Voluntary-Threat Approaches to Reduce Ambient Water Pollution

Abstract

This article uses theory and experiments to investigate voluntary-threat approaches for regulating nonpoint source water pollution. The policies allow a group of polluters to voluntarily meet a pollution standard, under threat of a mandatory tax policy to be implemented in the case of noncompliance. Building upon recent work by Segerson and Wu (2006), who propose what we label an "exogenous" voluntary-threat approach, we develop an "endogenous" voluntary-threat approach wherein the severity of the threatened tax policy is increasing in the level of noncompliance in the voluntary stage. This endogenous mechanism offers theoretical advantages; in particular it can be parameterized so as to induce a unique subgame perfect Nash equilibrium and the elimination of equilibria in which firms engage in zero abatement. Experimental evidence suggests that the level of the threshold for the ambient tax and the opportunity for communication play critical roles in determining policy outcomes.

JEL: H23, Q53, C92

Keywords: Voluntary-threat approach; Ambient taxes; Nonpoint source pollution control; Laboratory experiments

Improvements in surface water quality since the passage of the Federal Clean Water Act Amendments of 1972 are primarily a result of emissions reductions from point sources, such as wastewater treatment plants and factories. While opportunities for further point source reductions remain, nonpoint source pollution presently represents the greatest share of surface water impairment in the United States (Ribaudo 2003). Agricultural production, which occurs on approximately 60% of nonfederal land in the US (USDA-ERS 2002), is the largest contributor to nonpoint source water pollution and the leading source of water quality impairments among the rivers and lakes surveyed in the 2000 *National Water Quality Inventory* (US EPA 2000).

Given the prominence of nonpoint source pollution, economic theorists have devised a number of mandatory approaches to reduce surface water pollution stemming from agricultural production. Motivated by the work of Segerson (1988), the focus in recent years has been on mechanisms that regulate a group of polluters based on measured ambient pollution levels (e.g., Xepapadeas 1991; Cabe and Herriges 1992; Hansen 1998; Horan et al. 1998; Karp 2005). These mechanisms can be used to address point source emissions, but are particularly well-suited for nonpoint settings, where it is prohibitively costly to identify and monitor firm-level emissions.

Although the economics literature on nonpoint source water pollution has mainly focused on mandatory tax approaches, policy makers have historically addressed agricultural pollution almost exclusively through voluntary measures, such as education, technical assistance, and financial assistance (Ribaudo 1998). The purely voluntary programs have been widely accepted by agricultural producers, but there is little evidence that they have delivered water quality improvements that would warrant declaring them a success (Shortle et al. 2001).

Motivated by concerns regarding the effectiveness of purely voluntary approaches to controlling agricultural pollution and the observation that voluntary programs are more effective under the threat of regulation (Ribaudo 1998), Segerson and Wu (2006) examine the theoretical properties of a policy that uses voluntary and mandatory programs as complementary instruments. Building on previous work on point source pollution control mechanisms (Segerson and Miceli 1998), the key to their approach is to motivate firms into voluntary compliance by threatening the implementation of a relatively costly mandatory policy.[1] In particular, their proposed voluntary-threat approach allows a targeted group of firms to voluntarily meet an ambient pollution standard. If, however, the standard is not met voluntarily, then the regulator imposes an ambient-based pollution tax. With an appropriately structured tax threat, Segerson and Wu show that, as in the context of point source pollution,[2] combining a voluntary approach with a regulatory threat can induce firms to make efficient abatement decisions.

While the theoretical properties of alternative policies to control nonpoint source pollution have been established, economists have recently sought to examine how effective these policies are likely to be in practice. Although there is a substantial empirical literature evaluating purely voluntary programs (e.g. Cooper and Osborn 1998; Parks and Kramer 1995; Suter et al. 2008), due to the novelty of ambient-based policies, empirical evaluation of these policies using naturally occurring data is not possible. Researchers have therefore turned to the experimental economics laboratory as an important intermediate testing ground for gaining perspective on how proposed policies might work in practice. To date, research has focused on experimental tests of mandatory ambient-based policies (e.g., Spraggon 2002, 2004; Alpizar et al. 2004; Poe et al. 2004; Cochard et al. 2005; Vossler et al. 2006; Suter et al. 2008b, 2009). The most favorable evidence from previous studies is on pure ambient tax instruments, which have been shown to engender highly efficient outcomes (Spraggon 2002, Suter et al. 2008b). However, to date, voluntary-threat approaches to controlling either point or nonpoint source pollution have not been tested. Before advocating the use of a voluntary-threat approach based on its theoretical properties, or other criteria, experimental testing is an important first step to ascertain whether such approaches are likely to be effective in practice.

This article reports the results of experiments designed to test and compare the effectiveness and efficiency of two voluntary-threat approaches for reducing nonpoint source pollution. The first voluntary-threat approach that we investigate is the policy proposed by Segerson and Wu (hereafter referred to as the "exogenous V-T"). The second approach, introduced in this paper, endogenizes the severity of the threat (hereafter the "endogenous V-T"), which offers some theoretical advantages. In particular, when taxes cannot be applied retroactively, the exogenous V-T has multiple Nash equilibria in the voluntary stage game, including a zero-abatement equilibrium. The endogenous V-T makes the severity of the threatened tax a function of the degree of noncompliance in the voluntary stage, which eliminates the zero-abatement equilibrium. Moreover, the mechanism can be specified to induce least-cost voluntary compliance as a unique Nash equilibrium. To gain further insight on the voluntary-threat approaches, our experimental design also includes pure ambient tax treatments.

Overall, our results suggest that the pure ambient tax and both voluntary-threat approaches are capable of reducing pollution below status quo levels. However, contrary to economic-theoretic expectations, tradeoffs in policy design, most notably in setting the severity of the threatened ambient tax, are likely to play a critical role in determining the effectiveness and efficiency of V-T policies. Our results clearly illustrate that increasing incentives for voluntary abatement by (effectively) threatening lower tax thresholds tends to make voluntary approaches more effective and improve the social efficiency of voluntary outcomes. However, if the pollution standard is not met voluntarily and the tax is imposed, social efficiency under the tax tends to diminish with lower tax thresholds. Further, in contrast to previous experimental investigations that suggest non-binding communication can severely decrease the efficiency of ambient tax and ambient tax/subsidy instruments, we find that non-binding communication under both voluntary-threat approaches leads to least-cost voluntary compliance in nearly all cases. In the absence of communication, voluntary compliance is only consistently observed when the threatened tax threshold is low.

Theoretical Background

We begin by defining the first-best abatement choices, using a model that closely follows Segerson and Wu (2006). Using this model, we then summarize the theoretical properties of the pure ambient tax and the exogenous V-T, and develop the properties of the endogenous V-T.

Consider a watershed in which *n* firms, indexed by *i*, pollute a common water source. Assume that abatement can be represented by a scalar, denoted a_i, and let $\boldsymbol{a} = (a_1, a_2, ..., a_n)$ denote the vector of abatement decisions by all firms. $C_i = C_i(a_i)$ is the abatement cost function, which is assumed to be twice continuously differentiable and strictly convex, with $C_i^{'}(a_i) > 0$, $C_i^{''}(a_i) > 0$ and $C(0) = 0$. Given that abatement is costly, in the absence of any policy intervention it is expected that in equilibrium $a_i = 0$ for all *i*. Ambient pollution[3] at a monitoring point, denoted by *x*, is a function of the abatement decisions of all firms, i.e., $x = x(\boldsymbol{a}) = x(a_1, a_2, ..., a_n)$ with $\partial x / \partial a_i < 0$, and $\partial^2 x / \partial a_i^2 = \partial^2 x / \partial a_i \partial a_j = 0$ for all *i* and *j*.[4] In general, both costs and expected ambient pollution will depend not only on abatement decisions but also on firm characteristics, such as slope, soil quality, and management capability, that may influence both the explicit and opportunity costs of abatement. Following Segerson and Wu, if we denote the vector of characteristics of all firms by $\boldsymbol{\theta} = (\theta_1, \theta_2, ..., \theta_n)$, then explicitly incorporating firm characteristics implies that $C_i = (a_i, \theta_i)$ and $x = x(\boldsymbol{a}, \boldsymbol{\theta})$. For simplicity of notation, we suppress the θ_i and simply incorporate heterogeneity by subscripting the cost functions by firm and allowing the values of $\partial x/\partial a_i$ to vary by firm.

A social planner is interested in meeting an exogenously determined water quality standard, which is denoted by the scalar x^s. The standard could be based on a Total Maximum Daily Load (TMDL) requirement or simply be a product of political bargaining. If we assume an interior solution, the social planner's problem can then be written as

$$\underset{\boldsymbol{a}}{Min} \sum_{i=1}^{n} C_i(a_i) \quad s.t. \quad x(\boldsymbol{a}) \leq x^s, \tag{1}$$

and the vector of optimal abatement decisions can be denoted by $\boldsymbol{a}^*$. At the optimum, $\lambda^* = -\frac{C_i'(a_i)}{\partial x/\partial a_i}$ (evaluated at a_i^*) for all *i*, where λ is the Lagrangian multiplier on the constraint in (1), which gives the marginal cost to the group of polluters of decreasing the ambient standard by one unit. We assume that x^s is set below the unconstrained water quality level, which implies that $\lambda^* > 0$, the constraint is binding, and, at the optimum, ambient pollution exactly equals the standard.

Pure Ambient Tax Policy

Under a pure ambient tax policy, firms pay a marginal tax, τ, on units of ambient pollution above a tax threshold, $\bar{x}$, where $\bar{x} \leq x^s$.[5] Thus, firm *i*'s costs in a given period are

$$C_i(a_i) + TP(\boldsymbol{a}), \tag{2}$$

where *TP(**a**)* denotes the total tax payment owed by each firm given by

$$TP(\boldsymbol{a}) = \begin{cases} 0 & if \quad x(\boldsymbol{a}) \leq \bar{x} \\ \tau \cdot (x(\boldsymbol{a}) - \bar{x}) & if \quad x(\boldsymbol{a}) > \bar{x}. \end{cases} \tag{3}$$

Note that tax payments depend on the tax threshold, $\bar{x}$, but not on the standard itself.

Importantly, changes in $\bar{x}$ do not influence a firm's marginal incentives, but do influence the total amount of tax it must pay. The regulator can therefore increase the magnitude of the tax payments by reducing $\bar{x}$ below x^s. In addition, the total tax each firm pays depends not only on its own abatement decision but also on the abatement decisions of all other firms.

The efficiency properties of a pure ambient tax policy are well-known (see, for example, Suter et al. 2008b). In particular, using the above model specification, it can easily be shown that, if $\tau = \lambda^*$, the pure ambient tax induces a unique Nash equilibrium (NE) in which all firms choose the efficient abatement levels for all $\bar{x} \leq x^s$. Thus, in equilibrium, abatement costs are minimized and ambient pollution is equal to the standard. Note that at the NE, the standard is met with equality even when the tax threshold is set below the standard, i.e., $\bar{x} < x^s$.

