Ambient-Based Pollution Mechanisms: A Comparison of Homogeneous and Heterogeneous Groups of Emitters[1]

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Abstract:

Over the last two decades, ambient tax mechanisms have been offered as a potential solution to the problem of non-point source water pollution. Previous theoretical analyses suggest that the performance of ambient tax mechanisms does not depend on firm characteristics, such as size, whilst policy discussions advocate that such mechanisms are best suited for regulating relatively homogeneous firms. Using controlled laboratory experiments, we provide empirical evidence that the distribution of firm sizes does have a significant impact on observed group decision making and further that heterogeneity has the potential to generate some relatively desirable outcomes. These results suggest that richer theoretical models that capture important strategic interactions are needed to better describe laboratory behavior and, by extension, behavior in potential policy settings.

Key words: nonpoint source pollution, ambient taxes, firm heterogeneity, laboratory experiments, dairy farms

1. Introduction

Despite decades of policy intervention, accumulated evidence indicates that agricultural nonpoint source pollution remains the largest obstacle to attaining the fishable-swimmable goals of the 1972 Clean Water Act (USEPA, 2002; Riboudo, 2003). Coincidently, it has been argued that the voluntary, incentive-based pollution abatement programs of the Farm Bill's Conservation Title have largely been ineffective in mitigating non-point source pollution from agriculture (Shortle, Abler and Ribaudo, 2001). Motivated by the Total Maximum Daily Load (TMDL) provisions of the Clean Water Act (CWA) and the determination that these water quality objectives may be implemented through the use of "incentive-based, non-regulatory or regulatory approaches" (US EPA, 2007), this research uses experimental economic techniques to evaluate an ambient-based tax in homogeneous and heterogeneous firm settings. The economic-theoretic foundations for such mechanisms stem from Segerson's (1988) seminal paper on ambient-based incentive mechanisms for controlling non-point source pollution, and subsequent theoretical developments including Xepapadeas (1991), Cabe and Herriges (1992), Hansen (1998), Horan, Shortle and Abler (1998), Karp (2005), and Segerson and Wu (2006). In recent years these theoretical efforts have been augmented by a set of experimental explorations of ambient-based pollution policies (e.g., Spraggon, 2002, 2004; Alpizar, Requate and Schram, 2004; Poe et al., 2004; Cochard, Willinger and Xapapadeas, 2005; Vossler et al., 2006; Suter et al., 2008).

Our study is related to, but distinct from, past experimental economics efforts on ambient-based pollution control mechanisms. Past studies have largely been directed toward comparing the performance of alternative ambient pollution control mechanisms, including marginal taxes and subsidies, fixed penalty mechanisms, and combined fixed penalty and tax/subsidy mechanisms. The work reported here is deliberately limited to evaluating the ambient tax mechanism, whereby each polluter pays a (constant) marginal tax on each unit of pollution in excess of an exogenously specified pollution standard. Our attention to this particular policy instrument derives from lessons gleaned from recent experimental research on ambient pollution control mechanisms. Specifically, Spraggon (2002), Vossler (2003) and Vossler et al. (2006) demonstrate that incentive mechanisms involving subsidies lead to over-abatement in collusive settings, and that fixed penalty policies lead to underabatement relative to the social optimum in non-cooperative settings. Subsequent research reported in Poe et al. (2004) and Suter et al. (2008) demonstrates that appropriately designed ambient tax mechanisms can, however, provide efficient outcomes in both non-cooperative and collusive settings.

With the exception of Spraggon (2004), the relevant experimental economics literature has centered on evaluating mechanisms for a group of homogeneous firms, reflecting Weersink et al.' s (1998) suggestion that watershed settings consisting of small numbers of homogeneous farms would be most conducive to the application of ambient-based mechanisms. The intent of the present research is to compare group performance and individual decision making in a homogeneous firm setting with those in a heterogeneous setting. In the homogeneous pollution setting six firms have identical profit and emission functions; in the heterogeneous setting there are three "small" firms, two "medium" firms, and one "large" firm, each with size-specific profit and emissions functions. As discussed below, our experimental design is based on characteristics of the New York (NY) dairy industry.

Our approach differs from Spraggon's (2004) homogeneous-heterogeneous experimental design in three important ways. First, our experimental instructions use associative framing that reflects the watershed pollution setting we wish to provide insight on, and design parameters calibrated to reflect the relative profitability and size distributions of "small" (60 cows), "medium" (200 cows), and "large" (600 cows) dairy farms in NY. Spraggon (2004), by comparison, investigates a context-free setting with two firm sizes. Reflecting this specificity, we will henceforth refer to farms in our discussion and analysis. Second, our analysis specifically investigates the effect of heterogeneity in farm-level abatement cost functions, whereas the abatement cost function is held constant across firms in Spraggon (2004). Third, Spraggon's design includes a corner solution in which the optimal response for "small" firms is to abate to an emissions level of zero, thus precluding overabatement. Our design allows both over- and under- abatement relative to the social and private optima.

