Dynamic Pollution Taxes under Regulatory Uncertainty

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Abstract

This paper considers a setting where a regulator with incomplete information from which to optimally set a pollution tax uses a linear, dynamically adjusting tax mechanism to cost-effectively meet a specified pollution standard. This mechanism provides strong incentives for firms to strategically misrepresent their true abatement costs in order to lower the tax rate while maintaining long-run incentives for least-cost abatement. Using laboratory experiments, we examine dynamic taxes in both point and nonpoint source pollution regulatory settings. We find that in equilibrium the pollution standard is met on average across a variety of policy designs. Further, the observed equilibrium tax rates, and the effects of policy design on tax rates, are generally consistent with a theoretical model that allows for a mix of myopic and strategic firms.

Keywords: dynamic taxes; emissions tax; ambient tax; laboratory experiments; regulatory uncertainty

1. Introduction

Uncertainty regarding individual firm and industry-level marginal abatement costs has been a consideration in pollution control instrument design since the 1970s. Of particular prominence is Weitzman's "prices versus quantity" proposition that the expected efficiency equivalence of price (i.e. emissions taxes) and quantity (i.e. tradable pollution permits) control instruments ceases to hold in situations where marginal abatement costs and/or benefits are not known with certainty (Weitzman, 1974). In recent years, uncertainty over the benefits and costs of possible climate change policies has reinvigorated academic and policy interest in this issue (e.g. Fischer, Parry and Pizer, 2003; Pizer, 1999; Quirion, 2004). Weitzman's seminal article and many of the theoretical analyses that have followed, however, focus on static pollution control instruments that seek to achieve optimal pollution levels. In practice, regulators have the potential to make iterative adjustments to pollution control instruments to achieve an exogenously determined standard, using signals relayed through past behavior. This design issue and the potential for a dynamic tax solution were introduced by Baumol (1972):

> "Though we are unable to determine in advance precisely a set of tax values that will achieve the desired output standards, the output level achieved by a given tax arrangement is readily observed and, at least in principle, it is possible to learn by trial and error, continuing in the direction of change of any tax modifications that turn out to bring outputs closer to their target levels." (p. 391)

In this article we test dynamically adjusting tax policies, following on the ideas of Baumol, through the use of laboratory economics experiments.

On the whole, emissions and environment-related taxes – most prevalent in EU countries – have not been fixed, but have rather increased (in real terms) over time (ECOTECH, 2001). For example, taxes on transportation fuel in many European countries have increased over time following pre-announced programs of rate hikes (Sterner and Kohlin, 2003). Although we have not found any direct evidence to suggest that tax rate *changes* have been motivated by past tax responses, in theory dynamic taxes can be either increased or decreased in response to observed levels of pollution abatement. Dynamic tax policies in combination with the information asymmetry that results from polluters having greater knowledge of abatement costs than the regulator, however, brings about the potential for strategic responses by polluters. In particular, firms have an incentive to strategically overabate in the short run, which signals to the regulator that they have higher abatement costs than they actually do, in order to lower future tax rates.

In addition to uncertainty with regard to the abatement cost functions of polluting firms, the inability to effectively monitor emissions on a firm by firm basis (i.e., the case of nonpoint source pollution) also complicates regulatory policy. Uncertainty over efficient tax rates is likely to be significant in cases of nonpoint source pollution, thus making dynamic policy solutions a necessity. Although there are only a few cases where nonpoint polluters are subject to tax-based regulatory policies (Segerson, 1999), there has been increased attention devoted to nonpoint source regulation in both academic and policy circles. Given that firm emissions are not readily observed, the focus in the economics literature has been on ambient tax mechanisms, whereby firms pay taxes based on observed ambient water quality which depends on emissions from the polluter group as a whole. Relative to an emissions tax, the incentives for strategic overabatement are higher with an ambient-based tax instrument, as the potential long run tax savings from over abatement are more substantial.

In this paper we use laboratory experiments to gain insight on the empirical properties of a linear dynamic tax mechanism in both emissions (i.e. point source) and ambient (i.e. nonpoint source) pollution regulatory settings. While there has been substantial experimental research on ambient pollution based policies for addressing nonpoint source pollution (e.g., Alpizar et al., 2004; Cochard et al., 2005; Poe et al., 2004; Spraggon 2002, 2004; Suter et al. 2008; Vossler et al. 2006), there is a paucity of experimental research, beyond Plott's (1983) seminal study, on tax-based approaches to regulate point source pollution. Importantly, the experimental research to date on both point and non-point source tax policies has evaluated static regulatory mechanisms under the assumption that the regulator has complete information from which to parameterize the optimal policy instrument. This paper takes an important next step in the experimental pollution tax literature by examining the performance of a linear dynamic tax that provides appropriate long-run incentives for abatement in a setting when the regulator has incomplete information.

The policy that we investigate draws from the growing theoretical literature on dynamic policies to regulate point source (e.g., Karp and Livernois, 1994; Moledina et al., 2003; Costello and Karp, 2004) as well as nonpoint source polluters (Karp, 2005). The policy involves first formulating a tax policy using incomplete information and updating the policy based on deviations of aggregate emissions from a standard. One important property of this mechanism is that it provides the opportunity for firms to strategically overabate in the short term in order to lower the future (and steady state) tax rate.

2. Theoretical Framework

In this section we outline the theory underlying the linear dynamic tax mechanism, which extends the work of Karp and Livernois (1994) and Karp (2005) to allow for the regulated industry to be a mix of two firm types: myopic and strategic. Myopic firms are assumed to only maximize current period profits. Strategic firms are assumed to be forward looking in that they consider all future periods in order to maximize the present value of profits. Strategic firms seize the opportunity to reduce their future tax burden through overabatement.

Whether in a naturally-occurring or experimental setting, myopic behavior can be motivated by several possible factors. The simplest of explanations are of course a failure to see the big picture or employing the belief that maximizing current period profits is consistent with long-run profit maximization. Myopic behavior can also be motivated by a concern for relative profits, or similarly, remaining competitive. In the dynamic tax environment, not only is strategic behavior costly, but the benefits accrue to all through lower marginal taxes. Thus, even with full understanding of the long-term benefits of strategic play, a firm may opt to free-ride on the overabatement of others in order to maximize relative payoff or remain competitive. On the flip-side, even if a firm believes all others will behave myopically, under the dynamic tax a firm can nevertheless increase long-run profits through strategic overabatement. It is thus plausible that both myopic and strategic firms exist in equilibrium.

It is assumed that a dynamic tax policy is imposed on an industry of *n* polluting firms with homogeneous profit functions. Let $x_{it,k}$ represent the emissions for firm *i* at time *t*, with *k* denoting firm type. Aggregate emissions by the group are defined as $\sum_{i \in n} x_{it,k} = X_t$. It is assumed that emissions reductions below a baseline level of emissions, $\bar{x}$, are increasingly costly for a firm so that the pre-tax profit function $R(x)$ has $R'(x) > 0$, and $R''(x) \leq 0$. Importantly, it is also assumed that regulators do not have knowledge of the industry profit function.

2.1 Dynamic emissions tax

Suppose that a regulator desires to reduce aggregate emissions to an exogenous standard X^* through the imposition of a dynamic emissions tax. In each period, the firm pays a per-unit tax $\tau_t \geq 0$ on their emissions. As the regulator has incomplete information from which to efficiently set the tax, it is assumed that the initial tax rate, τ_0, is set at some exogenously determined initial value and evolves according to

$$\begin{aligned} \tau_{t+1} &= \tau_t + \alpha\left(X_t - X^*\right) && \text{if} \quad \tau_t + \alpha\left(X_t - X^*\right) > 0 \\ \tau_{t+1} &= 0 && \text{if} \quad \tau_t + \alpha\left(X_t - X^*\right) \leq 0, \end{aligned} \tag{1}$$

where $\alpha > 0$ is an adjustment parameter freely chosen by the regulator. In words, if aggregate emissions are above (below) the emissions standard in a given period, then the tax rate increases (decreases) in the period immediately following. The magnitude of the increase or decrease depends both on the magnitude by which emissions diverge from the standard and the size of the adjustment parameter.