This would not be true, however, under a collusive equilibrium. With collusion, as long as $\bar{x} < x^s$, under the pure ambient tax the firms *as a group* have an incentive to reduce emissions below the NE, since the marginal benefit to the group of an increase in abatement by any firm is *n* times the marginal benefit to that individual firm. Thus, although the standard is met under the NE when $\bar{x} < x^s$, pollution will be less than the standard if profit maximizing firms collude effectively.[6]

The NE under the pure ambient tax for the case of *n=2* is illustrated in Figure 1, which shows the best response functions, $b_i(a_j)$, for both firms for the case where $x(a_1, a_2) = x^m - a_1 - a_2$ (where x^m is the level of ambient pollution under zero abatement) and $\bar{x} < x^s$. As shown, as long as abatement effort by the other firm is sufficiently high, each firm's best response is to abate just enough to ensure that ambient pollution is equal to the tax threshold (so that tax payments are zero). However, as abatement effort by the other firm is reduced, the firm is better off choosing a_i^* and facing positive tax payments rather than undertaking the abatement necessary to ensure that ambient pollution does not exceed the threshold. This yields the best response functions depicted in Figure 1, which intersect at only one point, the unique NE, in which abatement costs are minimized and ambient pollution is equal to the standard.

The NE under the ambient tax is important not only for understanding the theoretical properties of the tax policy but also for understanding the incentives created by the threats under the two voluntary approaches, since it determines the cost to the firm of not voluntarily complying with the standard. Given that under the tax policy all firms choose efficient abatement levels and the ambient standard is met with equality, the cost to firm *i* from one period of the tax policy is

$$C_i\left(a_i^*\right)+\tau\left(x^s-\bar{x}\right). \tag{4}$$

The firm will incur this cost in every period under the policy and, as described below, under the voluntary-threat approaches during all periods in which the tax policy is imposed following voluntary noncompliance.

Exogenous Voluntary-Threat Approach

Consider next the exogenous V-T proposed in Segerson and Wu, under which the policy maker allows firms to respond to the pollution standard voluntarily, but includes a threat of a mandatory tax policy if the standard is not achieved. Specifically, if ambient pollution is above the standard in the voluntary stage,[7] then the tax policy described above, with $\bar{x} < x^s$, is put into place for *K* periods. In Segerson and Wu, once imposed, the tax remains in effect indefinitely. Here we consider a tax that lasts for a finite number of periods, which parallels the structure of the experiments described below. In either case, as long as the costs that firms face if the tax is imposed are sufficiently high, firms will be induced to meet the standard voluntarily.

Following Segerson and Wu, it can easily be shown that, when $\bar{x}$ is sufficiently below x^s, there is a subgame perfect Nash equilibrium (SPNE) in which firms optimally choose $\{\boldsymbol{a}^{v}, \boldsymbol{a}^{t}\} = \{\boldsymbol{a}^{*}, \boldsymbol{a}^{*}\}$, where the superscripts v and t denote the abatement choice in the voluntary and tax stages, respectively. For $\boldsymbol{a}^{v} = \boldsymbol{a}^{*}$ to be part of a SPNE, $\bar{x}$ must be chosen so that for each firm $C_i\left(a_i^*\right) \leq \sum_{k=1}^{K} \delta^k \tau\left(x^s - \bar{x}\right)$, where δ is the discount factor. In words, the discounted penalty for not achieving the standard must be at least as great as the cost of abating to a_i^*.

Figure 2 depicts the firms' best response functions during the voluntary stage under the exogenous V-T with $\bar{x} < x^s$. It illustrates that, although the exogenous V-T can induce efficient voluntary abatement by all firms, this equilibrium is not unique for two reasons. First, there will also exist SPNE in which the ambient standard is achieved at greater than least cost when $\bar{x}$ is set so that at least one firm would be worse off under the tax, i.e., it is set such that $C_i\left(a_i^*\right) < \sum_{k=1}^{K} \delta^k \tau\left(x^s - \bar{x}\right)$ for some firm(s). Such a firm will strictly prefer the voluntary policy to the tax policy and will thus be willing to voluntarily abate more than a_i^* in equilibrium, implying that the aggregate costs of meeting the ambient standard are not minimized. These equilibria are illustrated by the overlapping portion of the best response functions in Figure 2. Note that this overlapping range expands as $\bar{x}$ decreases (i.e., as the threatened tax policy becomes more costly). Decreasing $\bar{x}$ increases the level of abatement a firm is willing to undertake to ensure the standard is met voluntarily. In turn, this increases the potential for another firm to reduce abatement without violating the standard and overall implies a tradeoff in the choice of the tax threshold. Setting $\bar{x}$ low relative to x^s generates a more severe penalty for the group if the standard is not achieved voluntarily. However, it opens the door to a greater range of disparity between cost-minimizing and realized abatement choices.

Second, in addition to the multiple equilibria under which the standard is met voluntarily, there is a SPNE in which all firms choose zero abatement in the voluntary stage, shown where the best response functions intersect at the origin. In past experimental analyses of ambient-based policies, groups achieved significantly lower levels of social efficiency under policies that had a zero abatement NE, in addition to a Pareto optimal NE (Spraggon 2004; Vossler et al. 2006). Unfortunately, under the exogenous V-T the choice of $\bar{x}$ alone cannot eliminate the SPNE with zero voluntary abatement.

Finally, we note that while the exogenous V-T leads to multiple Nash equilibria, there is a collusive equilibrium in which all firms abate to cost-minimizing levels and the standard is met voluntarily. Although collusion serves to weaken the threat of the tax policy in the exogenous V-T, as long as the tax threshold is set such that the cost of voluntary abatement summed across all firms is less than the cost of facing the tax, the group as a whole is better off achieving the standard voluntarily. Thus, in contrast to the pure ambient tax, collusion under the exogenous V-T can lead to a first-best outcome.

Endogenous Voluntary-Threat Approach

The third policy instrument we consider, which has not been discussed elsewhere, relies on an endogenously determined tax threshold. That is, the threshold in the tax stage is determined by the level of noncompliance in the voluntary stage, making future tax bills conditional on voluntary period behavior. This implies, for example, that even if all other firms undertake zero abatement in the voluntary stage, firm *i* has an incentive to abate to reduce its own future tax payments. Formally, let x^v and x^t represent realized ambient pollution in the voluntary and tax stages respectively and let φ be a scale factor that is freely chosen by the regulator. Then, if ambient pollution exceeds the standard in the voluntary stage, the payment due in each period of the tax stage is defined as:

$$\text{Tax Payment} = \tau \cdot \left(x^t - \widetilde{x}\right) \; where \; \widetilde{x} = x^s - \varphi\left(x^v - x^s\right) \; and \; \varphi \geq 0 \quad (5)$$

or, equivalently,

$$\text{Tax Payment} = \tau \cdot \left[x^t - x^s + \varphi\left(x^v - x^s\right)\right]. \quad (5')$$

It follows from (5') that tax payments under the endogenous V-T are equivalent to tax payments under the exogenous V-T (or the pure ambient tax) when $\overline{x} = x^s$ and $\varphi = 0$. When $\varphi > 0$, the endogenous V-T corresponds to the exogenous V-T coupled with an additional penalty that varies with the degree to which the standard is exceeded during the voluntary stage. Increasing φ lowers the tax threshold for all levels of $x^v > x^s$ and therefore increases the severity of the threatened tax policy.

In the tax stage, when $\tau = \lambda^*$, any threshold $\overline{x} \leq x^s$ will induce the unique NE $\boldsymbol{a}^t = \boldsymbol{a}^*$ and hence $x^t = x^s$. Given this, the present value of the tax payments over *K* periods following voluntary noncompliance is given by

$$\sum_{k=1}^{K} \delta^k \tau \varphi\left(x^v - x^s\right). \quad (6)$$

Note that the *K* period tax penalty in (6) can be made identical to one period of tax payment under the pure ambient tax policy by choosing a scale factor defined as $\hat{\varphi} = \left(\sum_{k=1}^{K} \delta^k\right)^{-1}$, which reduces to $\hat{\varphi} = 1/K$ when $\delta = 1$.

The equilibria generated by the endogenous V-T depend on the magnitude of φ, as summarized in the following proposition.

Proposition: *Under the endogenous V-T with* $\tau = \lambda^*$,

(i) if $\varphi > \hat{\varphi}$, *then* $\left\{\boldsymbol{a}^v, \boldsymbol{a}^t\right\} = \left\{\boldsymbol{a}^*, \boldsymbol{a}^*\right\}$ *is a SPNE but it is not unique;*

(ii) if $\varphi = \hat{\varphi}$*, then* $\{\boldsymbol{a}^{v}, \boldsymbol{a}^{t}\} = \{\boldsymbol{a}^{*}, \boldsymbol{a}^{*}\}$ *is a unique SPNE; and*

(iii) if $\varphi < \hat{\varphi}$*, then* $\{\boldsymbol{a}^{v}, \boldsymbol{a}^{t}\} = \{\boldsymbol{a}^{*}, \boldsymbol{a}^{*}\}$ *is not a SPNE.*

A formal proof of the proposition is provided in the appendix, but the intuition can be gleaned from the best response functions depicted in Figure 3. Figure 3a shows the two firm case where $\varphi > \hat{\varphi}$. The kink in the response function reflects the fact that, as under the previous two policies, if the abatement level of the other firm is sufficiently high, firm *i*'s best response will be to undertake only the abatement necessary to ensure that the standard is met voluntarily and therefore that the tax is avoided. When the other firm "under-abates" (i.e., abates less than a_j^*) and $\varphi > \hat{\varphi}$, firm *i* will be willing to "over-abate" (i.e., abate beyond a_i^*), provided the cost of doing so is still less than the cost of facing the tax. However, when the abatement level of the other firm is sufficiently low, this will not be true. In this case, firm *i*'s best response is simply to choose the level of abatement that minimizes its own costs, given that the tax will be imposed. The cost minimizing level of abatement for an individual firm depends on the magnitude of φ and will exceed a_i^* when $\varphi > \hat{\varphi}$, since the tax penalty from a marginal reduction in abatement exceeds the marginal abatement cost at a_i^*.

The willingness of one firm to over-abate when the other firm under-abates gives rise to the possibility of multiple equilibria, as depicted in Figure 3a. This stems from the fact that, with $\varphi > \hat{\varphi}$, over some range it is cheaper for a firm to incur the costs of over-abatement than to face the tax penalty. However, as φ decreases, the range over which this is true shrinks, as the vertical and horizontal portions of the best response functions move toward the origin and the two kink points move up the constraint. When $\varphi = \hat{\varphi}$, this range is reduced to a single point, namely, a_i^*, as depicted in Figure 3b, yielding a unique SPNE. As φ is reduced below $\hat{\varphi}$, the best response functions move further to the left (for b_1) or down (for b_2), yielding the unique equilibrium depicted in Figure 3c, in which abatement levels during the voluntary stage are less than the efficient levels (implying that the standard is not met and as a result the tax is imposed). It should also be noted that for all $\varphi \geq \hat{\varphi}$ the equilibrium with zero voluntary abatement is eliminated. Equilibrium voluntary abatement is also likely to be greater than zero for $0 < \varphi < \hat{\varphi}$, unless the marginal cost of abatement is sufficiently high.

Finally, group payoffs under the endogenous V-T are maximized when all firms voluntarily choose the cost-minimizing abatement levels and hence meet the standard voluntarily, as long as the threatened tax policy is sufficiently severe. In the case of the endogenous V-T, the threat parameter, φ, necessary to induce compliance under the collusive equilibrium is smaller than that required under the non-collusive SPNE. This is due to the fact that the increased cost of the tax following noncompliance in the voluntary stage is borne by all group members. Thus, as with the exogenous V-T, collusion under the endogenous V-T can lead to a first-best outcome.

