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The voluntary-threat approach to control nonpoint source pollution under uncertainty

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A R T I C L E I N F O

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A B S T R A C T

This paper extends the voluntary-threat approach of Segerson and Wu (2006) to the case that the ambient level of nonpoint source pollution is stochastic. It is shown that when the random component is bounded from the above, fine-tuning the cutoff value of the tax payments avoids the actual imposition of the tax while the threat of such payments retains necessary incentive for the polluters to engage in abatements at the optimal level. If the random component is not bounded, the imposition of the tax cannot be completely avoided but the probability can be reduced by setting a higher cutoff value. It is also noted that the regulator has additional flexibility in randomizing the tax imposition but the randomization process has to be credible.

1. Introduction

The regulation of nonpoint source (NPS) pollution has attracted considerable interest among agricultural and environmental economists for both its practical importance and the theoretical challenge it imposes. The U.S. Environmental Protection Agency reports that NPS pollution is the leading remaining cause of water quality problems. Unlike point source pollution, NPS pollution comes from diffuse sources and usually only the combined (ambient) level can be measured. Any policy to control NPS pollution thus must cope with the free riding problem. Also, the ambient pollution level depends on not only the activities of polluters, but also exogenous factors like rainfall and temperature. This makes the detected pollution level an imprecise measurement of polluter activities (abatements and discharges). Moreover, the implementation of any public policy, e.g., taxes or fines, entails possibly substantial information and transaction costs. All these issues must be considered in designing an incentive scheme to control NPS pollution.

Policies that encourage voluntary compliance with water quality standards such as best management practices and technical assistances have been criticized for not providing sufficient incentives from an economic perspective. In her seminal paper, Segerson (1988) proposed the use of ambient pollution taxes in controlling nonpoint pollution.[1] In this scheme, environmental quality above a given standard is rewarded but substandard quality is penalized. Although the first best outcome can be achieved theoretically, imposing an ambient tax (at the appropriate rate) incurs high information and transaction costs. To avoid the disadvantage of a pure ambient tax, Segerson and Wu (2006) introduced a mechanism combining a voluntary approach with a background threat of tax payments if the voluntary approach is unsuccessful in meeting the environmental goal. At the equilibrium, polluters voluntarily choose the cost-minimizing abatements and the tax is not actually imposed. Consequently, this "voluntary-threat" approach does not require the regulator to collect information about polluter characteristics or incur the transaction cost associated with the tax collection process. In their model, once triggered the tax is imposed for all following periods. It was noted by Suter et al. (2010) that the tax subgame may only last for a fixed number of periods as long as the magnitude of the threat is sufficient. They developed an "endogenous" version of the voluntary-threat approach by making the tax payments contingent on the firms' performance in the voluntary stage. They showed that compliance can be induced without the need of a retroactive tax as proposed in Segerson and Wu (2006).

In these voluntary-threat approaches, a critical assumption is that ambient pollution is deterministic on polluters' abatement efforts so the regulator can perfectly infer polluter activities at the aggregate level. However, as was discussed earlier, in addition to activities of the polluters, rainfall, wind, and temperature can all affect the ambient pollution level at some specific site. What the regulator observes and uses to design a policy is subject to stochastic shocks and thus an imperfect reflection of abatement efforts

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[1] Cabe and Herriges (1992), Horan et al. (1998), Hansen (2002), and Karp (2005), for example, have made extensions to this approach. Surveys on later developments of the use of ambient taxes can be found in Kling et al. (2010) and Xepapadeas (2011).

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exerted by the polluters.[2] Under the two voluntary-threat schemes, the tax subgame will be triggered whenever there is a positive shock (and then last either infinitely or for some periods) even if the polluters abate at the optimal level. The objective of this paper is to adapt the voluntary-threat approach to incorporate uncertainties. An important aspect of the adapted scheme is on how to avoid or reduce the probability of the actual imposition of the ambient tax, and thus save on the information and transaction costs.

Note that the cutoff value above which the tax payments are triggered is at the discretion of the regulator and can be different from the policy target. When the random component of the ambient pollution has a bounded support from the above, it is shown that fine-tuning the cutoff value of the tax payments avoids the actual imposition of the tax while the threat of such payments retains necessary incentive for polluters to abate at the optimal level. If instead the support is not bounded, the imposition cannot be avoided completely. But the probability can be reduced by setting a higher cutoff value and meanwhile adjusting the tax rate so that the magnitude of the threat remains at the desired level. In implementing such a policy, the regulator may further randomize the tax imposition even if the cutoff pollution level is exceeded. Nonetheless, the randomization process has to be credible for the method to work properly.

The rest of the paper is organized as follows. In Section 2, the model is set up to include a stochastic component in the ambient pollution level and the optimal design of the voluntary-threat approach is analyzed. Section 3 discusses flexibility in implementing the policy, and Section 4 concludes the paper.