Profits to a firm in a given period of the tax policy are simply

$$R\left(x_{it,k}\right) - \tau_t x_{it,k} = 0. \tag{2}$$

In any period a myopic firm, denoted as type *m*, will choose a level of emissions that equates marginal pre-tax profits to the marginal tax.

$$R'\left(x_{it,m}\right) = \tau_t. \tag{3}$$

If all firms in the market are myopic then, from the homogeneity of the polluter group, it follows that in steady state myopic firms emit $x_m = X^*/n$. The steady state tax rate, τ, that induces myopic firms to achieve the target level of pollution can therefore be defined as

$$\tau = R'\left(X^*/n\right). \tag{4}$$

Instead, one or more firms may be strategic, type *s* firms, and we next model the dynamic choice problem of a representative strategic firm in a setting where the industry is composed of $n_m < n$ myopic firms and $n - n_m$ strategic firms. If all firms are strategic, the solution to the control problem is an Open-Loop Equilibrium, which represents the schedule of emissions decisions across all rounds that maximize the present value of profits for a firm. Otherwise, the representative strategic firm conditions their emissions on the response of the myopic firm(s) to the tax and the solution is a Markov Perfect Equilibrium. In the mixed-type setting, the profit maximization problem of the representative strategic firm is given by

$$\begin{aligned} &Max \sum_{t=0}^{\infty} \rho^t \left[R\left(x_{it,s}\right) - \tau_t x_{it,s} \right] \\ &s.t.\ \tau_{t+1} = \tau_t + \alpha \left(\sum_{i=n_m+1}^{n} x_{it,s} + \sum_{i=1}^{n_m} x_{it,m}\left(\tau_t\right) - X^* \right) \\ &\quad \tau_t \geq 0 \\ &\quad \tau_0 \ \ given, \end{aligned} \tag{5}$$

where ρ is a discount factor that is functionally related to the discount rate, δ, according to $\rho = 1/\left(1+\delta\right)$. The discrete-time current-value Hamiltonian for the optimization problem above can be written as

$$H\left(x_{it,s}, \tau_t, \lambda_{t+1}\right) = R\left(x_{it,s}\right) - \tau_t x_{it,s} + \rho\lambda_{t+1}\alpha \left(\sum_{i=n_m+1}^{n} x_{it,s} + \sum_{i=1}^{n_m} x_{it,m}\left(\tau_t\right) - X^* \right), \tag{6}$$

and the associated first-order necessary conditions are

$$R'\left(x_{it,s}\right) = \tau_t - \rho\lambda_{t+1}\alpha \tag{7a}$$

$$\rho\lambda_{t+1} - \lambda_t = x_{it,s} - \rho\lambda_{t+1}\alpha \sum_{i=1}^{n_m} x'_{it,m}\left(\tau_t\right) \tag{7b}$$

$$\tau_{t+1} - \tau_t = \alpha \left(\sum_{i=n_m+1}^{n} x_{it,s} + \sum_{i=1}^{n_m} x_{it,m}\left(\tau_t\right) - X^* \right). \tag{7c}$$

where $x'_{it,m}\left(\tau_t\right) \leq 0$ is the marginal change in emissions for a myopic firm associated with a marginal increase in the tax rate.

In steady state, $\tau_{t+1} = \tau_t$, which implies that $X_t = X^*$, i.e. the aggregate emissions target is exactly met. Assuming that strategic firms play symmetrically, the first order necessary conditions for a strategic firm must satisfy

$$\tau = R'(x_s) - \frac{\alpha x_s}{\delta - \alpha n_m x_m'(\tau)}. \tag{8}$$

In the special case where all firms are strategic (i.e. $n_m = 0$), $x_s = X^*/n$ and equation (8) yields an explicit solution for τ:

$$\tau = max\left[R'(X^*/n) - \frac{\alpha X^*}{n\delta}, 0\right]. \tag{9}$$

Equations (8) and (9) imply that the steady state tax is decreasing in α and does not depend on τ_0. Higher values of the adjustment parameter allow strategic firms to gain a more immediate benefit from overabatement, and thus increase the discounted benefits of reducing the tax below static levels. Given that $\delta \geq 0$, $\alpha > 0$ and $X^* \geq 0$, comparison of (9) with (4) reveals that the steady state tax rate is at least as high in the case where all firms behave myopically relative to the case when all firms behave strategically. From equation (8) it is straightforward to show that the steady state tax rate is increasing in the number of myopic firms. The intuition for this is that the presence of myopic firms decreases the benefits to a strategic firm from overabatement, as the myopic firm responds to the resultant lower tax with an increase in emissions.

2.2 Dynamic ambient tax

We next consider a dynamic ambient tax, which is better suited for a case where it is prohibitively costly to measure individual firm emissions, as in the case of nonpoint source pollution. Under the ambient tax each firm pays the tax rate, τ_t, on each unit of *aggregate* emissions rather than on individual emissions. Basing tax payments on aggregate emissions as opposed to individual emissions does not alter the myopic firm's marginal incentives in a given period, since equation (3) continues to hold. If a firm behaves strategically, however, the incentives for abatement are different than in the emissions tax case, given that the firm's tax payment in a particular period is the product of the period specific tax rate and the quantity of aggregate emissions, as opposed to own emissions.

When the market is composed of one or more strategic firms, the analytical solution for a representative strategic firm's steady state condition becomes more complex with the ambient tax. The tax paid by the strategic firm is a function of the pollution decisions of all firms, which are themselves a function of the tax level for myopic firms. The Hamiltonian for a strategic firm under the ambient tax in a market comprised of myopic and strategic firms can be written as

$$H\left(x_{it,s},\tau_t,\lambda_{t+1}\right)=R\left(x_{it,s}\right)-\tau_t\left(\sum_{i=n_m+1}^{n}x_{it,s}+\sum_{i=1}^{n_m}x_{it,m}\left(\tau_t\right)\right)+\rho\lambda_{t+1}\alpha\left(\sum_{i=n_m+1}^{n}x_{it,s}+\sum_{i=1}^{n_m}x_{it,m}\left(\tau_t\right)-X^*\right). \tag{10}$$

From the first order necessary conditions, it can be shown that the steady state ambient tax condition for strategic firms is given by

$$\tau=R'\left(x_s\right)-\frac{\alpha}{\delta}\left[R'\left(x_s\right)n_m x_m'\left(\tau\right)+X^*\right]. \tag{11}$$

For the case where all firms behave strategically, the steady state tax is

$$\tau=max\left[R'\left(X^*/n\right)-\frac{\alpha X^*}{\delta},0\right]. \tag{12}$$

Equations (11) and (12) imply that – as in the case of the emissions tax – the steady state tax rate is invariant to the choice of τ_0. When all firms are strategic, α is inversely related to the steady state tax and comparison of (9) with (12) implies that the ambient tax is relatively lower than the emissions tax. When there is a mixture of firm types, however, the effect of α and the comparison of steady state emission and ambient taxes becomes more complex. Inspection of equation (11) reveals that α is inversely related to the steady state tax, as in the emissions tax case, when $-R'(x_s)n_m x'_m(\tau) < X^*$. When $-R'(x_s)n_m x'_m(\tau) > X^*$, however, increases in α are positively related to the steady state tax. This result is more likely to occur as the marginal costs of abatement, the number of myopic firms, and the response of myopic firms to marginal changes in the tax increase and as the emissions standard is reduced...

To compare outcomes under the emissions and ambient taxes in the mixed-type case, we next state the main theoretical results in the form of two propositions.

Proposition 1. *When the industry is composed of both myopic and strategic firms, in steady state* $x_s < X^*/n < x_m$ *if and only if* $\tau < R'(X^*/n)$ *and* $x_s > X^*/n > x_m$ *if and only if* $\tau > R'(X^*/n)$.

Proof. Given the decision making of myopic firms, $x_m < X^*/n$ if and only if $\tau > R'(X^*/n)$. The steady state condition requires $n_m x_m + (n - n_m)x_s = X^*$, so that if $x_m < X^*/n$ it follows that $x_s > X^*/n$ in steady state and thus $x_s > X^*/n > x_m$. The same reasoning can be used to show that $x_m > X^*/n$ requires $\tau < R'(X^*/n)$ and $x_s < X^*/n$.