In the experiments described in this paper, profit levels are designed to correspond with herd size and returns data from the NY Dairy Farm Business Summary (Knoblauch, Putnam and Karszes, 2001-2005). Emissions and abatement functions across herd-size groupings are informed by discussions with extension personnel from NRCS-NY and Cornell Cooperative Extension. Additionally, pollution targets are set to 40% below the zero-abatement level, corresponding to the 40% nutrient reduction goals called for in the original Chesapeake Bay Agreement (Chesapeake Bay Program, 2005).

The remainder of the paper is organized as follows. In the following section we review the theoretical foundations of the ambient-based tax mechanism in a non-cooperative setting. The third section details the experimental design, and the experimental results are presented in Section 4. The last section provides a discussion of the policy implications of this research.

2. Theoretical Foundations

Our experimental design is predicated on the theoretical nonpoint source pollution model of Segerson and Wu (2006). Specifically, we assume that abatement and farm characteristics can each be represented by scalars and that the policy objective is to achieve an ambient water quality standard on average, so that stochastic elements such as weather are averaged out.[2]

Suppose there are n farms, indexed by i, in a given watershed. The abatement decision by farm i is denoted by a_i and $\boldsymbol{a} = (a_1, a_2, ..., a_n)$ represents the vector of abatement decisions by each of the n farms. The abatement cost function, $C_i = C(a_i, \theta_i)$ is allowed to vary by farm and θ_i represents farm-specific characteristics related to the farm's location and size. The vector of characteristics of all farms in a given watershed is denoted by $\boldsymbol{\theta} = (\theta_1, \theta_2, ..., \theta_n)$. It is further assumed that the abatement cost function is strictly convex, so that $\partial C / \partial a_i > 0$, $\partial^2 C / \partial a_i^2 > 0$ and $C(0, \theta_i) = 0$. The abatement decisions and farm characteristics of all farms jointly determine ambient pollution at a monitoring point, x, by the function $x = x(a_1,\ldots,a_n; \theta_1,\ldots, \theta_n)$, with $\partial x / \partial a_i < 0$ and $\partial^2 x / \partial a_i^2 \geq 0$. In the absence of any policy intervention we expect that farms will engage in zero abatement effort in equilibrium, since the cost abatement is strictly positive.

Now suppose that the objective of the social planner is to reduce ambient pollution to an exogenously determined water quality standard, which we denote x^s. This standard could potentially be based on a Total Maximum Daily Load (TMDL) requirement or simply be the product of political bargaining. The social planner's problem and corresponding Lagrangian, assuming an interior solution, can then be written as

$$\underset{\boldsymbol{a}}{Min} \sum_{i=1}^{n} C(a_i, \theta_i) \quad s.t. \quad x(\boldsymbol{a}; \boldsymbol{\theta}) \leq x^s, \; \boldsymbol{a} \geq 0 \tag{1}$$

$$L = -\sum_{i=1}^{n} C(a_i, \theta_i) + \lambda\left(x^s - x(\boldsymbol{a}; \boldsymbol{\theta})\right) \tag{2}$$

[2] Evidence from Spraggon (2002) suggests that the performance of ambient mechanisms does not depend on whether or not ambient pollution is assumed to be stochastic.

The first-order necessary conditions that result from equation (2) are solved with each farm in the watershed making abatement decision $a_i = a_i^*$, which implies a vector of optimal abatement decisions given by $\boldsymbol{a} = \boldsymbol{a}^*$. In addition, the curvature of the farm-level cost and pollution functions imply that $\lambda^* = -\frac{\partial C / \partial a_i^*}{\partial x / \partial a_i^*}$ for all *i*.

Suppose further that the social planner seeks to achieve the ambient standard at least cost through the use of a policy that charges all farms in the watershed a marginal tax, τ, on units of ambient pollution above x^s. Setting $\tau = \lambda^*$, the cost minimization problem for farm *i*, where the superscript *t* indicates abatement decisions made under the tax, is

$$\underset{a_i^t}{Min} \; C(a_i^t, \theta_i) + max(0, \tau \cdot (x(\boldsymbol{a^t}; \boldsymbol{\theta}) - x^s)). \qquad (3)$$

Under the ambient tax policy $\boldsymbol{a}^t = \boldsymbol{a}^*$ is a Nash equilibrium, where a_i^* is the optimal abatement level for farm *i* as defined previously. A formal proof is provided in Segerson and Wu (2006) and here we provide an intuitive demonstration of this equilibrium. If the *n* – 1 farms in the watershed abate optimally (i.e., $\boldsymbol{a}_{-i}^t = \boldsymbol{a}_{-i}^* = (a_1^*, ..., a_{i-1}^*, a_{i+1}^*, ..., a_n^*)$), then ambient pollution will be equal to or less than the standard if abatement by farm *i* is $a_i^t \geq a_i^*$. Since there is no marginal benefit to reducing ambient pollution below the standard, $a_i^t > a_i^*$ can never be a best response. Farm *i* will therefore choose $a_i^t = a_i^*$ and achieve the standard with equality or $a_i^t < a_i^*$ and pay the ambient tax.