Experimental Design

To test the performance of the pure ambient tax, exogenous V-T, and endogenous V-T policies, experiments were conducted at Cornell University in a designated experimental laboratory. Participants were undergraduate students who had taken at least one economics class, and the majority had previously participated in at least one (unrelated) experiment. The experimental sessions lasted approximately one hour and participants earned experimental tokens during each decision round, which were exchanged for dollars at the end of the session at the announced rate of 70,000 tokens per $1US. Overall, 240 participants took part in the experiment and individual earnings averaged approximately $20.

There are ten separate experimental treatments, with four groups of six participants in a given treatment. The experiment consists of at least 23 decision rounds and the rounds are split into Part A (rounds 1-5) and Part B (rounds 6-23). In Part A there is no ambient-based policy in place, in order to establish a pre-policy baseline. In Part B, a particular formulation of a pure ambient tax, exogenous V-T, or endogenous V-T is instituted. Preceding Parts A and B, participants read through a set of written instructions, provided in the Appendix, and view a Powerpoint presentation given by the experiment administrator.

To determine the actual number of rounds, a number between 23 and 30 is chosen at random prior to each session. Only results up through round 23 are included in our analysis. To minimize possible end-of-game effects, instructions do not indicate the number of decision rounds nor mention how the final round is determined, and the computer interface displays fields corresponding with 30 decision rounds. While the experiment is designed to minimize end-of-game effects (which is likely to be the only possible source of discounting in this context), we cannot rule out the possibility that some participants' decisions might have been influenced by perceived continuation probabilities. We discuss below the implications of this for the interpretation of our results.

In the experiment all participants face the identical abatement cost function $C(a_i)=\phi(a_i)^\alpha$. Participant emissions, r_i, are related to abatement through the function $r_i = r(a_i) = \gamma - a_i$, where γ represents the baseline level of emissions. Abatement is related to ambient pollution in a given round through the linear function $x = \sum_{i=1}^{6}(\gamma - a_i)$. To avoid the need to explain the baseline to participants, the participants' decisions are framed in terms of choosing a level of emissions rather than a level of abatement. Note that although our theoretical model allows heterogeneity across firms, our experimental design is based on homogeneous firms.

Consistent with previous experimental literature (e.g., Spraggon 2002; Vossler et al. 2006), we seek first to understand the incentives created by the different policies in this simpler context, leaving the role of heterogeneity for future study. However, the theoretical results derived under the assumption of heterogeneity also apply to the special case of homogeneous firms, and hence can still be used to predict outcomes for our experimental design.

Each participant is provided an *"Emissions Decision Sheet"* that lists the firm earnings associated with all possible levels of emissions. Table 1 lists the assumed functional forms and experiment parameters, which conform to the underlying assumptions of the theoretical model. The experiment earnings under a zero abatement strategy are calibrated to the net income of a medium sized dairy farm in New York State (Knoblauch et al. 2001–2005; Suter et al. 2009). In Part A of all treatments, each participant makes an emissions decision in an environment where the group's ambient pollution does not result in penalties to individual firms. As such, the expectation is that each participant will choose an emissions level of 20 in each round, which maximizes firm earnings. Therefore in Part A the expected ambient pollution level, given that each of the six participants chooses an emissions level of 20, is 120.

In Part B, there is an ambient-based policy designed to induce a 40% reduction in ambient pollution levels, from an unconstrained pollution level of 120 to an ambient standard, x^s, of 72. Reaching the ambient standard of 72 at least cost requires each participant to reduce their emissions to 12 units, from the unconstrained level of 20. The marginal tax, τ, is 2,500 in all treatments and at this tax rate, choosing an emissions level of 12 is a NE for all participants whenever the tax is in place, and is part of a SPNE in the voluntary stage for each V-T treatment. The tax payment, if any, in a given round is subtracted from the participant's earnings for that round. To aid decision making, a "*Tax Calculation Sheet*" is provided to participants that includes the tax payment corresponding to different levels of ambient pollution. Examples of the *Tax Calculation Sheet* and *Emissions Decisions Sheet* are included in the Appendix.

Treatments 1 and 2 test the pure ambient tax policy with tax thresholds, $\bar{x}$, of 66 and 50, respectively, with no communication. As discussed earlier, achieving the standard at least-cost is a unique NE for any threshold at or below the standard of 72. However, when the tax threshold is below the standard, the polluter *group* can maximize its payoff when participants emit fewer than 12 units. While collusive outcomes in the absence of explicit communication are not seen in recent experimental results when pollution is a stochastic function of total emissions (Suter et al. 2008b), it is an open question whether participants behave in a collusive manner without communication in a non-stochastic environment.

Treatments 3-6 test the exogenous V-T under various tax threshold and communication settings. After the five pre-policy rounds (1-5), each group begins round six in the voluntary stage of the policy. As long as ambient pollution for the group is at or below the ambient standard of 72, the voluntary policy remains in place. If ambient pollution exceeds the standard, the threatened ambient tax policy is implemented in the next round and persists for three rounds, i.e., K=3, after which groups are again given the opportunity to meet the standard voluntarily. Using three tax policy rounds allows for multiple restarts of the voluntary scenario while retaining the crux of a threat where participants pay a penalty over time for not meeting the standard, as suggested by Segerson and Wu.

In Treatments 3-5 no communication is allowed. Treatment 3 involves a threatened ambient tax with a threshold of 66, the minimum symmetric threshold that theoretically provides the necessary incentives for voluntarily abatement. In Treatment 4 the threshold is 50, providing stronger than theoretically necessary incentives for voluntary abatement, but also increasing the range of SPNE. Treatment 5 provides the most draconian threat by reducing the threshold to 0. Varying the exogenous tax threshold provides insight into the tradeoff in setting the threshold. Reducing the threshold (thereby making the tax more costly) increases the incentive to abate voluntarily but also increases the range of possible SPNE and allows for the possibility of collusive outcomes in the tax stage. Note that in each of the exogenous V-T treatments there is also a SPNE whereby each participant chooses to emit 20 units (i.e., zero abatement) in the voluntary stage.

Previous ambient-based experiments have shown that group communication has a significant impact on pollution outcomes (e.g., Poe et al. 2004; Vossler et al. 2006; Suter et al. 2008b). In addition, as discussed in the theory section, the V-T approaches can be parameterized such that least cost voluntary compliance occurs as part of a collusive equilibrium. In Treatment 6, the exogenous V-T with a threatened tax threshold of 50, under which voluntary compliance is a unique collusive equilibrium, is tested allowing groups to engage in "cheap talk" communication. Groups are allowed up to five minutes of cheap talk before rounds 6, 11, 16 and 21. During the cheap talk sessions, participants can discuss any aspect of the experiment, but are not allowed to make threats or arrange for side payments.

Treatments 7-10 test the endogenous V-T described above. Similar to the exogenous V-T, as long as groups achieve the ambient standard, the voluntary policy remains in place. If ambient pollution exceeds the standard in a voluntary round, however, then an ambient tax policy is implemented for the following three rounds. The tax threshold is determined by the degree of noncompliance in the voluntary stage. In Treatment 7, $\varphi = 1/K = 1/3$, so that for every unit of ambient pollution above the standard in the voluntary stage, the tax threshold is reduced by 1/3 of a unit below 72 in the subsequent tax policy rounds. Note that $\varphi = 1/3$ corresponds to $\varphi = \hat{\varphi}$ if there is no discounting (i.e. δ=1), and each firm choosing to emit 12 units is part of a *unique* SPNE for this treatment. While we believe that end-of-game effects should be minimal, we cannot rule out the possibility that some participants discounted future period payouts. Such discounting would, in general, weaken the incentives for voluntary compliance as it decreases the expected costs under the ambient tax. As such, Treatment 7 would correspond to the case where $\varphi < \hat{\varphi}$, implying that in equilibrium firms would under-abate (and hence not meet the standard) in the voluntary period (see Figure 3c).

Treatments 8 and 9 increase the scale parameter to $\varphi = 1$ and $\varphi = 3$ respectively, increasing the incentives for voluntary abatement. These treatments correspond to the case where $\varphi > \hat{\varphi}$, which implies that, in addition to the least cost equilibrium, there are additional SPNE under which the ambient standard is achieved voluntarily but at greater than least cost (see Figure 3a). In Treatment 10 the endogenous V-T with $\varphi = 1$ is tested under conditions of cheap talk and least-cost voluntary abatement is a unique collusive equilibrium. In all endogenous V-T treatments, the equilibrium with zero abatement is eliminated.

Experimental Results

In this section, the outcomes from the ten experimental treatments are reported. Consistent with the related experimental literature, our primary focus is on the correspondence between observed and predicted emissions choices and overall efficiency. We further investigate the probability of voluntary compliance. Except where noted, in discussing our results we refer to the corresponding theoretical predictions under the assumption of no discounting, since, with the possible exception of Treatment 7, discounting does not appear to be a reasonable explanation for any observed group under-abatement. When discussing some of the results for

Treatment 7, we specifically address the possible implications of discounting.

We begin by providing frequency distributions of individual emissions decisions across all ten treatments in Table 2. Formal statistical results are then presented in Tables 3 and 4. We also provide a graphical display of group-level emissions results for one exogenous V-T treatment and one endogenous V-T treatment in Figures 4a and 4b to provide a visual depiction of round by round outcomes. The saw-toothed nature of the emissions outcomes displayed in the two figures are indicative of the differences between decisions in the voluntary stage, where emissions tend to exceed the standard, and the tax stage, where emissions tend to fall below the standard.

Emissions

The frequency distributions of individual emissions decisions are provided in Table 2. For simplicity we report the decisions made in the non-policy rounds (Part A), aggregated across all treatments in the first column, given that there is little variance across treatments. In Part A, consistent with expectations, over 70 percent of participants choose the payoff-maximizing emissions decision of 20. In the policy rounds (Part B), there is considerable variance across treatments, despite the fact that an emissions decision of 12 is part of the relevant equilibrium in each scenario. All participants choosing an emissions level of 12 is a unique NE in the pure ambient tax policy. For the voluntary-threat policies, all participants choosing emissions of 12 in both the voluntary and tax stages is a SPNE, although other equilibria are possible in the voluntary stage. In particular, it should be noted that there exist SPNE under which abatement is zero in the voluntary stage of all of the exogenous V-T treatments. However, zero abatement is never part of a SPNE in the endogenous V-T treatments even in the presence of discounting.

Interestingly, in the ambient tax treatments and the tax stage of the exogenous V-T treatments, the modal emissions decision is, in each case, lower than 12. This reflects individual efforts towards tax avoidance as discussed in more detail below. Across the voluntary and tax stages of the endogenous V-T treatments, the modal decision is equivalent to the NE of 12 in each case, with the exception of Treatment 8, where the modal decision is 11. These results are at least indicative of greater decision-making consistency across stages and a greater propensity for optimal abatement under the endogenous V-T in comparison to the exogenous V-T.