Proposition 2. *When the industry is composed of both myopic and strategic firms, in steady state* $\tau < R'(X^*/n)$ *in the emissions tax case, while in the ambient tax case both* $\tau < R'(X^*/n)$ *and* $\tau > R'(X^*/n)$ *are possible.*

Proof. We proceed by first showing that $\tau > R'(X^*/n)$ is not possible in the emissions tax case and then show that $\tau > R'(X^*/n)$ is possible in the case of the ambient tax. If $\tau > R'(X^*/n)$ then it follows from Proposition 1 that $x_m < X^*/n < x_s$. However, if $X^*/n < x_s$ then equation (8) implies that under the emissions tax $\tau < R'(X^*/n)$ and we reach a contradiction. Under the ambient tax, it is possible to have $\tau > R'(X^*/n)$. Equation (11) implies that when $-R'(x_s)n_m x_m'(\tau)$ is sufficiently greater than X^*, then the steady state ambient tax will have $\tau > R'(X^*/n)$.

Propositions 1 and 2 imply that although the ambient tax is unambiguously lower than the emissions tax case when all firms are strategic, in the mixed-type case it is possible to have an ambient tax that is higher than the emissions tax. In addition, when there is a mix of firm types, the standard is no longer met at minimum cost.

2.3 Testable hypotheses

The theory lends itself to several testable hypotheses related to policy design, as they pertain to the steady state emissions and tax rate:

Hypothesis 1. Aggregate emissions are equal the standard, X^*

Hypothesis 2. The tax rate is equal to the efficient static tax

Hypothesis 3. The tax rate is invariant to the speed of adjustment parameter, α

Hypothesis 4. The tax rate is invariant to instrument choice (ambient or emissions tax)

Hypothesis 5. The tax rate is invariant to the initial tax, τ_0

In terms of aggregate emissions the pollution standard is exactly met regardless of firm type(s), policy design or instrument choice. Thus, if Hypothesis 1 is true it follows that emissions are invariant to policy design. With respect to the steady state tax, if all firms are myopic, regardless of policy design or instrument choice the tax rate is the efficient static tax, i.e. the one the regulator would set under complete information that satisfies $\tau = R'(X^*/n)$. Given the parameters chosen in our experimental design, the steady state tax when at least some firms are strategic is: (i) lower than when all firms are myopic; (ii) a decreasing function of the speed of adjustment parameter (α); and (iii) lower for the ambient tax relative to the emissions tax.[1] As evidenced by the fact that the initial tax (τ_0) does not appear among the first-order conditions, even when some players are strategic this design parameter has no effect on the steady state tax. In sum, when all firms are myopic all null hypotheses are true and when one or more firms are strategic, only Hypotheses 1 and 5 hold.

3. Experimental Design

One hundred and sixty undergraduate students at the University of Tennessee participated in the experiment between November 2008 and April 2009. These individuals came from a large subject pool of students that had previously registered to be potential participants in economics experiments. The participant pool is similar to the general undergraduate population in terms of age, gender, and academic major. Experiments were conducted in a designated experimental laboratory. Participant earnings were denominated in experimental currency, which were exchanged for dollars at the end of the session at the known rate of 60,000 to $1US. The experiment lasted approximately ninety minutes and individual earnings averaged $19.

In each period of the experiment participants were asked to choose a level of "output" between 0 and 24. This choice is synonymous to emissions (x), and although we use an environmental context in our discussion of the experimental design and results, the experiment used neutral framing. Paired with each emissions choice was a level of (pre-tax) profit, generated from the profit function $R(x) = A - 150(20 - x)^2$. In the absence of taxes, profits are maximized

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[1] Although the ambient tax can be higher than the emissions tax in theory when there is a mix of types, in our experimental design the ambient tax is always lower than the emissions tax in steady state.

with $x = 20$, which corresponds with the value $\bar{x}$ in the theory section. The parameter A varied across treatments in order to roughly equate expected earnings while maintaining marginal incentives. In order for participants to gain familiarity with the computer software and the decision environment, as well as to establish a no-tax baseline, in each of the first five decision periods (labeled as Part A) participants made an emissions choice in the absence of the tax mechanism. This was followed by Part B (20 periods) of the experiment, whereby participants faced the linear dynamic tax. As the underlying theoretical framework assumes an infinitely-repeated game, to implement this as well as possible in the lab we told participants that the number of periods in Part B would be between 20 and 30.

Participants were anonymously placed in groups of four, which remained intact for the duration of the experiment, and were told that the payoff functions were identical for all of the participants in their group. The linear tax mechanism was described in two stages. First, participants were told how payoffs would be determined for a particular period. To help facilitate learning, participants were then asked to work through a calculation exercise which involved making a hypothetical emission decision (and in ambient tax settings both own and aggregate emissions) and then determining their profits for a particular marginal tax. Second, participants were told the value of the marginal tax in the first tax period and that the tax would adjust in the second tax period based on the deviation between aggregate emissions and the emissions standard $X^* = 48$. With groups of four, least-cost compliance occurs when each participant chooses $x = 12$, which represents a 40% reduction from the unregulated state. Participants were provided a "Tax Rate Adjustment Sheet" which mapped all possible levels of aggregate emissions (referred to in the experiments as "group output") to the resulting change in next period's marginal tax. Then, they undertook a second calculation exercise which had them provide a hypothetical level of own and aggregate emissions and determine the resulting marginal tax for the next period. There were three unpaid practice periods prior to the first tax period, whereby the experiment moderator stated verbally how changes in the marginal tax rate were determined and how profits were calculated.

Decisions were made via networked computers using software programmed with z-Tree [Fischbacher, 2007]. The software collected all decisions and made all relevant earnings calculations. Written instructions were provided to each participant, and are included as an Appendix. One of the authors read instructions aloud, for purpose of common knowledge, and addressed questions. Experiment moderators privately checked the two practice calculation questions made by each participant and re-explained procedures in the case of wrong answers.

There are eight distinct dynamic tax treatments, representing a full factorial of the following policy attributes: regulatory setting (emissions or ambient tax), initial tax rate (High and Low), and tax adjustment parameter (Fast and Slow). Each participant faced the same tax treatment during all tax periods of the experiment. For the two regulatory settings, participants under the emissions tax pay a tax on own emissions only, whereas with the ambient tax each participant pays a tax on aggregate emissions. The two initial values for the tax rate are $\tau = 1200$ (Low) and $\tau = 3600$ (High). Given four identical players with marginal profit function $R'(x) = 300(20 - x)$, the aggregate marginal profit function is $R'(X) = 75(80 - X)$. With the aggregate emissions standard of $X^* = 48$, if the regulator had complete information on the profit function the optimal tax would be $R'(48) = \tau = 2400$. As such the Low and High initial values used represent 50% deviations from the optimal (static) tax. The two values for the adjustment parameter that we explore are $\alpha = 75$ (Fast) and $\alpha = 12.5$ (Slow), which represent the slope and 1/6 of the slope, respectively, of the aggregate profit function.

Figures 1a and 1b depict the tax and aggregate emissions paths for the eight treatments when all players are myopic.[2] Under myopic behavior the emissions and ambient tax generate identical marginal incentives. The steady-state equilibrium is $\tau = 2400$ and $x_m = 12$. With the Fast adjustment parameter, convergence to steady state occurs after one period. With the Slow adjustment parameter, convergence occurs in period 13.

Under strategic behavior, the optimal tax and aggregate emissions paths depend on the discount rate and the proportion of myopic players. For purpose of illustration we consider the extreme case where all players are strategic and the discount rate is zero, and present this in Figures 2a and 2b for the eight treatments. This extreme case gives rise to the lowest steady-state tax ($\tau = 0$) under all treatments. Further, for each treatment, this represents the fastest approach to steady state. Thus, discounting and increasing the proportion of myopic players leads to convergence to higher tax rates and slows the approach to steady state. As in the myopic case, with the Fast adjustment parameter, convergence to steady state occurs after one period.