If $a_i^t < a_i^*$, the marginal benefit of abatement by farm *i*, in terms of tax payments avoided, is $-\tau \cdot \partial x / \partial a_i^t$, where $\partial x / \partial a_i^t < 0$. Substituting $\tau = -\frac{\partial C / \partial a_i^*}{\partial x / \partial a_i^*}$, the marginal benefit of abatement becomes $\frac{\partial C / \partial a_i^*}{\partial x / \partial a_i^*} \cdot \partial x / \partial a_i^t$. The strict convexity of the abatement cost function implies that the marginal cost of abatement by farm *i* is $\partial C/\partial a_i^t < \partial C/\partial a_i^*$ for $a_i^t < a_i^*$ and the concavity of the pollution function implies $\frac{\partial x/\partial a_i^t}{\partial x/\partial a_i^*} \geq 1$ for $a_i^t < a_i^*$. Therefore $\partial C/\partial a_i^t < \frac{\partial C/\partial a_i^*}{\partial x/\partial a_i^*} \cdot \partial x/\partial a_i^t$ for $a_i^t < a_i^*$. Since the marginal benefit of abatement is greater than the marginal cost for all $a_i^t < a_i^*$, abating less than a_i^* is never a best response. Thus, farm *i* will optimally abate to $a_i^t = a_i^*$ and $\boldsymbol{a}^t = \boldsymbol{a}^*$ is a NE.

Additionally, $\boldsymbol{a}^t = \boldsymbol{a}^*$ is a *unique* NE, since the marginal benefit of abatement for abatement levels below a_i^* is always greater than the marginal cost, independent of the decisions of the other farms in the watershed, no firm will ever optimally choose $a_i^t < a_i^*$. If no farm will optimally underabate, then it is not rational to choose $a_i^t > a_i^*$, since this would result in pollution being strictly below the ambient standard.

3. Experimental Design

3.1 Participant Pool and Procedures

To test the relative performance of the ambient tax policy in homogeneous and heterogeneous settings, a set of economics experiments were conducted at Cornell University. Experiment participants were required to have taken at least one class in economics and the majority had participated in at least one prior, but unrelated, economics experiment. The experimental sessions lasted one hour, on average, and participants earned experimental tokens based on their decisions in each round of the experiment. At the end of the session, tokens were exchanged for dollars based on a known exchange rate. Overall, 72 participants took part in the experiment and individual earnings averaged $20.

The experimental treatments presented here include two treatments with a heterogeneous group structure and one treatment with a homogeneous group structure. The two heterogeneous treatments involve groups composed of three farm sizes that differ in assumed abatement costs, as described in more detail below. In each experimental session, one group of six participants plays the role of independent farm operators and take part in 24 decision rounds. There are four sessions (i.e. replications) for each group structure. Each group first plays 5 regulation-free rounds (hereafter referred to as "Part A") and then faces an additional 19 rounds with the ambient tax ("Part B"). Preceding Parts A and B, participants read through a set of written instructions (see Appendix) and view a Powerpoint presentation given by the experiment administrator.

The sole task in each round is for participants to determine their own emissions level. Although the choice variable in the theoretical model is abatement, the term "abatement" generally implies a reduction in emissions from a previous level and might therefore confuse participants. Each participant receives an *Emissions Decision Sheet* that lists the (pre-tax) earnings associated with all possible levels of emissions (see Appendix). The *Emissions Decision Sheet* is specific to farm size, as different farm sizes have different emissions ranges and different abatement cost structures. In addition, all participants receive identical *Tax Calculation Sheets*, which provide the tax liability associated with all possible group emissions levels.

3.2 Parameter Calibration based on the NY Dairy Industry

In the heterogeneous treatments, the objective of the experimental design is to mimic the anticipated pyramidal structure of NY dairy farm sizes. In 2005 approximately 80% of NY dairy farms had herd sizes of between 1 and 99 cows, and these farms accounted for fully 35% of all milk cows. Another 16% of NY dairy farms (31% of milk cows) were included in the herd size category 100-399 cows. The remaining 4% of NY dairy farms (33% of milk cows) had 400 or more animals. These figures represent a temporal snapshot of the ever-evolving herd size distribution in NY: "in 1985 farms with 200 cows or more represented less than 2 percent of all farms; in 2005, farms with 200 or more cows made up over nine percent of the total number of dairy farms. The average size of herds was 57 cows in 1985 and 97 cows per farm in 2005" (Knoblauch, Conneman, and Putnam, 2006).