Another means of comparing the exogenous to the endogenous V-T treatments is to look at the frequency with which participants choose zero abatement, which corresponds to emissions decisions of 20 or greater. Zero abatement is a best response under the exogenous V-T if the participant believes that other participants will under-abate, but is never a best response under the endogenous V-T. When the incentives generated by the threatened tax penalty are weak, participants choose the zero abatement strategy at a statistically higher rate of 38.9% (SE=8.1) under the exogenous V-T as compared to only 12.1% (4.5) in the endogenous V-T. At the intermediate threat level the zero abatement rate of 10.6% (4.3) under the exogenous V-T is not statistically different from the 7.8% (3.5) rate under the endogenous V-T. Finally, participants choose the zero abatement strategy when the tax threat provides the greatest incentive for voluntary abatement at a rate less than 1% for both the exogenous and endogenous V-T. Taken together, participants choose the zero abatement strategy in the voluntary stage with lower frequency as incentives are increased and participants choose zero abatement under the endogenous V-T at rates equal to or lower than under the exogenous V-T. It should be noted, however, that a non-trivial number of subjects do still choose a zero-abatement strategy in the voluntary stage of the endogenous V-T, despite the theoretical predictions to the contrary. This observed behavior could be attributable to subjects motivated by relative rather than absolute payouts, but we leave a more rigorous investigation for future study.

To facilitate hypothesis testing we use an ordinary least squares (OLS) regression model that specifies individual emissions as a linear function of a set of indicator variables, which allows estimated mean emissions to vary by treatment, and, within each treatment, to vary across non-policy (Part A) and policy rounds (Part B). To allow for a possible structural break due to factors such as learning, mean emissions are estimated separately for two aggregate policy-round groupings, rounds 6-14 and 15-23. In addition, for the voluntary-threat treatments mean emissions are allowed to vary across voluntary and tax stages.

Because OLS coefficients are consistent in the presence of cross-sectional and serial correlation inherent in panel data but the usual OLS standard errors are not, we use robust standard errors adjusted for clustering at the individual-level (i.e., "cluster-robust" standard errors). In particular we use the heteroskedasticity-autocorrelation consistent (HAC) covariance estimator of White (1984) and Arellano (1987). Monte Carlo evidence suggests that test statistics based on this covariance estimator have the correct size for panel data with a moderate number of cross-section units, under various data generating processes (Bertrand, Duflo, and Mullainathan 2004; Kezdi 2004; Vossler 2008). By clustering at the individual-level, model errors are freely autocorrelated and conditionally heteroskedastic for an individual, and this error correlation is allowed to vary across all individuals. Errors across individuals and groups are treated as independent.

Table 3 presents the parameter estimates of the Individual Emissions Model, where all estimated coefficients are interpretable simply as mean emissions for the specified treatment conditions. Echoing the frequency distribution in Table 2, and similar to previous experiments that include a no-policy baseline (e.g., Vossler et al. 2006), we find that emissions are not statistically different from the zero-abatement outcome of 20 units, with the exception of Treatment 3 where emissions are only slightly below 20. This can be taken as evidence that participants understand the decision-making framework and respond by choosing the level of emissions that maximizes their payoffs.

Turning to our analysis of emissions under the various policies, we focus on whether estimated mean emissions differ from 12. Although the focus of this article is on the performance of voluntary-threat approaches, analyzing participant emissions in the pure tax policy treatments is an important way of gauging the incentives generated by the ambient tax. The voluntary-threat approaches require that the NE strategy be chosen in the tax stage in order for the threat to be fully salient. Our overall finding for the ambient tax is that mean emissions are statistically equal to 12 when the threshold is 66, but emissions are statistically different and lower than 12 when the threshold is reduced to 50.

The low emissions level observed in the ambient tax treatment with the threshold of 50 contrasts with the findings of Suter et al. (2008b), where the tax threshold is found not to have a significant influence on average emission decisions. By reducing emissions below the NE level, participants are effectively engaging in tacit collusion, which increases payoffs to the group. One explanation for the lack of correspondence between the two studies with respect to outcomes under the ambient tax is that Suter et al. consider a case where ambient pollution is a stochastic function of emissions. Stochastic factors in the public monitoring of group behavior have been shown to make collusion more difficult in previous experimental studies (e.g., Feinberg and Snyder 2002; Aoyagi and Fréchette 2009).

The econometric results presented in Table 3 also provide evidence regarding the performance of the voluntary-threat approaches. In the absence of communication, mean emissions in the voluntary stage are generally not statistically different from 12. The three exceptions are the two treatments with weak threats (late round grouping only for the endogenous V-T) and the late rounds of the exogenous V-T with the intermediate threat: in all three cases mean emissions are significantly greater than 12. In the case of the endogenous V-T with φ=1/3 (Treatment 7), discounting is one possible reason for the observed voluntary stage under-abatement. As noted above, with discounting this policy scenario corresponds to the case where the theoretical model predicts under-abatement in equilibrium. For the tax stage, mean emissions are generally statistically different (and lower) than 12 except for the endogenous V-T with a weak or intermediate threat. Under communication, voluntary stage decisions are not significantly different from 12 in either the exogenous or endogenous V-T treatments. We note that there is no tendency for voluntary stage emissions to increase during the last few rounds of the experiment. This provides some anecdotal evidence that our experimental controls mitigated end-of-game effects.

The emissions results from the tax stage of the exogenous V-T compare closely with the analogous pure ambient tax treatments. In the late round grouping, emissions under the exogenous V-T are not statistically different from emissions under the pure ambient tax for threshold levels equal to 66 ($p = 0.43$) and 50 ($p = 0.30$). Additionally, emissions under the tax stage of the exogenous V-T decline with lower thresholds. In the late round grouping, emissions are significantly different and lower at a threshold of 50 than at a threshold of 66 ($p < 0.01$) and lower at a threshold of 0 than at a threshold of 50 ($p < 0.01$). In the tax stage of the endogenous V-T, emissions are significantly lower than the NE of 12 only when the scale factor is highest.

Finally, average emissions aggregated across all three no-communication treatments are significantly different and lower in the tax stage of the exogenous V-T compared to the endogenous V-T ($p < 0.01$). There are two plausible explanations for this outcome. First, the realized tax threshold in the endogenous V-T is closer to the ambient standard of 72 than under the exogenous V-T treatments. In Treatment 7 (φ=1/3) the average threshold is 69.3, in Treatment 8 (φ=1) the average threshold is 63.6, and in Treatment 9 (φ=3) the average threshold is 56.5. Given that participants tend to over-abate as the threshold is reduced in the pure tax setting, the higher thresholds observed under the endogenous V-T appear to be the strongest explanation for the divergence in outcomes across policies. A second possible explanation is that, because the threshold is determined after each noncompliant voluntary round, participants have to adopt a strategy for the particular realization of each threshold, making coordination more challenging. Statistical testing,[8] however, indicates that there is no difference in terms of the responsiveness of participants to changes in the threshold across the pure ambient tax, exogenous V-T, and endogenous V-T. Therefore the most plausible explanation for average emissions being closer to the ambient standard in the tax stage of the endogenous V-T is the higher realized tax thresholds.

Voluntary Compliance

Similar to our analysis of individual emissions, voluntary compliance at the group level is analyzed using a linear regression model with cluster-robust standard errors (errors are clustered at the group-level). The only included covariates are indicator variables corresponding to treatment. Because there is no notion of compliance in the no-policy rounds 1-5, corresponding data are omitted from the model. Since noncompliance in the experiment is followed by three rounds of tax policy, rounds corresponding with the tax mechanism are also excluded. In the Voluntary Compliance Model, presented in Table 4, the dependent variable is an indicator that equals 1 if the group complies with the ambient standard voluntarily (i.e. ambient pollution is less than or equal to 72) and equals 0 otherwise. The estimated coefficients are thus interpretable as treatment-specific voluntary compliance rates.

The main finding from the Voluntary Compliance Model is that allowing communication or increasing the severity of the threat increases voluntary compliance. In Treatments 3, 4, 7 and 8, where the incentives generated by the threatened tax are theoretically sufficient but not practically severe, voluntary compliance rates range from 18.2 to 61.1%. When the incentives are increased in Treatments 5 and 9, however, voluntary compliance jumps to 93.5 and 78.3%, respectively. In terms of statistical differences, compliance rates under the weakest and strongest threatened tax regimes are different under both voluntary-threat approaches; however, the intermediate threat is not statistically different. This inability to detect statistical differences is due to rather large standard errors for the two intermediate threat treatments, which in part stems from small sample sizes (groups faced the voluntary stage in only 46% of the policy rounds in Treatments 4 and 8). These results are at least suggestive that groups are responsive to the level of the threat and that only when they are confronted with a relatively consequential threat can voluntary compliance be reasonably expected.

For the two communication treatments, the ambient standard is always achieved under the voluntary policies, with the exception of one group in one voluntary round. The one observed instance of voluntary noncompliance was a result of a participant that accidentally typed in the wrong emissions decision number, as revealed in the cheap talk session immediately following. Voluntary compliance in the face of opportunities to communicate is consistent with the predicted outcome under a collusive equilibrium (as well as the outcome under the SPNE). Under both the exogenous and endogenous V-T approaches, both individual and group earnings are maximized when all individuals voluntarily choose an emissions level of 12. Therefore communication provides a strong motive for groups to achieve the standard, since each participant and the group as a whole maximize profits when the standard is achieved at least cost. This is in contrast to observed behavior in experiments where subjects either receive subsidy payments when ambient pollution is less than the ambient standard or when the tax threshold that triggers tax payments is set below the ambient standard (e.g., Vossler et al. 2006; Suter et al. 2008b). In these cases communication has been shown to result in inefficiently low emissions (i.e., over-abatement) since the group profit maximizing level of emissions is lower than the ambient standard.

Efficiency

The social efficiency measure defined initially by Spraggon (2002), and widely adopted in subsequent experimental research on ambient pollution mechanisms, jointly accounts for mean emissions deviations from the optimum as well as variation in emissions decisions across individuals. We operationalize the calculation of social efficiencies through the introduction of a linear damage function that equates the ambient standard of 72 with social optimality. In particular, since marginal abatement costs at the standard are 2,500, the damage function starts at the origin and has a slope of 2,500. Although arbitrary, our specification of the damage function allows for comparisons across individual treatments in this experiment. Such a linear damage function is also consistent with most previous experimental analyses (e.g., Poe et al. 2004; Spraggon 2004; Vossler et al. 2006; Suter et al. 2008b).

The economic surplus in a given round is determined by summing the pre-tax earnings of each of the six participants (the social benefit) less the social damage, determined by the aggregate emissions in that round. The observed surplus in treatment *m*, group *g*, and round *t*, S_{mgt}, is then measured against the surplus in the zero abatement scenario, S_{zero}, and the maximum surplus possible, $S_{\max}$, to give a measure of efficiency according to the formula

$$Social\ \ Efficiency_{mgt} = \frac{S_{mgt} - S_{zero}}{S_{\max} - S_{zero}}. \qquad (7)$$

Given the construction of the social efficiency measure, efficiency decreases as group emissions diverge from the efficient level of ambient pollution, and, given the convexity of the abatement cost function, as the variation in individual decision-making increases. The social efficiency measure is separately analyzed using linear regression with cluster-robust standard errors. The observational unit is the (group-level) efficiency measure for a particular round and errors are clustered at the group level. Efficiency is allowed to vary by treatment and, for the V-T treatments, by policy stage. The results are reported in Table 5. Pre-policy outcomes, which are consistent with the theoretical expectation of 0% efficiency, are included in the model but not reported in Table 5.