As mentioned above, to better coincide with the theory of an infinitely repeated game participants were not told that the end period of the tax game would be between 20 (which was the true end period) and 30. If all players are myopic, beliefs about the end period do not alter behavior. When one or all players are strategic, theoretical predictions for the infinitely-repeated game are identical to those of the finite game if participants held an expectation of at least 22 tax periods. If the expected end period is less than this, then strategic players converge to the myopic emissions levels for the last one or two periods, depending on the particular treatment. The data suggest no evidence of such behavior.

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[2] Dynamic optimization solutions presented in this section were generated using Microsoft Excel's Solver, subject to the additional choice constraints introduced by experimental design – namely, that only integer values between and including 0 and 24 were included in the choice space.

4. Results

We begin with a simple and transparent analysis to test our first two hypotheses. To examine individual emissions choices, we use an ordinary least squares regression model that specifies individual emissions as a linear function of a set of indicator variables that allow mean emissions to vary by treatment, and, within each treatment, to vary across no policy (Part A) and policy rounds (Part B).[3] To allow for tests of equilibrium behavior, mean emissions are allowed to vary across period 1, period 2, and two policy-round groupings, periods 3-12 and 13-20. In particular, we focus on mean outcomes corresponding with periods 13-20.[4] As discussed above, considering all treatments and any proportion of myopic players, steady state is reached at or before period 13.[5]

To freely allow model errors to be autocorrelated and conditionally heteroskedastic for an individual, as well as to allow this error correlation to vary across all individuals, we use robust standard errors adjusted for clustering at the individual-level (i.e. "cluster-robust" standard errors). Errors across individuals and groups are assumed to be independent. In particular we use the heteroskedasticity-autocorrelation consistent (HAC) covariance estimator of White (1984) and Arellano (1987).[6] This covariance estimator is a generalization of the oft-used heteroskedasticity-consistent covariance estimator of White (1980), and is similar to the Newey-West (1987) HAC covariance estimator except that all autocovariances particular to an individual are included and no kernel weighting function is used. Monte Carlo evidence suggests that test statistics based on this covariance estimator have the correct size for panel data with a

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[3] We also analyzed aggregate (i.e. group-level) emissions, which lead to the same conclusions.

[4] All our conclusions remain if we instead base these hypothesis tests on outcomes from any particular period between 13 and 20, or from any grouping of these periods.

[5] The results presented below are robust to the duration of the final round grouping (i.e., evaluating only decisions up to round 18 does not significantly change the empirical outcomes).

[6] This is implemented in Stata using the "cluster" option for the "regress" command.

moderate number of cross-section units, under various data generating processes (Bertrand, Duflo, and Mullainathan, 2004; Kezdi, 2004; Vossler, 2008).

Table 1 presents the parameter estimates of the Individual Emissions Model, where all estimated coefficients are exactly equal to mean emissions for the specified treatment and time period (grouping). We further analyze the observed tax rates and present estimates of the Tax Rate Model in Table 2. The estimation methods are similar to those used for individual emissions data with the exception that data is necessarily at the group-level, and standard errors are clustered at the group-level. Further, given that participant decisions have no impact on the observed tax rate in the no policy periods, and period 1 of the tax policy, these data are excluded from the model.

Similar to previous ambient tax experiments that included a no-policy baseline (e.g., Plott, 1983; Vossler et al., 2006), we find that emissions are not statistically different from the profit-maximizing level of unregulated emissions, in particular mean emissions are equal to 20 for each treatment, as well as jointly across all treatments [F=1.44; p=0.18] at the 5% level.[7] This can be taken as evidence that participants understand the decision-making framework and that financial incentives are salient enough to motivate identification of the profit-maximizing outcome. Below we summarize our results with respect to the first two hypotheses by focusing on the outcomes from rounds 13 – 20, which we refer to as the steady state outcomes.

Result 1. *In all treatments, average individual emissions are equal to the standard.*

Result 2. *With the exception of Treatment 4, the tax rate is statistically different and lower than the efficient static tax.*

Consistent with the theoretical prediction of aggregate compliance (aggregate emissions equal to 48 or, equivalently, average individual emissions equal to 12), which is invariant to

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[7] Throughout the paper, a 5% significance level is used.

policy design or the proportion of myopic players, we fail to reject that emissions equal 12 in each treatment. Across all treatments, the average emissions choice is 11.98 in steady state, and we fail to reject the hypothesis that mean emissions jointly equal 12 across all treatments [F=0.48; p=0.87]. Further, we fail to reject equality of emissions for any pair of treatments.

Tax rate outcomes are theoretically dependent upon the proportion of myopic players, although if all players are myopic the tax rate is invariant to treatment. Overall, the realized tax rates are not consistent with completely myopic behavior and instead are supportive of some degree of strategic behavior. In particular, the average tax rate across all treatments is $1266, which is approximately 50% below what is predicted when all players are myopic. Further, with the exception of Treatment 4, we reject equality between the mean tax rate and $2400.

4.1 Policy Design Effects

Hypotheses 3 – 5 correspond with the effects of policy design on the tax rate, i.e. treatment effects. To test these hypotheses, we use data from periods 13 to 20 to estimate a Policy Design Effects model, presented in Table 3.[8] The policies we explore have three attributes (regulatory setting, speed of adjustment, initial tax rate), each with two levels, and these design effects can thus be captured using indicator variables.

> **Result 3**. *The equilibrium tax rate decreases, ceteris paribus, with an ambient tax, Fast adjustment parameter, and a Low initial tax.*

As illustrated in Table 3, all three policy variables have a statistically significant and large negative effect on the steady-state tax rate. In particular, using an ambient tax, Fast

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[8] We estimated a similar model using individual emissions choice data, available upon request. The estimated coefficients of the policy variables are quite small in magnitude and are neither individually nor jointly statistically significant. Further, the policy variables explain less than 1% of the variation in the data. This simply confirms our earlier result that there are no differences in average emissions across any pair of treatments.

adjustment parameter, or a Low initial tax rate reduces the steady-state tax rate by approximately \$500. The magnitude of these effects is apparent when looking at two ends of the policy design spectrum. For treatment 4 (emissions tax, Slow adjustment, High initial tax) the steady-state tax is \$2510, whereas in treatment 5 (ambient tax, Fast adjustment, Low initial tax) the steady-state tax is \$619. The policy variables explain 32% of the overall variation in tax rates.

Thus, the findings reject Hypotheses 3 – 5. Rejection of Hypotheses 3 and 4 is consistent with the comparative statics of the dynamic model with (one or more) strategic players, but is in contrast to complete myopic behavior. Rejection of Hypothesis 5 is not supported under any mix of player types.

4.2 Efficiency

To provide insight on individual and group heterogeneity as it pertains to policy evaluation, we analyze measures corresponding with social efficiency. Although average aggregate emissions are found to be equal to the standard, since players have homogeneous profit functions, any substantial variation in choices across individuals and groups can lead to efficiency loss. We operationalize our efficiency analysis by assuming a linear total damages from pollution function with an intercept of 0 and a slope of 2400, which makes the standard consistent with social efficiency.

The economic surplus in a given period is determined by summing the pre-tax earnings of each of the participants (the social benefit) less the social damage, determined by the group emissions in that round. The observed surplus in a particular period is then measured against the surplus under a zero abatement scenario (i.e. the theoretical outcome in the absence of policy), and the maximum surplus possible, to yield a measure of efficiency according to the formula

$$Social\ Efficiency = \frac{S_{actual} - S_{zero}}{S_{max} - S_{zero}} \times 100\% . \qquad (9)$$

The social efficiency measure is thus interpreted as the percentage of the available social welfare gain captured by the tax policy. The social efficiency measure is further partitioned into measures of emissions efficiency (EE) and allocative efficiency (AE) similar to those introduced in Suter et al. (2008). The emissions efficiency measures the degree to which group-level emissions deviates from the pollution standard, while allocative efficiency provides a measure of the variance in emissions choices across participants. Formally, the emissions and allocative efficiency measures multiplicatively determine social efficiency according to

$$Social\ Efficiency = \frac{S_{emissions} - S_{zero}}{S_{max} - S_{zero}} \times \frac{S_{actual} - S_{zero}}{S_{emissions} - S_{zero}} \times 100\% \ , \qquad (10)$$

where $S_{emissions}$ is the social surplus given the sum of emissions choices, under the assumption that emissions decisions do not vary across participants.