Our experimental design for the heterogeneous settings consists of three herd size groups: three "small", two "medium" and one "large" farm, with representative herd sizes of 80, 200, and 660 cows respectively. As indicated in the experimental instructions provided in the Appendix, these farm size categories and distributions were public knowledge for all group members. The small and large farm sizes were selected to represent distinct animal housing, feeding and grazing characteristics, and manure storage and handling technologies (see Table 1). There are no clear expectations of relative emissions and abatement costs for the medium sized farms, as farms in this category tend to selectively utilize methods from either of the other herd size categories depending on the specifics of the farm operation. In the homogeneous setting, each session involved six medium-sized farms.

Profit functions associated with the zero abatement (i.e., pre-mechanism) optima were calibrated to the average net income for each of the representative herd sizes using 1999-2003 data from the Dairy Farm Management Summary (Knoblauch, Putnam and Karszes, 2001-2005). This information is presented in the top section of Table 2. Whereas objective data exists for farm income, no such data are presently available for calibrating emissions abatement functions, C_i, across farm sizes. Consultation with various Cornell University faculty failed to provide a consensus as to relative magnitudes of emissions attributed to each farm size, and even less consensus about relative abatement costs across herd sizes. Because of this uncertainty we endeavored to identify a plausible set of assumptions corresponding to the range of experts' perceptions of relative magnitudes. Normalizing to the medium-sized herd (which is the herd size used for all farms in the homogeneous setting) the baseline Emissions per Cow (EPC) for the small, medium and large farms were set at 0.125, 0.100, and 0.075, respectively, at their corresponding herd-size specific optima. This translates to 10 units of emissions for the small farms, 20 units of emissions for the medium farms, and 50 units of emissions for the large farms, at their respective baselines. Such relative emissions per cow levels reflect data on manure management practices obtained from a survey of NY Dairy Farms (Poe et al., 2002).

Even assuming these relative per cow and aggregate emissions levels, one can only speculate about the relative shapes of the abatement cost functions for the small, medium, and large farms. Lacking guidance on this matter, we investigate two alternative scenarios. The first, which we call Heterogeneous Type 1, involves a relatively elastic abatement cost function for the small farms compared to the large farms. In the Heterogeneous Type 2 setting, small farms have a relatively inelastic abatement cost function. Under the ambient tax, small farms will optimally engage in proportionally more abatement than medium and large farms in the Type 1 setting, while in the Type 2 setting large farms optimally abate proportionally more than the small and medium farms. The emissions per cow and the total cost functions necessary to effectuate each permutation are provided in Table 2, assuming an optimal ambient tax. Figures 1 and 2 provide the respective emission-income relationships.

3.3 Theoretical Predictions

In Part A of each treatment, each participant makes their emissions decision in an environment where ambient pollution does not influence their earnings in any way. As such, our expectation in the *homogeneous* treatment is that each participant will choose an emissions level of 20, which maximizes their personal earnings, in each of the five Part A rounds. Therefore in Part A the expected ambient or group pollution level, given that each of the six participants chooses an emissions level of 20, is 120. For the *heterogeneous* treatments, the expected group emissions level also equals 120 in Part A of the experiment. However, this level is an outcome of each of the three small farms producing 10 emission units, each of the two medium farms generating 20 emission units, and the large farm generating 50 emission units.

In Part B, there is an ambient-based tax policy designed to induce a 40% reduction in ambient (group) pollution levels, from an unconstrained pollution level of 120 to an ambient standard, x^s, of 72. In the homogeneous setting, reaching the ambient standard of 72 at least cost requires each participant to reduce their emissions to 12 units, from the unconstrained optimum of 20. Setting τ =2500, an emissions level of 12 is a unique NE for all participants. For this same marginal tax, the optimal emissions levels are 4, 12 and 36 for the small, medium, and large farms, respectively in the Heterogeneous Type 1 case. For Heterogeneous Type 2, the respective optimal emissions levels are 8, 12, and 24. Note that despite variations in C_i and a_i, in both the heterogeneous cases the group emissions sum to 72 units.

4. Results

The outcomes of the experimental treatments generate three primary policy results that are outlined in detail in this section.

Result 1: The tax mechanism lowers emissions levels substantially in both the homogeneous and heterogeneous settings. Further, group emissions levels are significantly different from the ambient standard in the homogeneous setting in all rounds, while aggregate emissions in the heterogeneous setting are not significantly different from the standard in late rounds of the experiment.

We first provide graphical evidence of this result, and then follow with a formal statistical analysis. As demonstrated in Figures 3, 4, and 5, farms operating under the policy rounds of the experiment approximate the profit maximizing level of group emissions of 120. Further, in all cases a substantial drop in emissions is observed after implementation of the ambient tax policy, although the degree to which group levels approximate the ambient standard varies significantly across rounds and across treatments. Overall, group emissions levels tend to be higher than the ambient standard, with the heterogeneous settings appearing to better approximate the 40% desired reduction.