2. The model

Consider a body of water which is polluted by the activities of n risk-neutral polluters. These polluters can engage in abatement efforts that reduce pollution discharges. The vector of abatement is denoted as $a = (a_1, a_2, \ldots, a_n)$, where a_i is the abatement level chosen by polluter i, $i = 1, 2, \ldots, n$. The cost of abatement for polluter i is determined by both its level of abatement and its characteristic, θ_i. Write the cost function as $C_i(a_i, \theta_i)$, and assume it is weakly convex in the abatement level: $\partial C_i(\cdot)/\partial a_i > 0$, $\partial^2 C_i(\cdot)/\partial {a_i}^2 \geq 0$. Actual pollution caused by these polluters is $x(a, \theta)$ with $\partial x(\cdot)/\partial a_i < 0$. However, due to uncertain weather conditions, the ambient pollution level detected by the regulator is an imprecise reflection of their activities: $\tilde{x}(a, \theta) = x(a, \theta) + \varepsilon$, where ε is a random component that captures exogenous factors. Suppose ε is drawn from a distribution $F(\varepsilon)$ with zero mean and probability density function $f(\varepsilon)$ which is strictly positive in all ranges considered.[3] Initially assume its support is bounded, $\varepsilon \in [\underline{\varepsilon}, \overline{\varepsilon}]$. This assumption is reasonable since ambient pollution will not be infinitely high or negative. The design of policy in the second proposition relies on that ε is bounded from the above. The case of unbounded support is also discussed at the end of the section.

Suppose the government aims to achieve, on average, some target level of water quality, x^s.[4] The cost-minimizing abatement choices $a^* = (a_1^*, a_2^*, \ldots, a_n^*)$ are obtained by solving

$$\min_{(a_1, a_2, \ldots, a_n)} \sum_{i=1}^{n} C_i(a_i, \theta_i)$$

$$\text{s.t.} E[\tilde{x}(a, \theta)] \leq x^s.$$

Assuming the second order condition holds such that a unique interior solution is implicitly defined by the following first order conditions:

$$\frac{\partial C_i(a_i^*, \theta_i)}{\partial a_i} + \lambda^*(x^s, \theta)\frac{\partial x(a^*, \theta)}{\partial a_i} = 0, i = 1, 2, \ldots, n. \quad (1)$$

The shadow cost of pollution is $\lambda^*(x^s, \theta) = -\partial C_i(a_i^*, \theta_i)/\partial a_i / (\partial x(a^*, \theta)/\partial a_i)$, which is equal for all i. Whether the targeted quality could be achieved is determined by the polluters' activities, $x(a, \theta)$. However, the policy instrument can only be based on what is observed, $\tilde{x}(a, \theta)$.

Imposing an ambient pollution tax requires the knowledge of polluter characteristics, θ_i. The information cost associated with learning the characteristics of all polluters can be quite high. Also the process of collecting the tax payments necessarily involves transaction cost such as administrative expenditures. The voluntary-threat approach of Segerson and Wu (2006) avoids these and works as follows. The regulator gives the polluters a chance to meet the standard voluntarily. If the standard is met, no further policy is imposed. However, if the standard is not met, the regulator will spend the resources to learn θ and impose a tax in all subsequent periods. Suter et al. (2010) pointed out that the tax subgame does not have to last infinitely and they used some fixed number of periods to run experimental tests. Actually, if a retroactive tax is used as a threat, the tax subgame is not even necessary. The regulator can simply threat to impose the tax each period the standard is not met. An advantage of this adaptation is that the voluntary approach is preserved even if in some period the set standard is not met due either to mistakes by polluters or severe weather conditions.

Following the literature, I restrict attention to the threat of a linear ambient tax. Consider the tax payments that polluter i faces, TP_i, at the end of each period:

$$\text{TP}_i = \begin{cases} 0 & \text{if} \tilde{x}(a, \theta) \leq \overline{x}; \\ \tau_i \cdot [\tilde{x}(a, \theta) - x'] & \text{if} \tilde{x}(a, \theta) > \overline{x}. \end{cases} \quad (2)$$

where τ_i is the ambient tax rate for polluter i, $\overline{x}$ is the cutoff level of ambient pollution, and $x' \leq \overline{x}$ is the tax payments threshold. When the ambient pollution is lower than the cutoff level, nothing happens. However, when the cutoff level is exceeded, the regulator collects the specified taxes. This game is played repeatedly regardless of what happened in the previous period. The tax payments threshold, x', and the cutoff ambient level, $\overline{x}$, are both at the discretion of the regulator and do not have to be equal. They can also differ from the target level of water quality. While Suter et al. (2010) modified the tax threshold in providing appropriate incentives, I will focus on the design of the cutoff value (besides the choice of tax rates). This additional instrument is unique to the stochastic setting since in a deterministic case there would be no incentive for the polluters to achieve x^s, if $\overline{x}$ is set to be different from it.

Facing the threat of the ambient tax in (2), polluter i's problem is then

$$\min_{a_i} C_i(a_i, \theta_i) + \int_{\overline{x}-x(a,\theta)}^{\overline{\varepsilon}} \tau_i \cdot [x(a, \theta) + \varepsilon - x'] \mathrm{d}F(\varepsilon).$$

The second term in the polluter's objective function is the expected tax payment given its abatement level. Assuming the second

[2] The regulator may monitor pollution every day but only take actions on a monthly or yearly basis based on averaged data. However, as long as the individual observations are subject to stochastic shocks, averaged data are also stochastic.

[3] Nonzero expected values of the distribution are included into the deterministic component, $x(a, \theta)$.

[4] Alternatively, the regulation may attempt to limit the probability of ambient pollution exceeding some certain hazardous level. Both approaches have been widely used in the literature (Shortle and Horan, 2001).