When the ambient-based policies are implemented, social efficiencies in each treatment and policy stage are significantly higher than in the pre-policy rounds with the exception of the tax stage of Treatment 5. Social efficiency is not significantly different from zero in Treatment 5 because group emissions fall significantly below the ambient standard and there is considerable variation in individual emissions choices. With the exogenous V-T in the absence of communication, social efficiencies in the voluntary stage increase with the threatened tax and decline in the tax stage with lower tax thresholds, reflecting patterns in the mean difference between optimal and observed emissions. With the endogenous V-T, social efficiency increases in the voluntary stage with the magnitude of the threat parameter, but efficiency levels in the tax stage are not significantly different across treatments, due in part to the large standard error in the estimated mean efficiency level in Treatment 9. While much of the variation in efficiency outcomes across treatments is attributable to deviations in aggregate emissions, variation in individual emissions levels is evident from direct comparisons between the pure ambient tax policies and the corresponding tax stage of the exogenous V-T. For example, when $\overline{X}$ = 66 (Treatments 1 and 3) although neither of the mean emissions levels are significantly different from each other or 12 in later rounds of the tax stage, the efficiency level is significantly different and higher in the tax stage of Treatment 3 ($p < 0.01$).

A final result from Table 5 is that, when communication is allowed, social efficiency is not significantly different from 100% in either V-T treatment. Reflecting the high level of coordination afforded by group communication, not only do groups consistently achieve the ambient standard, but there is essentially no variation in emissions decisions across participants.

Conclusion

This article provides empirical evidence, through controlled laboratory economics experiments, on the effectiveness and efficiency of three nonpoint source pollution control policies. Two of these policies, a pure ambient tax and an exogenous V-T approach, have previously been presented in the theoretical literature. The third, an endogenous V-T approach that offers some theoretical advantages over the exogenous V-T, is developed here. Both voluntary-threat approaches give the polluter group the option of meeting an ambient pollution standard voluntarily, but implement an ambient tax mechanism upon non-compliance. Importantly, from the perspective of the concluding remarks that follow, these three mechanisms can all generate appropriate incentives for groups to meet an ambient pollution standard at least cost. Our finding that this theoretical expectation is not consistently achieved in an experimental setting reinforces previous research in this area.

Of course, any policy conclusions drawn from our results are subject to the usual caveats connected with the use of a relatively simple experimental design and student participants.

Nonetheless, our experimental results suggest the existence of some tradeoffs not implied by theory. The most evident tradeoff relates to the level of the threshold associated with the threatened ambient tax, which plays a critical role in determining the policy outcomes. Increasing the incentives for voluntary compliance by (effectively) lowering the tax threshold in either the exogenous or endogenous V-T appears to have two effects: a) voluntary compliance increases with the severity of threat, as would be expected; and b) should the threatened tax be enacted, emissions and efficiency fall as the difference between the tax threshold and the ambient pollution standard increases. Thus, although a lower tax threshold is more likely to induce voluntary compliance, if the threat is not successful in preempting the tax, the result is likely to be over-abatement in the tax stage (consistent with results from the pure ambient tax).

We further find that non-binding, "cheap talk" communication, such as that which might occur in a small watershed (Weersink et al. 1998), enhances the performance of the voluntary-threat approaches. This contrasts with results under other ambient pollution control mechanisms where communication drives group outcomes away from the social optimum, both theoretically (i.e., under a collusive equilibrium) and in experimental settings. For example, Vossler et al. (2006) demonstrate that cheap talk can push pollution levels in tax/subsidy mechanisms drastically below optimal levels, leading to a situation where implementation of the policy actually decreases efficiency. Suter et al. (2008b) show that, for damage-based tax mechanisms with varying thresholds below the ambient standard, marginal tax rates have to be adjusted for communication levels in order to achieve the desired ambient standard in experimental settings.

In the case of the voluntary-threat approaches investigated here, communication reinforces the incentives laid out for both individuals and groups to voluntarily meet the desired ambient standard at least cost. The intuition behind this is that individuals as well as the group as a whole are better off when the standard is achieved voluntarily. Since there are no additional monetary benefits to over-abatement in the voluntary stage, the group maximizes profits by exactly achieving the standard. In contrast, under the ambient-based policies investigated in Vossler (2006) and Suter et al. (2008b), by reducing pollution below the standard groups benefit in the form of increased subsidies or lower tax payments, and as a result communication provides a catalyst through which to coordinate on over-abatement strategies. Given the benefits of communication under the voluntary-threat approaches, efforts to enhance communication can help push individuals toward choices that are both socially desirable and in their own best interests. The best approach for fostering communication is not entirely clear, but one possibility is to encourage the formation of producer-based watershed organizations.

Conclusions regarding the relative effectiveness and efficiency of voluntary-threat approaches could be bolstered by future research on variations of the policies tested here. Specifically, a better understanding of the tradeoffs between changing the number of threatened tax policy rounds (K) and increasing the severity of the tax in each of the tax policy rounds could provide important information. In addition, the policy relevance of this research could be improved by investigating empirically situations where participants are heterogeneous in terms of their baseline contributions to ambient water quality and the structure of their abatement costs. Finally, extending the theory of the voluntary-threat approaches studied here to allow ambient pollution to be stochastic is an important future step towards improving their policy relevance.

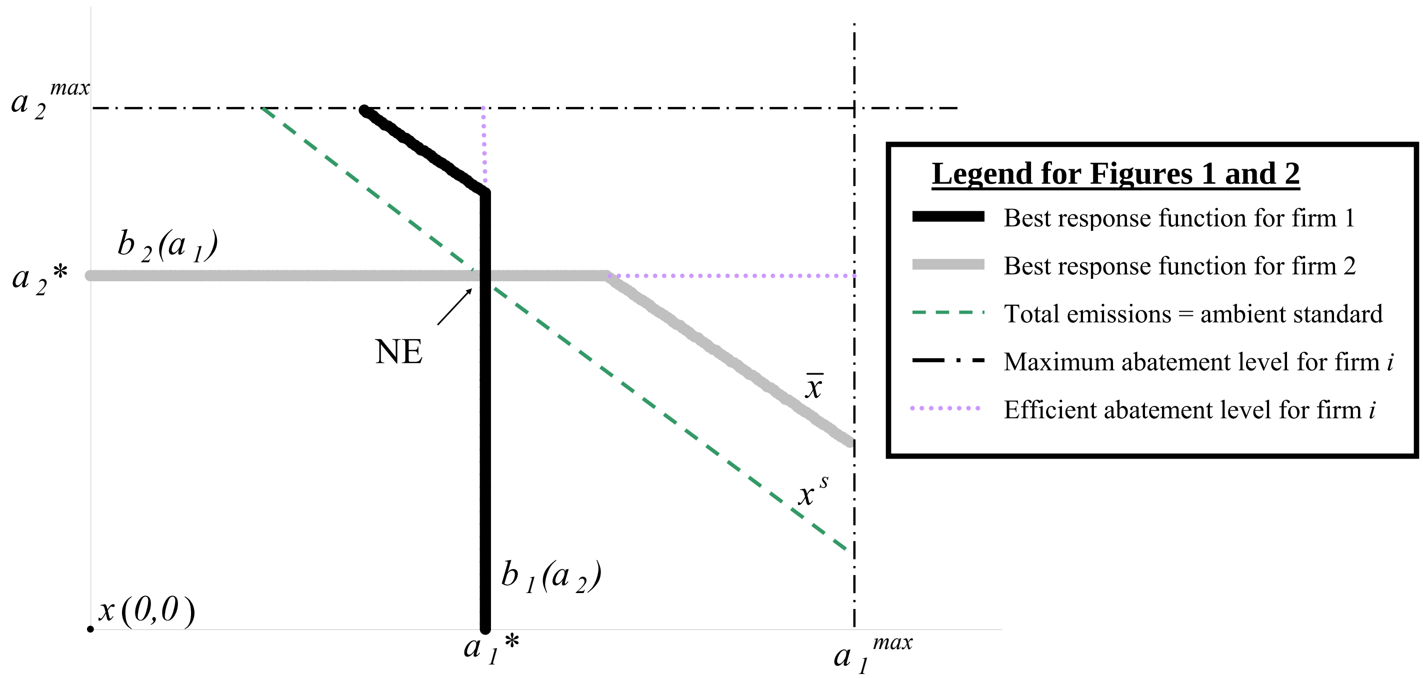

Figure 1 Best response functions for two firms facing pure ambient tax with $\bar{x} < x^s$

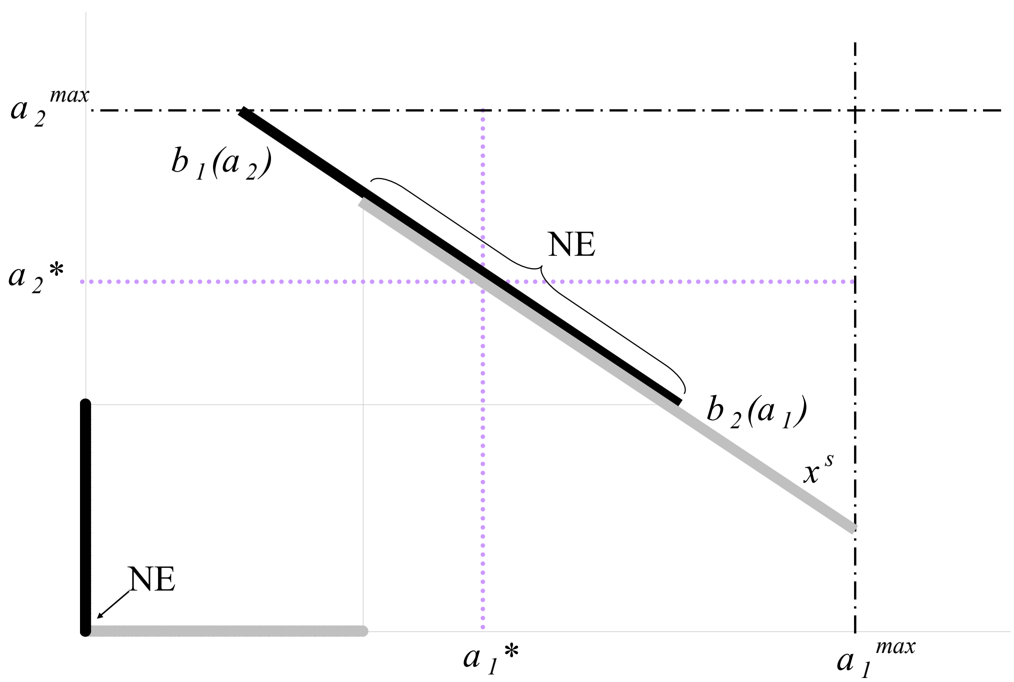

Figure 2 Best response functions for two firms in voluntary stage: Exogenous V-T

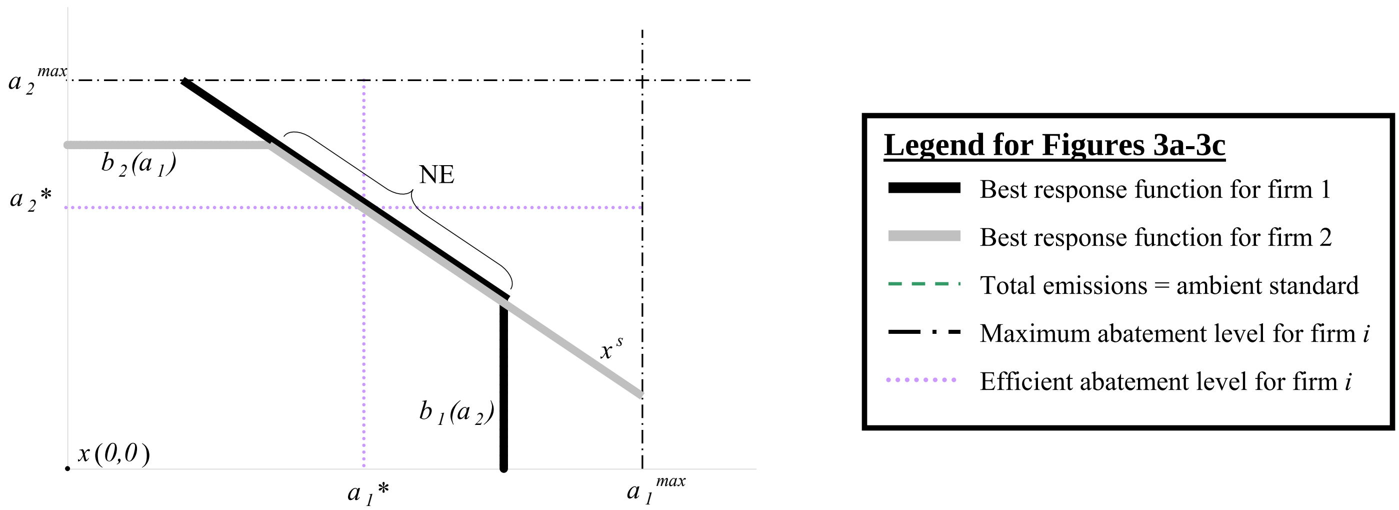

Figure 3a Best response functions for two firms in voluntary stage: Endogenous V-T, $\varphi > \hat{\varphi}$