The efficiency measures are analyzed separately using the same econometric estimator and indicator variables as the Individual Emissions Model, with the exception that data is necessarily at the group-level, and standard errors are clustered at the group-level. The models are presented in Table 4. We focus on steady-state efficiency measures corresponding with periods 13–20, and for brevity the coefficients (means) corresponding with no-policy decisions and tax periods 1–12 are omitted from Table 4. Overall, social efficiency averages 65%, with an emissions efficiency of 94% and an allocative efficiency of 68%. This suggests that there is little variation in group-level emissions and substantial variation in individual emission choices. There is also very little variation in emissions efficiencies across treatments, or within a particular treatment (i.e. the average treatment-specific standard error is roughly 2%). In contrast, allocative efficiency ranges from 43% to 87%, and along with the large treatment-specific standard errors (roughly 10%) suggests substantial variation both within and between treatments. With relatively large standard errors on the allocative efficiency measures (and likewise social efficiency measures), differences across treatments are not statistically significant. However, the allocative efficiencies for ambient tax treatments tend to be lower: 62% versus 74%.

4.3 Dynamic versus static taxes

As a robustness check, and to gain additional insight on behavior under a dynamic tax, we ran two static tax treatments (four groups of four participants in each). Treatment 9 is an emissions tax with a constant tax rate of 3600, and Treatment 10 is an ambient tax with a tax rate of 1200. The results from these treatments coincide with those from related experiments in the literature (e.g. Plott, 1983; Suter et al., 2008).[9] In particular, the average emissions choice is consistent with theoretical predictions (Treatment 9: actual = 8.02, predicted = 8; Treatment 10: actual = 15.62, predicted = 16). Adjusting for the fact that, theoretically, 75% of available surplus should be captured by these incorrect marginal taxes, observed social efficiency is 98% with the emissions tax (compare to 97% over the last three periods of the tax policy in Plott, 1983) and 79% for the ambient tax (compare to 80% of Treatment 1 in Suter et al., 2008). These efficiency results have two implications. First, ambient taxes in general are less efficient than analogous emissions taxes, regardless of whether they are dynamic. Second, under the assumption that the static tax is set efficiently, dynamic taxes are less efficient than static taxes. Of course, under regulatory uncertainty the second implication is moot.

4.4 Characterizing Observed Behavior

The results largely support the comparative statics suggested by the dynamic model with

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[9] The results presented here are treatment averages corresponding with tax periods 13-20. We note that there is little variation across groups or periods.

strategic players, with the exception of the fact that the initial tax rate has a significant effect on steady state outcomes. Excluding this latter effect, an important remaining question is what mix of player types is consonant with the observed tax rates? As a starting point, assume that all players are strategic. In this case, as suggested by Figure 2, we should observe very low tax rates; indeed, only with discounting does the theory support non-zero tax rates. Furthermore, the emission choice should not vary across subjects. Neither of these expectations is supported by the data. First, we calculated the treatment-specific discount rates that support the observed steady state tax rates. They range from 12% to over 232%, and average approximately 102%.[10] There are large differences in calculated discount rates between Fast adjustment and Slow adjustment treatments, as well as between emissions and ambient tax treatments and both the magnitude and variation across treatments are implausible. If discount rates are further calculated by group, the substantial variation within a treatment also casts doubt on the ability for discounting alone to explain the data. Second, as suggested by the allocative efficiencies – especially relative to the static tax case – there is substantial variation in emissions choices within groups.

We next explore the possibility that there is a mix of types. A myopic player equates marginal profits to the tax rate, and based on our experimental design this implies $x_m(\tau) = 20 - \tau/300$. To identify myopic players, at least statistically, we regressed the emissions choice on the tax rate separately for each individual. In particular, given the time-series nature of the data, we assumed the disturbance followed an AR(1) process and estimated the model using FGLS. Using a joint test for the intercept and slope, we fail to reject the null of myopic play for 34 of 128 or 27% of the sample. Using this proportion of myopic players, the observed tax rates can be

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[10] This does not include Treatment 4, as – given the tax rate is above the efficient static tax of 2400 – the implied discount rate is negative.

generated from the theoretical model with treatment-specific discount rates ranging from 3% to 133%, and 53% on average. All discount rate estimates are below 40% with the exception of Treatments 5 and 6. Thus, the variation among emission tax treatments, and ambient tax treatments with Slow adjustment, can be explained assuming a mix of types. Further, the allocative efficiency analysis supports the existence of different player types.

As a final examination into mixed player types, we used a probit model to analyze the probability of a player being myopic as a function of the treatment indicator variables used in the Policy Design Effects Model. The only statistically significant marginal effect (at 5.6% level) was that a Low initial tax decreases the probability of a player behaving myopically by 13%. Thus, one possible explanation for the identified initial tax effect, which is not supported by the theory, is that this aspect of policy design affects the decision of a player to behave myopically. This seems plausible given that under a high initial tax strategic players overabate relatively more than under a low initial tax (and thus strategy is more costly), and furthermore this causes a larger wedge between the emissions choice (and profitability) between myopic and strategic players both in steady state and on the approach path to steady state.

5. Discussion

The overall results suggest that the dynamic linear tax, in both an emissions tax and an ambient tax setting, provides the correct incentives to motivate average steady state compliance with an aggregate emissions standard. Further, at least some participants seized the opportunity to overabate in order to reduce their long term tax burden, a strategy that led to tax rates roughly 50% below those which would stem from purely myopic behavior. The majority of the observed policy design effects on tax rate outcomes are consistent with a dynamic optimization model that allows for a mix of myopic and strategic players. The lone observed treatment effect that is inconsistent with theory – that a lower initial tax rate lowers the steady state tax – can be explained by the observation that the initial tax rate affected the probability that a player behaved myopically. Theoretically, one negative consequence of having both myopic and strategic players is that the standard is no longer met at least-cost, as even in equilibrium strategic players overabate and myopic players underabate relative to least-cost abatement. This manifested itself empirically through social efficiency measures that were lower than those observed in comparable static tax experiments.

The ability for the ambient version of the linear dynamic tax to meet the aggregate emissions standard suggests promise for use of such a mechanism to regulate nonpoint source water pollution. Indeed, the evolution of the relevant theoretical literature has been motivated in part by refining ambient tax mechanisms to lessen the regulator's information burden. The linear dynamic tax represents seemingly the most extreme case whereby to achieve a particular aggregate emissions standard the regulator simply needs to specify the initial tax rate and adjustment parameter – which can be set somewhat arbitrarily – and then monitor aggregate emissions. If the regulator is interested in motivating an equilibrium with a relatively low tax rate, evidence from our experiments suggest the regulator should use a low initial tax rate and a rule that allows the tax to adjust quickly for deviations from the pollution standard. The end result is a mechanism that is politically more palatable, given that the overall tax burden is reduced. In fact, it might be preferred to set the initial tax rate too low even if the regulator had complete information on the aggregate profit function.

One concern of static ambient tax mechanisms is that they are not collusion-proof, in particular firms have incentives to overabate (see, for example, Hansen, 1998). With the dynamic tax, incentives to collude would seem both self-serving and socially desirable. The coalition can drive the tax rate expediently down to the group-profit maximizing level through overabatement. However, once the equilibrium tax rate is achieved there are no longer incentives to overabate but instead correct incentives to exactly meet the standard. As discussed by Suter et al. (2008), in the static ambient tax setting the optimal tax rate with collusion is much lower than in the noncooperative game. The linear dynamic tax would work to correct the distortion of applying the incorrect tax rate by iteratively lowering the rate in response to overabatement.