To formally analyze the results for each experimental treatment we evaluate treatment-specific emissions at the group-level. For each treatment we have four groups and emissions for each group are observed in each of the 24 rounds. To facilitate hypothesis tests against predicted values from the available data, we specify a pooled time-series cross-sectional model where the estimable coefficients can simply be interpreted as mean group emissions. As Part A of the experiment is identical for all participants, we assume that mean emissions for these rounds are the same across treatments. For Part B of the experiment, we allow mean group emissions to differ by group structure and across two aggregate round groupings that represent early (rounds 6 – 14) and late (rounds 15 – 24) portions of the experiment. Formally, the model is given by

$$x_{jt} = \alpha * R_{1-5,jt} + \sum_{m=1}^{3}\sum_{r=1}^{2} \beta^{m,r} * T_{jt}^{\ m,r} + \varepsilon_{\mathrm{jt}} \qquad (4)$$

where x_{jt} is the observed emissions for group j in round t; $R_{1\text{-}5}$ is an indicator variable that takes a value of 1 for round 1 to round 5 decisions; the $T^{m,r}$ are group structure-specific indicator variables that equal 1 if the decision corresponds to structure m and round grouping r, and the $\beta^{m,r}$ and α are estimable parameters.

We assume that the model errors (ε_{jt}) are correlated across time (rounds) and follow a common first-order autoregressive (AR(1)) process attributable to factors such as learning. To correct for autocorrelation, the model parameters are estimated using the Prais-Winsten FGLS estimation procedure for panel data. Errors are further assumed heteroscedastic and contemporaneously correlated across groups. To accommodate this covariance structure, the FGLS parameter estimates are accompanied by "robust" panel-corrected standard errors (Beck and Katz 1995).

The model estimation results are presented in Table 3 and indicate that in the regulation-free rounds, the average emissions level of 117.94 is not significantly different from 120, lending support to the previous observation that groups tended towards the profit maximizing level of production in the absence of any public incentives to abate.

The average level of group emissions in the homogeneous setting when the tax policy is implemented is 80.03 in the early round grouping and 81.68 in the late round grouping, both of which are significantly different from the ambient standard of 72. These results are not surprising as it has been observed elsewhere (Spraggon, 2002; Suter et al., 2008) that group emissions levels tend to be 10-15 percent higher than the ambient standard when the threshold for imposing the marginal tax is set equal to the standard (as was done in this study).

In the heterogeneous treatments, group emissions levels are also significantly different from the ambient standard in the early rounds. Outcomes in the late round grouping for both of the heterogeneous treatments, however, are not significantly different from the ambient standard. This is an important result, as it appears that individuals operating in a heterogeneous setting are more likely to approach the ambient standard than homogeneous groups.[3] This is in line with Spraggon's (2004) findings with heterogeneous groups operating under the tax/subsidy policy. It is, however, surprising that heterogeneous groups appear on average to be able to better approximate ambient standards than homogeneous groups of polluters. Anecdotal evidence suggests that individuals in the heterogeneous setting are less likely to increase emissions out of frustration with fellow group members that are not reducing their emissions to levels necessary to achieve the ambient standard. When everyone in the group is identical, some participants appear to respond more to relative payouts than absolute payouts and increase emissions in an attempt to earn more than their fellow group members.

Result 2: With heterogeneity, the ambient standard is achieved as a result of overabatement on the part of large farms and underabatement on the part of small farms in the Type 1 setting. In the Type 2 setting such systematic divergences do not occur, although there is some evidence of underabatement by small farms.

Correspondence with optimal emissions by farm size is investigated through a model similar to that presented above. The dependent variable in this case, however, is the difference, $y_{jt} = r_{jt} - r^{*s}$, between the actual farm emissions level (r_{jt}) and the theoretical optimum (r^{*s}) for each farm size in each treatment. The difference model that is estimated is given by

[3] This tendency may be strengthened in our experiments in that we do not allow a stochastic component in the emissions function in our effort to be consistent with the theoretical presentation of Segerson and Wu (2006). In contrast to the body of experiments that follow a stochastic formulation of the non-point source pollution problem, the deterministic pollution function allows participants to conclude that someone in the group is underabating in the homogeneous settings, likely creating frustration and a variety of possible strategic responses.

$$y_{jt} = \sum_{m=1}^{3}\sum_{s=1}^{3} \beta^{m,g} * T_{jt}^{m,g} + \varepsilon_{\text{jt}} \quad (5)$$

where *m* once again represents one of the three group structures and *g* represents one of the three farm sizes. The difference model is estimated using an econometric procedure identical to that described above and the results are presented in Table 4.[4] The results show that emissions from the large farms are significantly less than the optimal amount in the Heterogeneous Type 1 treatment. The large farms are, in essence subsidizing small farms and allowing them to underabate. Recall that in this instance the optimal abatement levels of small farms are relatively large, representing 60% of the regulation-free emissions levels. In contrast the optimal proportion of abatement for large farms, 28%, is relatively low. No systematic deviations from optimal abatement are observed for the medium size group in the Type 1 setting.