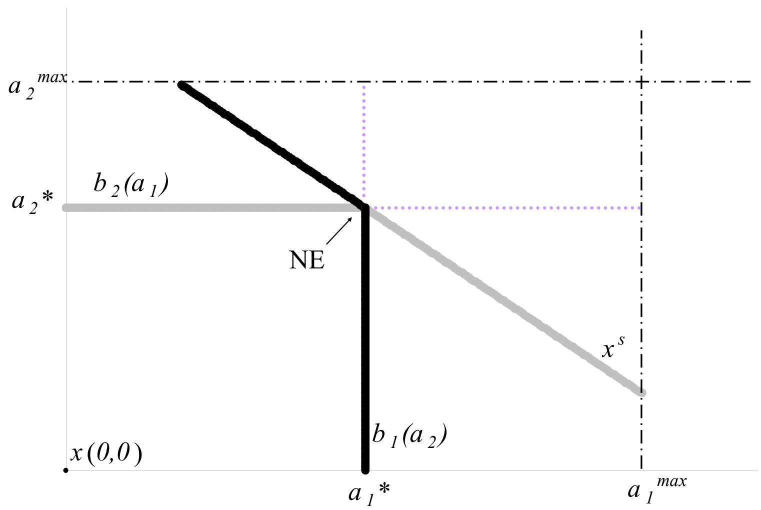

Figure 3b Best response functions for two firms in voluntary stage: Endogenous V-T, $\varphi = \hat{\varphi}$

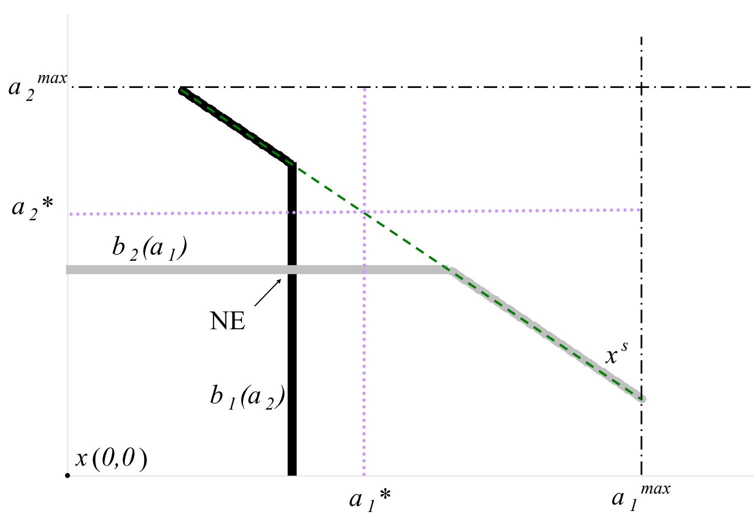

Figure 3c Best response functions for two firms in voluntary stage: Endogenous V-T, $\varphi < \hat{\varphi}$

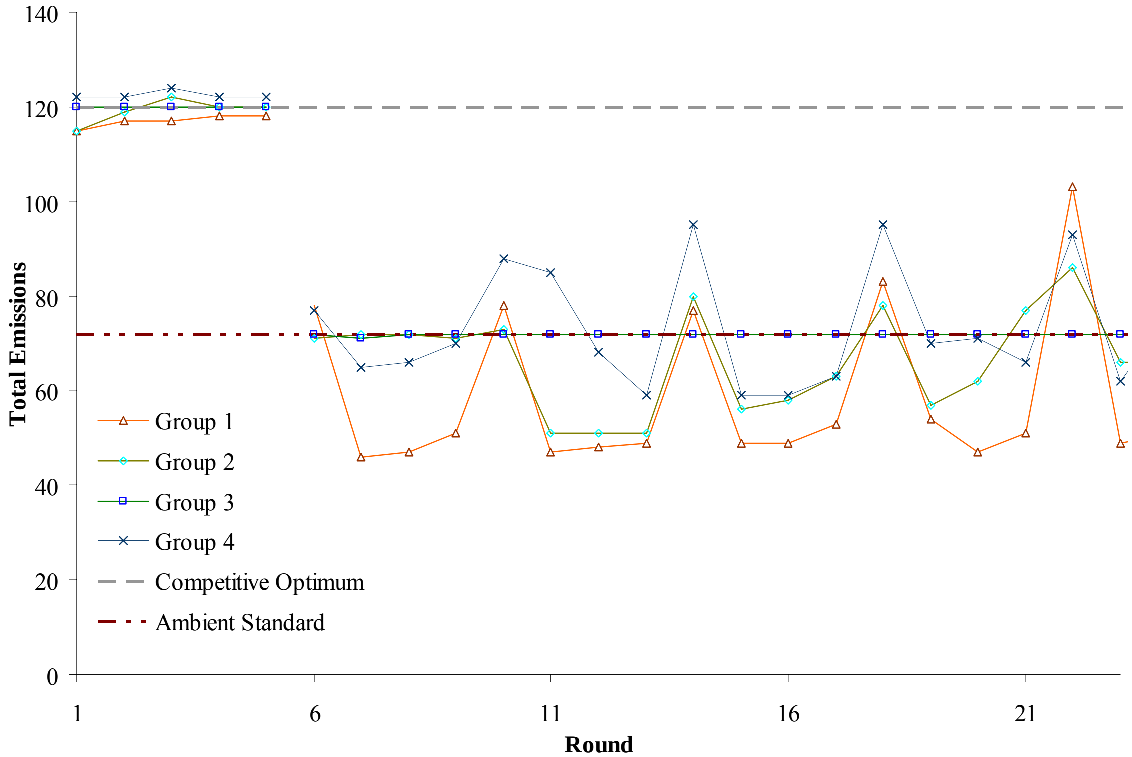

Figure 4a Total emissions by round in Treatment 4: Exogenous V-T, $\bar{x} = 50$

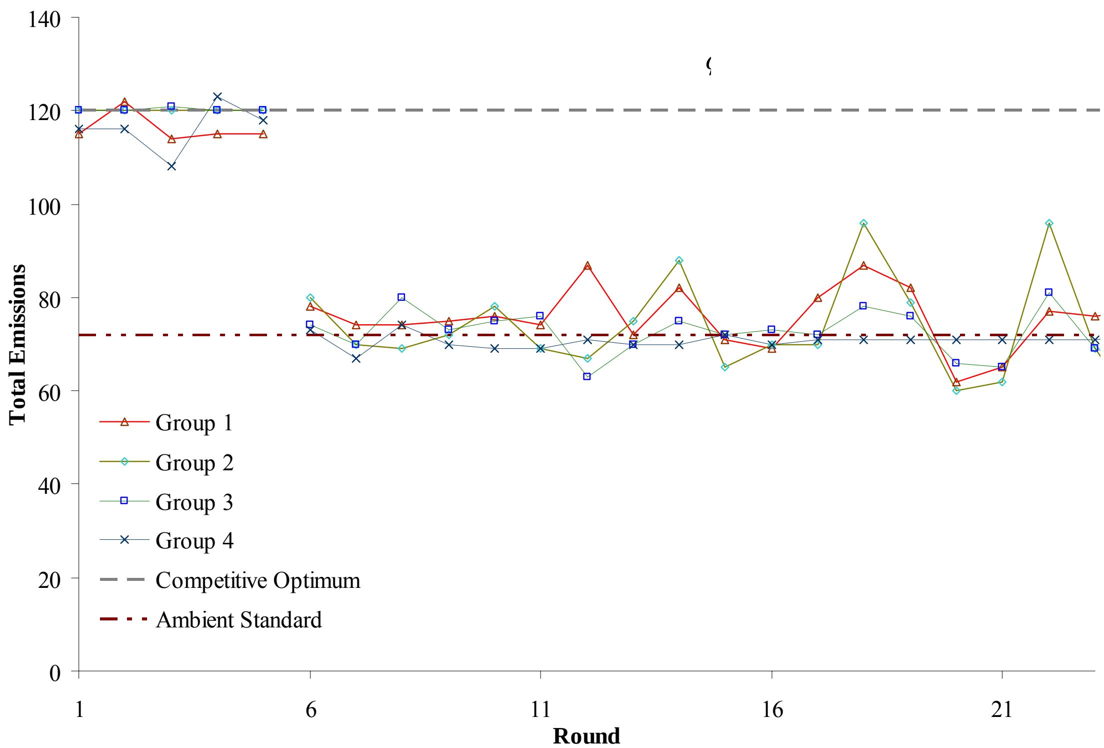

Figure 4b Total emissions by round in Treatment 8: Endogenous V-T, $\varphi = 1$

Table 1 Experimental Parameters

Description	Functional Form	Parameter Values
Abatement Cost Function	$\phi(a_i)^\alpha$	ϕ = 13.02; α = 3
Firm Earnings	$Y = Y^0 - \phi(a_i)^\alpha$	Y^0 = 75,000
Firm Level Emissions	$r_i = \gamma - a_i$	γ = 20
Ambient Pollution	$x = \sum_{i=1}^{n}(\gamma - a_i)$	n = 6