Although the linear dynamic tax can serve to reduce the costs of regulation to important industries, this ability to coordinate behavior to realize a low tax rate may not always be seen as favorable. One oft-cited long-run advantage of a tax policy over a policy that utilizes tradable permits is that taxes provide greater incentives for technological innovation. This result comes about because the benefits of future pollution abatement are more certain under a tax policy, where the price of pollution emissions is fixed, in comparison to a tradable permits policy, where the price of emissions is variable. The dynamic tax approach, however, increases the level of uncertainty with regard to future payoffs because the price of pollution evolves over time, thus increasing the risk of investment in abatement technologies. Additionally, a low steady state tax rate would further serve to dampen incentives for innovation. In fact, undertaking costly overabatement in the short term may act as a substitute for R&D in new technologies. Tax policies for addressing climate change will likely attempt to reduce greenhouse gas emissions in the long run by increasing the tax rate over time. Supposing that regulators base new tax rates on perceptions of industry costs, the ability for firms to signal to regulators information about abatement costs through their responses to emission taxes needs to be incorporated into theoretical work related to comparing price versus quantity instruments.

In the traditional debate between implementing pollution taxes or a system of tradable pollution permits, advocates for tradable permits often tout the political benefits of guaranteeing a “cap” on pollution emissions. The dynamic tax presented here allows the regulator to define such an emissions standard and we have shown both theoretically and practically that polluter groups achieve this standard in steady state. The dynamic tax therefore provides the regulator with a hybrid policy that can be adjusted to correspond to the specifics of the market and pollutant to be regulated. In cases where a pollutant has a relatively steep marginal damage function, the benefits of achieving the pollution standard quickly would warrant choosing a relatively fast adjustment parameter. On the other hand, if the slope of the marginal abatement cost curve is relatively steep and the stability of the emissions price is particularly important, then a more slowly adjusting tax may be preferable. Just as allowing for banking and borrowing as well as a “safety valve” price allow a system of pollution permits to take on some of the favorable aspects of a pollution tax, instituting a dynamic tax offers the regulator the opportunity to wed the favorable aspects of a tradable permit system with a pollution tax.

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Table 1 Individual Emissions Model

Dependent variable: individual emissions choice
Number of observations: 3,200 $R^2 = 0.89$

Treatment		**No Policy**	**Tax Policy**			
			Period 1	**Period 2**	**Pds 3-12**	**Pds 13-20**
Emissions Tax	1. α=75;	19.45	12.63	12.44	11.93	12.11
	τ_0=1200	(0.57)	(0.97)	(0.94)	(0.56)	(0.70)
	2. α=75;	20.51	11.38	10.94	11.53	11.93
	τ_0=3600	(0.53)	(2.08)	(1.95)	(0.78)	(1.00)
	3. α=12.5;	19.20	10.75	11.25	11.99	12.45
	τ_0=1200	(0.59)	(1.11)	(1.14)	(0.67)	(0.55)
	4. α=12.5;	20.04	10.75	8.50	10.48*	11.49
	τ_0=3600	(0.23)	(1.32)	(1.19)	(0.41)	(0.29)
Ambient Tax	5. α=75;	19.35	8.38*	14.88*	11.77	11.93
	τ_0=1200	(0.79)	(1.22)	(1.22)	(0.63)	(0.49)
	6. α=75;	19.01	10.06	8.25*	11.43	12.19
	τ_0=3600	(0.69)	(1.86)	(1.64)	(0.88)	(0.95)
	7. α=12.5;	18.93	12.38	11.63	11.61	12.17
	τ_0=1200	(0.66)	(1.30)	(1.42)	(1.01)	(1.14)
	8. α=12.5;	19.63	8.94	6.44*	8.28*	11.59
	τ_0=3600	(0.25)	(2.08)	(1.66)	(1.44)	(1.14)

Notes: Numbers in parentheses are cluster-robust standard errors. * indicates No Policy (Tax Policy) parameter is statistically different than 20 (12) at the 5% level**.**

Table 2 Tax Rate Model

Dependent variable: group-level tax rate
Number of observations: 608 $R^2 = 0.86$

Treatment			**Tax Policy**		
		Period 1	**Period 2**	**Pds 3-12**	**Pds 13-20**
Emissions Tax	1. α=75; τ_0=1200	–	1387.5 (196.5)	1404.4 (212.5)	1216.4 (181.7)
	2. α=75; τ_0=3600	–	3412.5 (699.9)	1946.3* (283.1)	1476.6* (106.7)
	3. α=12.5; τ_0=1200	–	1137.5 (100.0)	1028.8 (255.2)	1168.4 (306.3)
	4. α=12.5; τ_0=3600	–	3537.5 (73.61)	2882.2* (37.3)	2510.2* (182.9)
Ambient Tax	5. α=75; τ_0=1200	–	150.0* (83.0)	620.6* (173.2)	618.8* (238.6)
	6. α=75; τ_0=3600	–	3468.8 (118.6)	1218.8* (161.5)	848.4* (201.6)
	7. α=12.5; τ_0=1200	–	1218.75 (40.58)	1183.1 (186.9)	996.9 (291.3)
	8. α=12.5; τ_0=3600	–	3446.88 (154.8)	2145.9* (457.0)	1293.0* (499.2)

Notes: Numbers in parentheses are cluster-robust standard errors. * indicates parameter is statistically different than τ_0 at the 5% level.

Table 3 Policy Design Effects Model

Dependent variable: group-level tax rate

Variable	Description	Coefficient (Robust Std. Err.)
Ambient Policy	= 1 if ambient tax; = 0 if emissions tax	-653.6* (209.6)
Fast Adjustment	= 1 if α=75; = 0 if α=12.5	-452.1* (209.6)
Low Initial Tax	= 1 if τ_0=1200; = 0 if τ_0=3600	-531.9* (209.6)
Constant		2084.9* (220.4)
$R^2 = 0.32$		
$F = 8.76$*		
$N = 256$		

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

Table 4 Social Efficiency Models

	Dependent variable:	**Social Efficiency**	**Emissions Efficiency**	**Allocative Efficiency**
Emissions Tax	1. α=75; τ_0=1200	72.17 (8.60)	92.59 (3.18)	75.59 (7.50)
	2. α=75; τ_0=3600	60.56 (5.74)	94.42 (1.96)	63.08 (5.62)
	3. α=12.5; τ_0=1200	64.00 (8.59)	89.47 (3.63)	70.96 (6.82)
	4. α=12.5; τ_0=3600	85.10 (11.33)	96.50 (2.31)	87.15 (10.30)
Ambient Tax	5. α=75; τ_0=1200	82.09 (5.05)	95.62 (1.34)	85.38 (4.24)
	6. α=75; τ_0=3600	41.50 (17.37)	91.39 (2.41)	43.05 (18.49)
	7. α=12.5; τ_0=1200	59.16 (15.75)	97.24 (1.10)	61.13 (16.17)
	8. α=12.5; τ_0=3600	53.75 (12.86)	93.77 (1.76)	58.17 (14.39)
Number of observations = 800		R^2 = 0.79	R^2 = 0.94	R^2 = 0.70