In the Heterogeneous Type 2 treatment the small farms again significantly underabate, although the underabatement is significantly less than that of small farms in the Heterogeneous Type 1 treatment. The large farms do not, however, overabate in the Heterogeneous Type 2 treatment. This apparent reversal might be deemed consistent with each size farm gravitating toward the average emissions reduction level of 40%. However, such a conclusion is not supported by the continued tendency toward underabatement exhibited by the small farms. Again, there is no systematic deviation from the social optimum for medium-sized farms, which is an interesting contrast with the homogeneous treatment.

Result 3: In the heterogeneous case, predatory actions by large farms can result in bankruptcy by small farms.

[4] One of the Heterogeneous Type I groups is left out of the estimation as a bankruptcy occurred in this group.

Given that each farm in the group pays the identical tax for pollution levels above the ambient standard, the potential tax burden necessarily represents a greater proportion of gross income for the small-sized farms. This was made particularly apparent in group 3 of the Heterogeneous Type 1 treatment, which grossly underabated in early rounds. In particular, in rounds 6-12, the large farm participant took no efforts to abate relative to the baseline case (i.e., emission levels remained at 50 units[5]). The result was unavoidable bankruptcy by each of the three small farms in round 9. With farms exiting the industry, the ambient standard was clearly easier to attain for the surviving farms, resulting in higher profits for those that continued to produce in the watershed. This result should raise concerns as it suggests strategic possibilities by farms that can best weather taxes for a short period and opens the door for predatory opportunism when there are disparate proportional financial burdens borne by different sized farms under the ambient-based tax.

5. Policy Implications

This research adds to the limited body of experimental literature that evaluates ambient tax mechanisms. In contrast with Spraggon's (2004) experimental results, watersheds composed of homogeneous farms appear to perform worse, relative to the heterogeneous farm case, with respect to achieving water quality standards. Elsewhere, however, it has been demonstrated that underabatement in homogeneous settings can be reduced by lowering the tax threshold slightly below the ambient standard (Suter et al., 2008). Hence, from a policy perspective this relative disadvantage can potentially be mitigated.

[5] Anecdotally, post-experiment discussion with this participant suggests that the zero abatement was a deliberate, and indeed successful, attempt to control the market.

One overarching theme of our results is that that there appears to be important strategic motives in heterogeneous farm settings which are absent from existing theoretical models. These motives lead to, in some instances, large deviations between theoretical expectations and actual behavior at the participant level. We maintain that these outcomes may be attributed, at least in part, to a common characteristic of many of the proposed coercive ambient tax instruments: they impose equal or approximately equal liabilities regardless of farm characteristics. First, in the Heterogeneous Type 1 setting, large farms systematically overabated and thus subsidized underabatement by small farms. As noted by Spraggon (2004) such practices elevate the concern noted by Shortle and Horan (2001) and others "regarding the ability of ambient pollution instrument to effectively control the nonpoint source pollution problem" (p 854). Second, consider the occasion when a single large farm deliberately underabated relative to the social optimum. In this instance, the application of equal tax penalties across farm sizes drove small farms to bankruptcy. Hence, even if abatement levels approximate optimal levels on average in a watershed comprised of heterogeneous farms, our results suggest that the long run distribution of farm sizes may be affected by the implementation of ambient tax policies. Should such forced structural change be deemed undesirable, then implementation of ambient tax measures may need to be accompanied by secondary policies, such as tax circuit breakers that limit tax burdens for those farms demonstrating that they have indeed invested in significant pollution abatement technologies or practices.

Dynamic models that allow for possible farm insolvency due to excess tax burden, and allow a farm's decision to be based on expectations about collective deviations from optimal behavior on the part of the other farms, may better describe laboratory data and, by extension, potential policy applications. While in this research we concentrate on variations in abatement cost functions across farm sizes, this insolvency issue would seem to carry over to a setting with a group of farms that are relatively homogeneous in terms of size and emissions, but are heterogeneous in terms of their assets.