Table 2 Frequency Distribution of Individual Emissions Decisions

Emissions	**Part A**	**Pure Tax**		**Exogenous V-T**								**Endogenous V-T**						
		T 1	**T2**	**T3**		**T4**		**T5**		**T6**		**T7**		**T8**		**T9**		**T10**
		Tax $\bar{x}=66$	Tax $\bar{x}=50$	Vol	Tax $\bar{x}=66$	Vol	Tax $\bar{x}=50$	Vol	Tax $\bar{x}=0$	Vol (Com)	Tax $\bar{x}=50$ (Com)	Vol	Tax $\varphi=1/3$	Vol	Tax $\varphi=1$	Vol	Tax $\varphi=1/3$	Vol
3	1	0	5	0	0	0	0	0	**10**	0	0	1	0	0	2	0	6	0
4	1	3	1	1	0	0	0	0	3	0	0	0	0	0	0	0	2	0
5	2	13	2	3	0	0	2	1	6	0	0	3	6	0	1	0	1	0
6	1	6	8	1	0	0	8	2	8	0	1	0	5	0	1	2	6	0
7	1	4	34	1	0	0	18	15	2	0	0	2	8	0	1	4	32	0
8	2	9	**100**	0	2	1	**82**	0	6	0	**12**	4	9	0	17	4	13	0
9	0	4	61	0	8	1	34	2	0	0	1	2	9	3	21	4	12	0
10	5	16	96	4	18	3	10	24	**10**	0	1	3	29	17	33	12	11	0
11	3	**195**	35	3	**206**	18	7	22	3	0	0	17	47	5	**76**	30	10	0
12	2	57	22	**55**	23	**165**	19	**263**	7	**413**	3	**43**	**76**	**115**	42	**160**	**36**	**432**
13	24	32	7	9	6	3	14	26	0	0	0	13	19	16	9	34	14	0
14	12	9	2	1	13	0	13	7	0	0	0	4	17	2	7	18	3	0
15	18	16	11	8	4	0	0	6	0	0	0	12	21	1	10	3	2	0
16	21	23	18	1	2	1	0	2	1	0	0	5	20	4	7	0	0	0
17	26	13	2	0	1	0	0	0	0	0	0	4	12	1	0	0	0	0
18	26	8	2	1	1	0	0	0	0	0	0	2	9	2	2	0	0	0
19	49	2	10	0	0	1	0	0	0	1	0	1	1	0	2	0	0	0
20	**940**	15	14	51	4	20	9	1	3	0	0	16	12	13	19	1	8	0
21	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	173	7	2	5	0	3	0	1	1	0	0	0	0	1	2	4	0	0
Total	*1320*	*432*	*432*	*144*	*288*	*216*	*216*	*372*	*60*	*414*	*18*	*132*	*300*	*180*	*252*	*276*	*156*	*432*

Notes: Emboldened numbers in each column represent the modal decision for that treatment.

Table 3 Individual Emissions Model

Dependent variable: individual participant emissions
Number of observations: 5,520 $R^2 = 0.97$

Treatment		Pre-Policy	Policy Stage	Policy Rounds 6-14	Policy Rounds 15-23
Pure Ambient Tax	1 $\bar{x}$=66	19.44 (0.31)	Tax	12.27 (0.47)	12.01 (0.42)
	2 $\bar{x}$=50	19.76 (0.38)	Tax	9.90* (0.61)	10.61* (0.56)
Exogenous V-T	3 $\bar{x}$ = 66	19.39 (0.27)	Voluntary	14.02* (0.84)	17.38* (0.73)
			Tax	11.10* (0.19)	11.58 (0.35)
	4 $\bar{x}$ = 50	19.94 (0.33)	Voluntary	12.53 (0.31)	13.18* (0.49)
			Tax	9.49* (0.74)	9.85* (0.46)
	5 $\bar{x}$ = 0	19.52 (0.31)	Voluntary	11.70 (0.27)	11.85 (0.33)
			Tax	10.56 (1.25)	7.31* (0.81)
	6 $\bar{x}$ = 50 [com]	19.73 (0.32)	Voluntary	12.00 (0.00)	12.04 (0.04)
			Tax	- -	8.72* (0.30)
Endogenous V-T	7 φ =1/3	19.39 (0.32)	Voluntary	12.77 (0.52)	13.83* (0.84)
			Tax	12.49 (0.53)	12.40 (0.61)
	8 φ = 1	19.69 (0.34)	Voluntary	12.53 (0.42)	12.82 (0.46)
			Tax	12.07 (0.63)	11.69 (0.66)
	9 φ = 3	20.03 (0.32)	Voluntary	11.98 (0.25)	12.14 (0.36)
			Tax	9.89* (0.77)	10.15* (0.71)
	10 φ = 1 [com]	19.42 (0.39)	Voluntary	12.00 (0.00)	12.00 (0.00)
			Tax	- -	- -

Notes: Numbers in parentheses are cluster-robust standard errors. * indicates parameter is statistically different than 12 at the 5% level.

Table 4 Voluntary Compliance Model

Number of observations = 361		R^2=0.87
	Policy Treatment	**Estimated Compliance Rate (%)**
Exogenous V-T	3 $\bar{x} = 66$	25.0 (18.5)
	4 $\bar{x} = 50$	61.1 (23.6)
	5 $\bar{x} = 0$	93.5 (4.7)
	6 $\bar{x} = 50$ [Com]	98.6 (1.3)
Endogenous V-T	7 $\varphi = 1/3$	18.2 (8.5)
	8 $\varphi = 1$	46.7 (27.6)
	9 $\varphi = 3$	78.3 (5.8)
	10 $\varphi = 1$ [Com]	100.0 (0.0)

Note: Numbers in parentheses are cluster-robust standard errors.

Table 5 Social Efficiency Model

Treatment			Policy	Social Efficiency
Pure Ambient Tax	1	$\bar{x} = 66$	Tax	78.1 (3.96)
	2	$\bar{x} = 50$	Tax	64.3 (4.60)
Exogenous V-T	3	$\bar{x} = 66$	Voluntary	51.9 (13.34)
			Tax	94.0 (2.44)
	4	$\bar{x} = 50$	Voluntary	87.6 (8.24)
			Tax	63.1 (2.34)
	5	$\bar{x} = 0$	Voluntary	93.8 (3.05)
			Tax	1.2 (22.54)
	6	$\bar{x} = 50$ [com]	Voluntary	99.8 (0.18)
			Tax	63.1 (0.00)
Endogenous V-T	7	$\varphi = 1/3$	Voluntary	72.9 (4.23)
			Tax	78.0 (3.80)
	8	$\varphi = 1$	Voluntary	88.5 (6.27)
			Tax	77.9 (7.25)
	9	$\varphi = 3$	Voluntary	93.1 (1.97)
			Tax	55.8 (14.03)
	10	$\varphi = 1$ [com]	Voluntary	100.0 (0.00)
			Tax	- -
Number of observations = 920				$R^2 = 0.97$

Notes: Numbers in parentheses are cluster-robust standard errors. Estimates coinciding with Pre-Policy rounds are also included in the Social Efficiency model but are omitted for brevity.

Proof of Proposition 1:

The proof of Proposition 1 is presented in three parts as follows; *(i)* if the tax policy is imposed $\boldsymbol{a}^t = \boldsymbol{a}^*$ is a NE; *(ii)* $\{\boldsymbol{a}^v, \boldsymbol{a}^t\} = \{\boldsymbol{a}^*, \boldsymbol{a}^*\}$ is a SPNE if and only if $\varphi \geq \hat{\varphi}$; *(iii)* $\{\boldsymbol{a}^v, \boldsymbol{a}^t\} = \{\boldsymbol{a}^*, \boldsymbol{a}^*\}$ is a *unique* SPNE if and only if $\varphi = \hat{\varphi}$.

(i) If the tax policy is imposed, it is clear from (5') that each firm chooses a_i^t in every tax period to minimize $C_i(a_i^t) + \tau(x(a_i^t, \boldsymbol{a}_{-i}^t) - x^s + \varphi(x^v - x^s))$. The first order condition is $C_i'(a_i^t) + \tau \cdot \partial x / \partial a_i = 0$, which is independent of φ. Thus, given $\tau = -\dfrac{C_i'(a_i)}{\partial x / \partial a_i}$ evaluated at a_i^*, if all other firms choose a_i^*, firm *i* will choose a_i^* as well and $\boldsymbol{a}^t = \boldsymbol{a}^*$ is a NE in every tax period.

(ii) In the voluntary period, firm *i* solves the minimization problem

$$C_i\left(a_i^v\right) + \sum_{k=1}^{K} \delta^k \left[C_i\left(a_i^*\right) + \tau\varphi\left(x\left(a_i^v, \boldsymbol{a}_{-i}^v\right) - x^s\right) \right] \quad s.t. \quad a_i^v \leq \hat{a}_i \,, \tag{a1}$$

where $\hat{a}_i$ is defined as the level of abatement by firm *i* necessary to achieve the ambient standard with equality, conditional on the abatement choices of all other firms (i.e., $x(\hat{a}_i, \boldsymbol{a}_{-i}) = x^s$). Given that abatement is costly, firm *i* will never choose to voluntarily abate more than $\hat{a}_i$, since this results in higher abatement costs than exactly meeting the standard, without any benefit in terms of reductions in future tax liabilities. This result is independent of φ.

The K-T conditions corresponding to (a1) are,

$$C_i'\left(a_i^v\right) + \tau\varphi \sum_{k=1}^{K} \delta^k \, \partial x / \partial a_i (a_i^v) + \mu_i = 0 \tag{a2}$$

$$\mu_i\left(\hat{a}_i - a_i^v\right) = 0 \tag{a3}$$

$$\mu_i \geq 0 \,. \tag{a4}$$

At the NE, conditions (a2)-(a4) hold simultaneously for all *i*. Assume that all other firms choose a_i^* in the voluntary period (i.e., $\boldsymbol{a}_{-i}^{v} = \boldsymbol{a}_{-i}^{*}$), which implies that $\hat{a}_i^v = a_i^*$. Recalling that $\tau = -\frac{C_i'(a_i)}{\partial x/\partial a_i}$ evaluated at a_i^* and plugging this into (a2) implies $\mu_i = C_i'(a_i^*)[\frac{\varphi}{\hat{\varphi}} - 1]$. It is then immediately clear that when $\varphi \geq \hat{\varphi}$, the first order conditions (a2) - (a4) for all *i* are solved with $a_i^v = a_i^*$ and $\mu_i \geq 0$. Thus $\{\boldsymbol{a}^{\text{v}}, \boldsymbol{a}^t\} = \{\boldsymbol{a}^*, \boldsymbol{a}^*\}$ is a *SPNE* when $\varphi \geq \hat{\varphi}$.

Suppose instead $\varphi < \hat{\varphi}$ and $\boldsymbol{a}^v = \boldsymbol{a}^*$. Then (a2) implies $\mu_i = C_i'(a_i^*)[\frac{\varphi}{\hat{\varphi}} - 1] < 0$, which contradicts condition (a4). Thus, when $\varphi < \hat{\varphi}$, $\{\boldsymbol{a}^{\text{v}}, \boldsymbol{a}^t\} = \{\boldsymbol{a}^*, \boldsymbol{a}^*\}$ cannot be a SPNE.

(iii) When $\varphi > \hat{\varphi}$, other SPNE exist in which abatement is not efficient in the voluntary stage. To show this, suppose that $a_j^v = a_j^*$ for all $j = 3,...,n$, $a_2^v = a_2^* - \varepsilon < a_2^*$ for some $\varepsilon > 0$, and $\hat{a}_1^v = a_1^* + \varepsilon > a_1^*$. Given these abatement levels, the ambient standard is just met and (a3) holds for all firms. Furthermore, by strict convexity of C, $C_1'(a_1^*) < C_1'(\hat{a}_1^v)$ and $C_2'(a_2^*) > C_2'(a_2^* - \varepsilon)$ for all $\varepsilon > 0$. Then, when $\varphi > \hat{\varphi}$, by continuity of C' there exists an $\varepsilon > 0$ such that

$$\mu_1 = C_1'(a_1^*)\frac{\varphi}{\hat{\varphi}} - C_1'(\hat{a}_1^v) > 0 \qquad \text{(a5)}$$

$$\mu_2 = C_2'(a_2^*)\frac{\varphi}{\hat{\varphi}} - C_2'(a_2^* - \varepsilon) > 0 \qquad \text{(a6)}$$

$$\mu_j = C_j'(a_j^*)[\frac{\varphi}{\hat{\varphi}} - 1] > 0 \quad \text{for all } j = 3,...,n, \qquad \text{(a7)}$$

which implies that both (a2) and (a4) also hold for all *i*. Thus, $\{\hat{a}_1^v, a_2^* - \varepsilon, a_3^*,..., a_n^*\}$ during the voluntary stage, coupled with a_i^* for all *i* during the tax stage, is a SPNE.