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

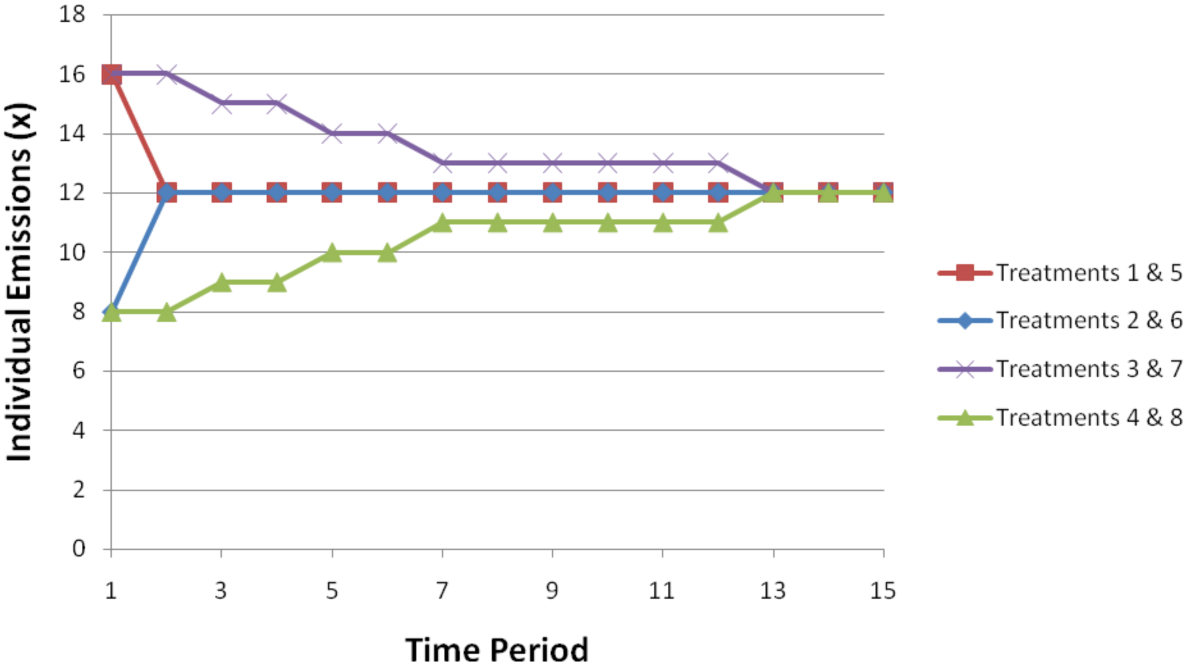

Figure 1a. Myopic Predictions by Treatment, Individual Emissions

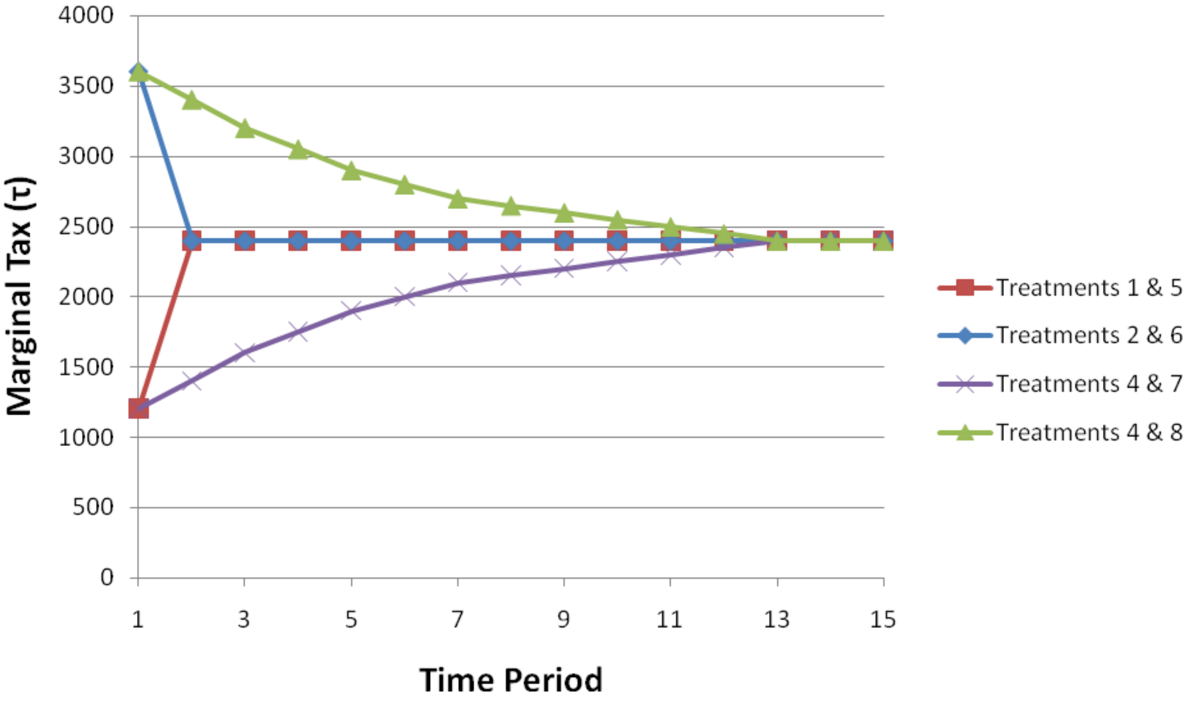

Figure 1b. Myopic Predictions by Treatment, Individual Emissions

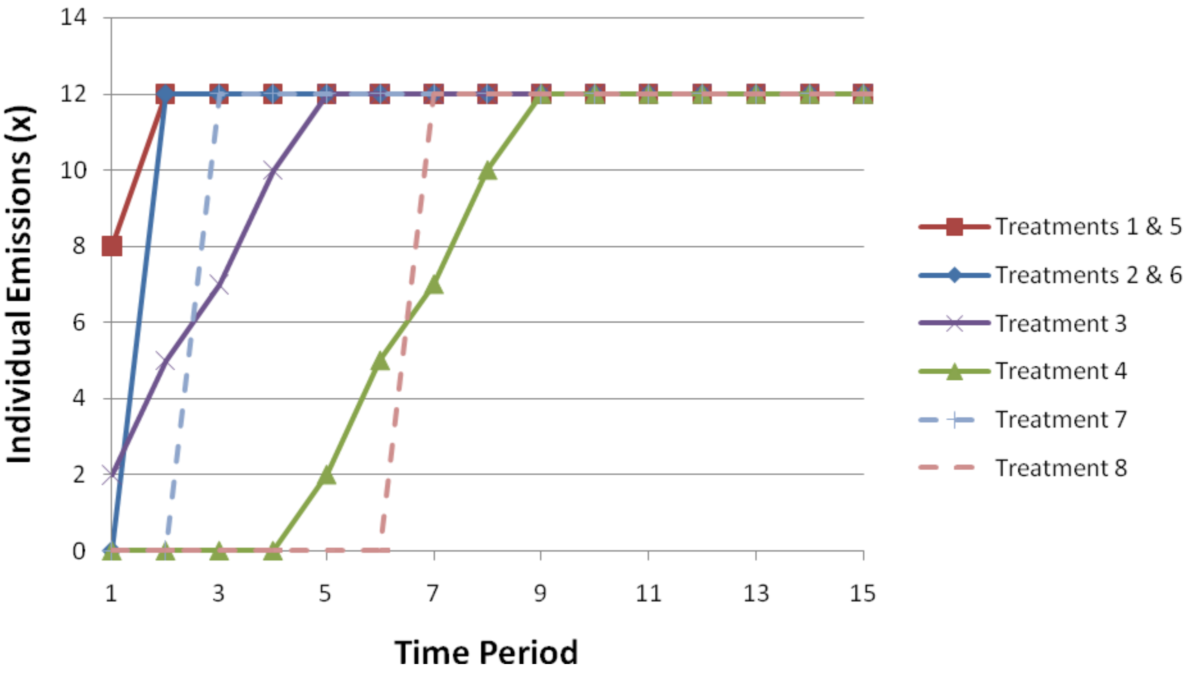

Figure 2a. Strategic Predictions by Treatment (δ=0; n_m=0), Individual Emissions

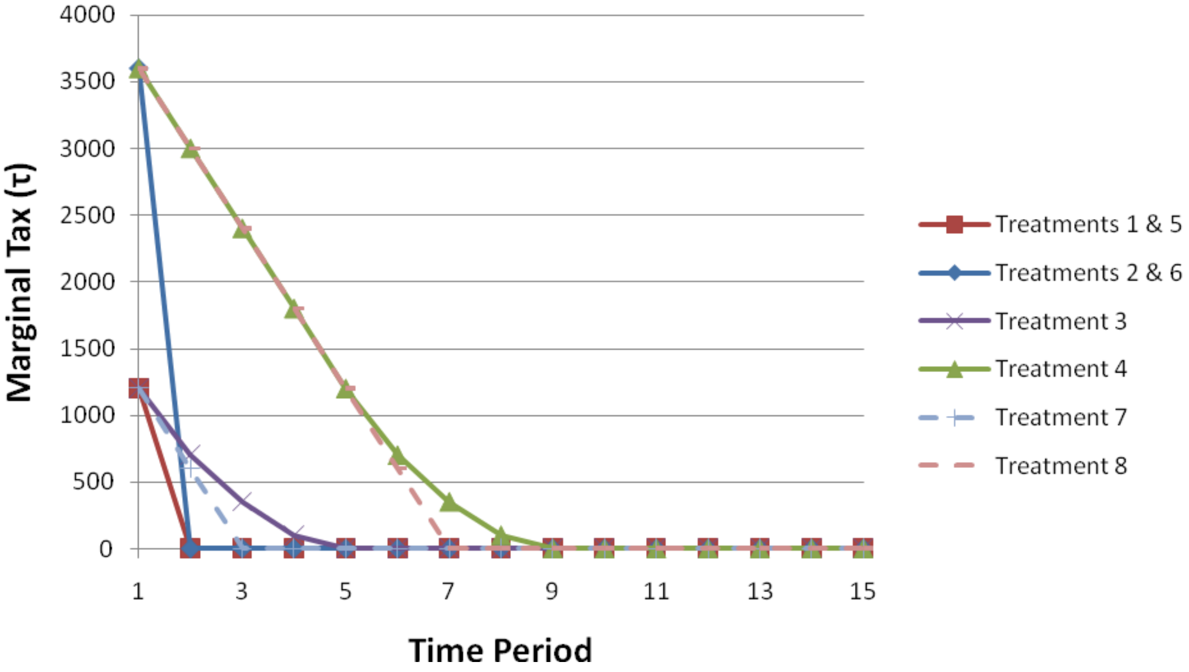

Figure 2b. Strategic Predictions by Treatment (δ=0; n_m=0), Individual Emissions

Appendix. Experiment Instructions (Part B instructions correspond with Treatment 1)

INTRODUCTION

This experiment is a study of group and individual decision making. The amount of money you earn depends on the decisions that you make and thus you should read the instructions carefully. The money you earn will be paid privately to you, in cash, at the end of the experiment. A research foundation has provided the funds for this study.

You will be in a group consisting of four players: you and three others. The other players in your group are people sitting in this room, but you will not be told who is in your group. You will remain in the same group throughout the experiment.

You will make decisions privately, that is, without consulting other group members. Please do not attempt to communicate with other participants in the room during the experiment. If you have a question as we read through the instructions or at any time during the experiment, please raise your hand and an experiment moderator will come by to answer it.

The experiment is broken up into many decision "periods". You will be paid based on your decision in each and every period, so that each decision you make is important in determining the amount of money you earn. There are two parts to the experiment. Part A of the experiment consists of 5 decision periods. Part B lasts between 20 and 30 periods. You will be given additional instructions after Part A is completed.

INSTRUCTIONS FOR PART A

In each period of this part of the experiment, you earn money by choosing a particular level of **Output**, which can be between 0 and 24. In general, the higher your Output is, the higher your level of **Earnings**. On your decision screen, please look closely at the each possible Output choice and the Earnings associated with it before making your decision.

The Earnings are denominated in experimental dollars, which will be exchanged at a rate of 60,000 to $1 U.S. at the end of the experiment.

Know that all four members of your group are identical in the sense that everyone faces the same relationship between their Output and Earnings.

After all members of your group have made an Output choice, you will see a results screen that displays: (1) Your Output; (2) the Group Output, which is simply the sum (i.e. total) of the output from all members in your group (including yourself); and (3) your Earnings for the period.

Although you will see the Group Output displayed on the results screen, know that this does not affect your earnings in any way during this part of the experiment.

Before we proceed to making decisions on the computer, are there any questions?

INSTRUCTIONS FOR PART B

As before, in this part of the experiment you earn money by choosing a level of Output between 0 and 24. The Earnings associated with each Output choice is the same as before. However, you will now have to pay a tax based on your **Output**. In particular, the amount you pay in taxes, which we will refer to as your **Tax Payment**, is determined as follows:

Tax Payment = **Tax Rate** * **Output**

The amount of money you make will then be the difference between the Earnings associated with your Output choice and your Tax Payment, which we will refer to as **Adjusted Earnings**:

Adjusted Earnings = **Earnings** – **Tax Payment**

Your Adjusted Earnings is the amount you earn in this part of the experiment, denominated in experimental dollars, and will be exchanged at the same rate of 60,000 to $1 U.S. at the end of the experiment.