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Table 1. Representative Characteristics of "Small" and "Large" Dairy Farms

	Small Dairy	Large Dairy
Regulation	no regulation	heavy regulation
Stall	tie stall	free stall
Feeding	individual feeding	total mix ratio-eat all you want
Forage management	tractors and wagons	trucks
Harvesting	choppers	self propelled
Storage	upright silos	bunker storage
Spreading	box spreader	tanker (liquid), pump system
Manure	daily spreading	storage
Treatment	no treatment system	digestion and manure separation
Grazing	field grazing	no grazing

Table 2. Experimental Design Parameters

	Description	Small Dairy	Medium Dairy	Large Dairy
	Baseline Income	30,000	75,000	180,000
	Number of Cows (N)	80	200	660
	Baseline Emissions per Cow (EPC)	0.125	0.100	0.075
	Baseline Emissions	10	20	50
Hetero Type 1	Abatement Cost Per Cow (CPC) Function (r is farm level emissions)	$(52.9(EPC-r/80))^3$	$(80.5*(EPC-r/200))^3$	$(125.8*(EPC-r/660))^3$
	Total Abatement Cost Function	CPC*80	CPC*200	CPC*660
	Optimal Emissions (% of Baseline)	4 (40%)	12 (60%)	36 (72%)
	Cost of Optimal Abatement	5,000	6,667	11,250
Hetero Type 2	Abatement Cost Per Cow (CPC) Function (r is farm level emissions)	$(96.1(EPC-r/N80))^3$	$(80.5*(EPC-r/200))^3$	$(82.5*(EPC-r/660))^3$
	Total Abatement Cost Function	CPC*80	CPC*200	CPC*660
	Optimal Emissions	8 (80%)	12 (60%)	24 (48%)
	Cost of Optimal Abatement	1,109	6,667	21,374

Table 3. Group Emissions Model

Group Structure	Round	Predicted Group Emissions	Actual Group Emissions
Pooled	1 – 5	120	117.94 (1.19)
Homogeneous	6 – 14	72	80.03** (1.42)
	15 – 25		81.68** (1.42)
Heterogeneous Type 1	6 – 14	72	82.68** (1.96)
	15 – 25		75.00 (1.97)
Heterogeneous Type 2	6 – 14	72	74.76* (1.58)
	15 – 25		73.61 (1.58)
N = 288			
Wald Chi Sq = 12,440**			

Note: Asterisks (**) and (*) denote estimated parameter that is significantly different from the predicted outcome at the 5% and 10% levels respectively. Standard errors are in parentheses.

Table 4. Difference Model

Treatment	Farm Size	Difference from Optimal Emissions
Homogeneous	M	1.57** (0.228)
Heterogeneous Type 1	S	1.95** (0.333)
	M	-0.420 (0.302)
	L	-2.40* (1.44)
Heterogeneous Type 2	S	0.688** (0.118)
	M	-0.485 (0.412)
	L	1.081 (1.251)
N = 1,254		
Wald Chi Sq = 243.82**		

Note: Asterisks (**) and (*) denote estimated parameter that is significantly different from the predicted level at the 5% and 10% levels respectively. Standard errors are in parentheses.

APPENDIX

INTRODUCTION

This experiment is a study of individual and group decision-making. If you follow these instructions carefully and make informed decisions you will earn money. The money you earn will be paid to you, in cash, at the end of the experiment. A research foundation has provided the funding for this study.

You will be in a group consisting of six players. Each player assumes the role of a different firm. Think of your firm and the five other firms as being located near a common water resource.

Your firm yields earnings through its operations. Your firm's operations also generate emissions, which affect the water quality of the common water resource. The combined emissions from each of the six firms located near the water resource determine the level of **Total Pollution** in each round. Pollution affects the well-being of water resource users. For example, high pollution levels affect the health of fish, causing losses to fisherman.

The experiment is broken up into many decision "rounds". There are two parts to the experiment. Part A of the experiment consists of the first 5 rounds, whereas Part B includes the remaining rounds. You will be given additional instructions after Part A is completed.

In each round you must make an **Emissions Decision**. In general, the lower your firm's emissions, the lower the level of earnings for your firm. You have been provided a sheet titled *Emissions Decision Sheet* that lists the level of **Firm Earnings** associated with various levels of emissions generated by your firm. Firm Earnings are denominated in "tokens", which will be exchanged for cash at the end of the experiment according to the exchange rate listed on the *Emissions Decision Sheet*. In addition to Firm Earnings, you are also given 5,000 tokens of **General Earnings** in each round.

In your group there are three "small" firms, two "medium" firms and one "large" firm. The size of your firm is indicated on your *Emissions Decision Sheet*.

A round of the experiment is complete when all six players have made their emissions decisions. The computer will then report the **Total Pollution** for that round. It will also calculate your ***Total Earnings*** by summing up **Firm Earnings** + **General Earnings**. Pollution does not affect your earnings whatsoever in Part A of the experiment. Below we explain how to make decisions using your computer.

USING THE COMPUTER

In each round, your task is to make an **Emissions Decision**. The Emissions Decision that you type in must be a whole number that is in the range listed on your computer screen. When you type in an emissions decision and hit the enter key, the corresponding **Firm Earnings** amount will appear on your screen. You can verify that the firm earnings amount that appears is identical to that provided on the *Emissions Decisions Sheet*.