When $\varphi = \hat{\varphi}$, $\boldsymbol{a}^v = \boldsymbol{a}^*$ is a unique NE in the voluntary stage. To see this, note that, when $\varphi = \hat{\varphi}$, (a2) requires that $\mu_i = C_i'(a_i^*) - C_i'(a_i^v) \geq 0$ for all $i = 1,...,n$. Given strict convexity of C, this in turn requires that in any NE in the voluntary stage $a_i^v \leq a_i^*$ for all $i = 1,...,n$. In addition, $\mu_i > 0$ for all $a_i^v < a_i^*$. Now suppose that there exists a NE in the voluntary stage in which $a_j^v < a_j^*$ for some firm *j*. Then given $a_i^v \leq a_i^*$ for all *i*, this implies that firm *j* is not choosing the abatement level that is necessary to ensure that the ambient standard is met, given the choices of the other firms, $\hat{a}_j^v$. Hence, by (a3) $\mu_j = 0$, which implies a contradiction.

References

Aoyagi, M., G. Fréchette, 2009. Collusion as public monitoring becomes noisy: Experimental evidence. Journal of Economic Theory 144(3), 1135-1165.

Arellano, M., 1987. Computing robust standard errors for within-groups estimators. Oxford Bulletin of Economics and Statistics 49, 431-434.

Arora, S., and T.N. Cason, 1996. Why do firms volunteer to exceed environmental regulation? Understanding participation in EPA's 33/50 Program. Land Economics 72, 413-432.

Alpízar, F., T. Requate, and A. Schram, 2004. Collective versus random fining: an experimental study on controlling ambient pollution. Environmental and Resource Economics 29, 231-252.

Bertrand, M., E. Duflo, and S. Mullainathan. 2004. How much should we trust differences-in-differences estimates? Quarterly Journal of Economics 119, 249-275.

Cabe, R., and J.A. Herriges, 1992. The regulation of non-point sources of pollution under imperfect and asymmetric information. Journal of Environmental Economics and Management 22, 134-146.

Cochard, F., M. Willinger, and A. Xepapadeas, 2005. Efficiency of nonpoint source pollution instruments: an experimental study. Environmental and Resource Economics 29, 231-252.

Cooper, J.C., and C.T. Osborn, 1998. The effect of rental rates on the extension of Conservation Reserve Program contracts. American Journal of Agricultural Economics 80, 184-194.

Dawson, N.L., and K. Segerson, 2008. Voluntary agreements with industries: participation agreements with industries. Land Economics 84, 97-114.

Delmas, M., and A. Keller, 2005. Free-riding in voluntary environmental programs: the case of US EPA's WasteWise Program. Policy Sciences 38, 91-106.

Feinberg, R.M., and C. Snyder, 2002. Collusion with secret price cuts: An experimental investigation. Economics Bulletin 3(6), 1-11.

Hansen, L.G., 1998. A damage based tax mechanism for regulation of non-point emissions. Environmental and Resource Economics 12, 99–112.

Hansen, L.G., 2002. Regulation of non-point emissions: A variance based mechanism. Environmental and Resource Economics 21, 303-316.

Hansen, L.G., and E. Romstad, 2007. Non-point source regulation – A self-reporting mechanism. Ecological Economics 62, 529-537.

Horan, R.D., J.S. Shortle, and D.G. Abler, 1998. Ambient taxes when polluters have multiple choices. Journal of Environmental Economics and Management 36, 186-199.

Karp, L, 2005. Nonpoint source pollution taxes and excessive tax burden. Environmental and Resource Economics 32, 229–251.

Kezdi, G., 2004. Robust standard errors estimation in fixed-effects panel models. Hungarian Statistical Review, Special English Volume 9, 95-116.

Khanna, M., and L. Damon, 1999. EPA's voluntary 33/50 Program: impact on toxic releases and economic performance of firms. Journal of Environmental Economics and Management 37, 1-25.

Knoblauch, W.A., Connemann, G.J., Putnam, L.D., 2001–2005. Dairy Farm Management: Business Summary New York State. Department of Applied Economics and Management. Cornell University, Ithaca, NY.

Lyon, T.P. and J.W. Maxwell, 2003. Self-regulation, taxation and public voluntary environmental agreements. Journal of Public Economics 87, 1453-86.

Newey, W. K. and K. D. West, 1987. A simple, positive semi-definite, heteroscedasticity and autocorrelation consistent covariance matrix. Econometrica 55, 703-708.

Parks, P.J., and R.A. Kramer, 1995. A policy simulation of the Wetlands Reserve Program. Journal of Environmental Economics and Management 28, 223-240.

Poe, G.L., W.D. Schulze, K. Segerson, J.F. Suter, and C.A. Vossler, 2004. Exploring the performance of ambient-based policy instruments when non-point source polluters can cooperate. American Journal of Agricultural Economics 86, 1203-1210.

Ribaudo, M.O. 1998. Lessons Learned about the Performance of USDA Agricultural Nonpoint Source Pollution Programs. Journal of Soil and Water Conservation 53, 4-10.

Ribaudo, M., 2003. Agricultural Resources and Environmental Indicators. Chapter 2.3, Water Quality Impacts of Agriculture, U. S. Department of Agriculture, Economic Research Service, Washington, D.C.

Segerson, K., 1988. Uncertainty and incentives for non-point source pollution. Journal of Environmental Economics and Management 15, 87-98.

Segerson, K., and T. Miceli, 1998. Voluntary environmental agreements: good or bad news for environmental protection? Journal of Environmental Economics and Management 36, 109-130.

Segerson, K., and J.J Wu, 2006. Nonpoint source pollution control: introducing first best outcomes through the use of threats. Journal of Environmental Economics and Management 51, 165-184.

Shortle, J., D. Abler, and M. Ribaudo, 2001. Agriculture and Water Quality: The Issues, In J. Shortle and D. Abler (Eds.) Environmental Policies for Agricultural Pollution, Walingford, UK, 1-18.

Spraggon, J., 2002. Exogenous targeting instruments as a solution to group moral hazards. Journal of Public Economics 84, 427-456.

Spraggon, J., 2004. Testing ambient pollution instruments with heterogeneous agents. Journal of Environmental Economics and Management 48, 837-856.

Suter, J.F., G.L. Poe, and N.L. Bills, 2008. Do landowners respond to land retirement incentives? Evidence from the conservation reserve enhancement program. Land Economics 84, 17-30.

Suter, J.F., C.A. Vossler, G.L. Poe, and K. Segerson, 2008b. Experiments on damage-based ambient taxes for nonpoint source polluters. American Journal of Agricultural Economics 90, 86-102.

Suter J.F., C.A. Vossler and G.L. Poe, 2009. Ambient-Based Pollution Mechanisms: A Comparison of Homogenous and Heterogeneous Groups of Emitters. Ecological Economics 68, 1883-1892.

U. S. Department of Agriculture, Economic Research Service, 2002. ERS Analysis: Conservation Programs, Washington, D.C.

U. S. Department of Agriculture, Natural Resources Conservation Service, 2002. Annual national resources inventory. Washington, D.C.

U.S. Environmental Protection Agency. 2000. National water quality inventory report, Chapter 3, Washington, D.C.

Vossler, C.A., G.L. Poe, W.D. Schulze, and K. Segerson, 2006. Communication and incentive mechanisms based on group performance: an experimental study of nonpoint pollution control. Economic Inquiry 44, 599-613.

Vossler, Christian A. 2008. Analyzing repeated-game economics experiments: robust standard errors for panel data with serial correlation. Working paper, Department of Economics, University of Tennessee, Knoxville.

Weersink, A., J.R. Livernois, and J. Shogren, 1998. Economic instruments and environmental policy in agriculture. Canadian Public Policy 24, 309-327.

White, H., 1984. Asymptotic Theory for Econometricians. Orlando, FL: Academic Press.

White, H., 1980. A heteroskedasticity-consistent covariance matrix estimator and a direct test for heteroskedasticity. Econometrica 40, 617-636.

Xepapadeas, A. 1991. Environmental policy under imperfect information: incentives and moral hazard. Journal of Environmental Economics and Management 20, 113-126.

[1] Initial compliance with the standard is voluntary in the sense that firms are not legally required to comply. However, the threat of imposition of the tax can make compliance in theory a best response, suggesting that compliance is the firm's only rational choice. The type of voluntary-threat policies explored in this article are often included under the broad category of "voluntary approaches." See, for example, Segerson and Miceli (1998).

[2] Although Segerson and Wu (2006) were the first to apply this approach to nonpoint pollution, other articles have examined the combination of a voluntary policy with a background threat of regulation in other contexts. See, for example Segerson and Miceli (1998), Lyon and Maxwell (2003), and Dawson and Segerson (2008).

[3] In contrast to Segerson (1988) and related literature, the theoretical developments in Segerson and Wu (2006) and in this article do not explicitly consider the role of random factors such as weather. This is consistent with either a deterministic ambient pollution function or, as in Segerson and Wu, an assumption that the policy goal is one of meeting an ambient water quality standard on average. Under this latter interpretation, the term "ambient pollution" as used throughout should be interpreted as the expected value of ambient pollution, where the expectation is taken over stochastic variables representing weather or other random factors. Extending the theory to explicitly account for stochastic variables in the ambient pollution function would make a fruitful area for future research.

[4] The assumption that all cross-partials are zero implies a linear relationship between abatement and ambient pollution, as in Hansen (2002) and Hansen and Romstad (2007). This is appropriate if abatement is defined as a reduction in (unobservable) emissions, some fraction of which eventually enter the water body as "loadings", and ambient pollution is simply the sum of these loadings from all sources. Note that it does not imply that the *damages* are necessarily a linear function of ambient pollution.

[5] Choosing $\bar{x} > x^s$ does not make sense, as firms never have an incentive to reduce pollution below the threshold and therefore would not abate sufficiently to achieve the ambient standard.

[6] Depending on the magnitude of the tax rate, abatement costs, and the level of the tax threshold, colluding firms could have an incentive to reduce ambient pollution to the level of the tax threshold, thereby avoiding tax payments altogether. With the parameters and functional forms used in our experiments, collusion by firms under the pure ambient tax implies an equilibrium under which ambient pollution equals the tax threshold.

[7] Many voluntary programs targeting agricultural nonpoint source pollution involve incentive payments to farmers, rather than tax payments. In theory, a voluntary approach that ties the amount of subsidy to environmental performance will create the same abatement incentives as a tax-based approach (see Section 6 of Segerson and Wu (2006)). For comparability with the pure ambient tax policy, which has been studied in previous experiments, we restrict consideration in this paper to voluntary approaches with tax-based threats. The performance of payment-based voluntary approaches is an interesting topic for future research. In particular, it would be interesting to see whether the theoretical equivalence of the tax and payment-based approaches holds in the lab and/or the field.

[8] An OLS regression was run with participant emissions regressed on the realized tax threshold, where the estimated parameter on the tax threshold was allowed to vary across the pure ambient tax, exogenous V-T and endogenous V-T. These three coefficients (while all significantly greater than zero) were not statistically different from one another.