Example 1. In this example you will calculate what your Adjusted Earnings would be based on particular values for your Output Choice.

Suppose the Tax Rate is **3600**. In the table below, please hypothetically choose your own Output. Then, please calculate what your Adjusted Earnings would be.

Output *(you choose)*	
Earnings *(determine from decision screen)*	
Tax Payment	
Adjusted Earnings	

Please raise your hand when you are ready to have your calculations checked or if you have a question.

How the Tax Rate is Determined

The Tax Rate in Period 1 is **3600**. It is the same for all members of your group. Your decision in no way can affect the Tax Rate in Period 1.

However, your Output decision and the Output decisions of your group members *can* affect the Tax Rate in Period 2. In particular, the *Change* in Tax Rate from one period to the next depends upon the **Group Output** in the following way.

Change in Tax Rate = **75** × [**Group Output** – 48]

In general,

If Group Output is *greater* than 48, the Tax Rate will be *higher* next period

If Group Output is *less* than 48, the Tax Rate will be *lower* next period

If Group Output is *equal* to 48, the Tax Rate will *not change* the next period

Using this same formula, the Tax Rate will continue to adjust from one period to the next. That is, the Tax Rate in Period 3 will just be the Tax Rate in Period 2 adjusted based on Group Output in Period 2. The Tax Rate in Period 4 will be the Tax Rate in Period 3 adjusted based on Group Output in Period 3. And so on.

Please note that regardless of the calculated Tax change, the minimum possible Tax is 0 and the maximum possible Tax is 6000.

To help you determine how the Tax changes from one period to the next you have been provided with a **Tax Rate Adjustment Sheet**. The Tax Rate next period will equal this period's Tax Rate plus (minus) the *Change* in Tax Rate.

Example 2. Suppose the Tax Rate is **3600**, which will be the Tax Rate in Period 1. In the table below, please hypothetically choose your own Output as well as the level of Group Output (of course in the experiment Group Output will be the sum of the output from all members of your group). Then, please calculate what the Tax Rate would be in Period 2.

Output *(you choose)*	
Group Output *(you choose)*	
Change in Tax Rate *(from Tax Rate Adjustment Sheet)*	
Tax Rate in Period 2	

Please raise your hand when you are ready to have your calculations checked or if you have a question.

After all members of your group have made an Output decision, you will see a results screen that displays: (1) your Output: (2) the Group Output; (3) your Adjusted Earnings for the period; and (4) what the next period's Tax Rate will be.

This part of the experiment lasts between 20 and 30 decision periods. Before proceeding to these paid decision periods, we will go through 3 practice periods which will not affect the amount you earn.

Before we proceed, are there any questions?

Tax Rate Adjustment Sheet

Group Output	*Change* in Tax Rate		Group Output	*Change* in Tax Rate		Group Output	*Change* in Tax Rate
0	-3600		33	-1125		66	1350
1	-3525		34	-1050		67	1425
2	-3450		35	-975		68	1500
3	-3375		36	-900		69	1575
4	-3300		37	-825		70	1650
5	-3225		38	-750		71	1725
6	-3150		39	-675		72	1800
7	-3075		40	-600		73	1875
8	-3000		41	-525		74	1950
9	-2925		42	-450		75	2025
10	-2850		43	-375		76	2100
11	-2775		44	-300		77	2175
12	-2700		45	-225		78	2250
13	-2625		46	-150		79	2325
14	-2550		47	-75		80	2400
15	-2475		48	0		81	2475
16	-2400		49	75		82	2550
17	-2325		50	150		83	2625
18	-2250		51	225		84	2700
19	-2175		52	300		85	2775
20	-2100		53	375		86	2850
21	-2025		54	450		87	2925
22	-1950		55	525		88	3000
23	-1875		56	600		89	3075
24	-1800		57	675		90	3150
25	-1725		58	750		91	3225
26	-1650		59	825		92	3300
27	-1575		60	900		93	3375
28	-1500		61	975		94	3450
29	-1425		62	1050		95	3525
30	-1350		63	1125		96	3600
31	-1275		64	1200			
32	-1200		65	1275			