When you are satisfied with your Emissions Decision, you must then click the **<SUBMIT>** button for that round. Once you have clicked the **<SUBMIT>** button, it is no longer possible to change your decision.

After all six players have clicked the submit button, the experiment moderator will instruct you to click the **<RECEIVE>** button. After clicking the **<RECEIVE>** button, the cells indicating the **Total Pollution** and ***Round Earnings*** will be filled in. The Round Earnings cell simply sums up your Firm Earnings plus General Earnings. Recall that pollution does not affect your earnings in Part A of the experiment.

As the experiment progresses, the total number of tokens you have earned will be calculated in the **Total Tokens** box located in the lower right portion of the spreadsheet. The **Total Earnings ($)** box displays the amount of money you have earned, in U.S. dollars, after the tokens have been exchanged.

INSTRUCTIONS FOR PART B

Please click the ***Go on to Part B*** button located underneath the Total Earnings ($) cell. In Part B of the experiment you will continue to make an **Emissions Decision**. A key difference, however, is that **Total Pollution** now affects your earnings. Recall that Total Pollution is the combined emissions from all firms in your group. In particular, in order to protect the water resource, the regulator requires you, and everyone else in your group, to make the following **Tax Payment** on Total Pollution:

If Total Pollution is less than or equal to **72**: **Tax Payment** = 0

If Total Pollution is greater than **72**: **Tax Payment** = 2,500 * **(Total Pollution** – 72)

In other words, if **Total Pollution** is less than or equal to 72, you pay <u>nothing</u>. If Total Pollution is greater than 72, <u>each</u> player pays 2,500 tokens for every unit of pollution above 72 units. Since Total Pollution is the combined emissions from all six firms, the amount of the Tax Payment is determined by the emissions decisions of <u>everyone</u> in your group, not just your own. The *Tax Calculation Sheet* that has been provided to you indicates the Tax Payment corresponding to levels of Total Pollution.

After everyone makes his or her management decision, Total Pollution will be calculated as before. The Tax Payment cell will be calculated using the formula above. The Tax Payment, if any, will be deducted from your earnings so that ***Round Earnings*** = **Firm Earnings – Tax Payment + General Earnings**.

<u>Understanding How the Experiment Works</u>

In this experiment, the computer makes all relevant calculations. However, it is very important for our research that you understand how the experiment works.

In the table below, first make an Emissions Decision and then make a guess at the combined emissions from the other five firms. Note that there are no right or wrong answers for these two items. Next, fill in the remaining empty fields of the table using the *Emissions Decision Sheet* and *Tax Calculation Sheet* as references.

Emissions Decision *(you choose)*	
Firm Earnings *(from Emissions Decision Sheet)*	
General Earnings	**5,000**
Combined emissions from the other 5 firms *(you choose)*	
Total Pollution	
Tax Payment *(from Tax Calculation Sheet)*	
Round Earnings	

Tax Calculation Sheet					
Total Pollution	**Tax**	**Total Pollution**	**Tax**	**Total Pollution**	**Tax**
31	0	65	0	99	67,500
32	0	66	0	100	70,000
33	0	67	0	101	72,500
34	0	68	0	102	75,000
35	0	69	0	103	77,500
36	0	70	0	104	80,000
37	0	71	0	105	82,500
38	0	72	0	106	85,000
39	0	73	2,500	107	87,500
40	0	74	5,000	108	90,000
41	0	75	7,500	109	92,500
42	0	76	10,000	110	95,000
43	0	77	12,500	111	97,500
44	0	78	15,000	112	100,000
45	0	79	17,500	113	102,500
46	0	80	20,000	114	105,000
47	0	81	22,500	115	107,500
48	0	82	25,000	116	110,000
49	0	83	27,500	117	112,500
50	0	84	30,000	118	115,000
51	0	85	32,500	119	117,500
52	0	86	35,000	120	120,000
53	0	87	37,500	121	122,500
54	0	88	40,000	122	125,000
55	0	89	42,500	123	127,500
56	0	90	45,000	124	130,000
57	0	91	47,500	125	132,500
58	0	92	50,000	126	135,000
59	0	93	52,500	127	137,500
60	0	94	55,000	128	140,000
61	0	95	57,500	129	142,500
62	0	96	60,000	130	145,000
63	0	97	62,500	131	147,500
64	0	98	65,000	132	150,000

Emissions Decision Sheet

Firm Size: Medium	Exchange Rate: $1 = 70,000 Tokens
Emissions Decision	**Firm Earnings**
22	74,896
21	74,987
20	75,000
19	74,987
18	74,896
17	74,648
16	74,167
15	73,372
14	72,188
13	70,534
12	68,333
11	65,508
10	61,979
9	57,669
8	52,500
7	46,393
6	39,271
5	31,055
4	21,667
3	11,029