming off cropland with restored wetlands. Ribaudo et al. (2005) uses data on point source dischargers and a model of the agricultural sector to develop a system of nitrogen reduction 'credits' trading among nonpoint sources to control nitrogen raining into the Gulf from the Mississippi basin.

The regulation described so far is mainly of the input-based type, although triggers related to environmental conditions and reference to ambient quality standards in water can be associated with ambient schemes. Ambient schemes are not encountered very often in practice. Segerson (1999) describes several such policies, including: (i) the Everglades Forever Act, where failure to reduce aggregate phosphorus levels causes land tax to increase; (ii) a policy for Lake Okeechobee, Florida, which taxes dairies if water quality goals are not met; (iii) the Coastal Zone Management Reauthorization Amendments; and (iv) a threat to list salmon as an endangered species unless voluntary measures succeed in restoring habitats in Oregon.

There are also examples where actual regulation relates to theoretical models. In France, according to a charge administered by 'Agence de l' Eau', firms can lower their effluent bill if they can prove that their emissions are lower than those estimated by the Agence. In fact the French water law allows firms to install monitoring equipment and pay according to their emissions instead of pre-calculated taxes based on production pollution coefficients (Millock et al. 2002). These are examples where firms opt for revealing individual emissions instead of paying exogenously determined fees which is very close to the theoretical models of incentive schemes inducing firms to reveal individual behavior.

Segerson (1999) proposes a mix of instruments for NPS pollution control which include subsidies, education and performance standards in a 'trigger' framework that is designed to induce farmers to meet ambient quality standards. It is interesting to note that the recent OECD (2007) review also concentrates on the use of instrument mixes for NPS pollution regulation.

8. Concluding Remarks

NPS pollution is undoubtedly an important pollution problem, primarily agricultural in nature, which is difficult to regulate due to inherent information asymmetries and stochastic effects. Since the early 1980's the theoretical analysis of NPS pollution regulation has gone through three major phases. The first was the use of input-based schemes, where observed polluting inputs are taxed (or their reduction is subsidized). Observed inputs are used as proxies of the unobserved individual emissions with the target being to reduce individual emissions and therefore ambient pollution by reducing the use of the polluting inputs.

The second phase was the introduction of ambient schemes, where observed ambient pollution standards in excess of what is desired or regarded as a cut-off level trigger ambient taxes, which are applied to all potential dischargers irrespective of their actual emissions. Ambient schemes could also operate with subsidies or with fixed collective fines.

The third phase was the introduction of the possibility of endogenous monitoring of individual emissions at a non-prohibitive cost so that individual dischargers could reveal part or all of their emissions, be charged for them, and reduce or eliminate ambient tax liabilities. Individual monitoring partially, or fully, transforms a nonpoint source pollution problem into a point source pollution problem.

It seems that all three schemes have advantages and disadvantages. Input-based schemes have high informational requirements, but seem to be 'fairer' relative to the ambient schemes. Ambient schemes have fewer informational requirements for the regulator, since only ambient pollution needs to be measured, but can be regarded as 'unfair taxes' due to their collective penalty characteristics. This notion of unfairness might create acceptability problems for ambient schemes. Monitoring schemes seem to overcome the 'fairness issue' but they entail monitoring costs that need to be covered. If, in addition to these complications, the issue of the relative efficiency of the instruments – an issue that has not yet been resolved by experimental approaches – and the wide variability of the characteristics of NPS pollution problems across space are taken into account, then the choice of instruments to regulate NPS pollution seems formidable.

In practice it seems that input-based instruments, either as economic instruments or as command and control instruments, are used the most with a few examples of ambient schemes. On the other hand, increasing technological capabilities might facilitate monitoring of individual discharges which contribute to NPS pollution. The existence of monitoring capabilities creates the means to transform an NPS pollution problem into a PS pollution problem and therefore the ability to regulate pollution through well-known, understood and – to a large degree – accepted environmental policy instruments, either market based or command and control. Kurkalova et al. (2004) estimate large benefits from the use of accurate NPS pollution assessment technologies, while the employment of geographic information systems (GIS) helps develop pollutant loading models (Srivastava et al. 2001) which help monitor individual emissions in an NPS pollution problem and transform it gradually into a point source problem. It seems that the use of monitoring technologies could produce an efficient way of regulating NPS pollution, but this depends on the evolution of the monitoring costs of individual emissions, since high monitoring costs financed by taxation may cause acceptability and enforcement problems. Therefore much depends on development of low cost monitoring technologies of the individual emissions which contribute to NPS pollution.

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