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Experimental evidence on dynamic pollution tax policies☆

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ABSTRACT

This paper uses laboratory experiments to provide primary empirical evidence on dynamic pollution tax policies. In particular, we investigate a setting where a regulator with incomplete information uses a pollution tax mechanism with a simple, endogenous tax rate adjustment rule to cost-effectively meet a pollution standard. This mechanism provides the opportunity for firms to strategically abate in order to reduce future tax rates. The experiments vary important policy design features such as the type of tax (ambient or emissions), the initial tax rate, and the tax rate adjustment speed. We find that in equilibrium the pollution standard is met on average for each of these settings. The observed long-run tax rates vary considerably across policy designs, which can be explained with a theory that allows for a mix of strategic and myopic firms, along with the recognition that the incentives generated by the policy design can influence whether an agent plays myopically or strategically.

1. Introduction

Though the Pigouvian tax solution to pollution externalities has theoretical appeal and has been popularly embraced in the form of the "polluter pays" principle, its practical implementation is encumbered by a number of factors. Prominent amongst these is uncertainty surrounding underlying pollution damage and abatement cost functions. In their influential book, Baumol and Oates (1988) argue that difficulties in accurately measuring damage functions preclude the implementation of optimal, efficiency-maximizing taxes, shifting attention instead to cost-effective solutions to reach an exogenously determined pollution standard. Even then, asymmetric information between regulators and firms regarding abatement technologies and cost functions impedes the identification of cost-effective tax rates. Since at least Baumol and Oates (1971), and

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Baumol (1972), a potential way to circumvent the problem of incomplete abatement cost information is to make iterative adjustments to pollution tax rates, using signals relayed through past behavior.

> "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" (Baumol, 1972, p. 319).

However, in introducing this approach, Baumol and Oates expressed some caution about the properties of such an iterative process, noting: "It is not clear, however, even in theory whether this sequence will in fact converge toward the optimal tax and resource allocation patterns" (1971, p. 44).

Several papers (e.g. Conrad, 1991; Karp and Livernois, 1994; Moledina et al., 2004; Querou, 2008) have explored the theoretical properties of dynamic pollution tax instruments – i.e. mechanisms with an endogenously adjusting tax rate – in models of incomplete information, demonstrating theoretically that potential strategic responses by polluters can affect firm-level emissions and equilibrium tax rates. In particular, excess abatement provides a signal that the current tax rate is higher than necessary to achieve the pollution objective and, accordingly, that the future tax rate should be lowered. As a result, the dynamic tax provides an incentive for firms to over-abate in the short run in order to maximize the net present value of profits. These studies have assumed symmetric play of regulated firms and have typically compared convergence criteria of "myopic" players that act as if in a one-shot, static decision framework and "strategic" players that account for the dynamic impact of present emission decisions on future tax rates. The practical importance of strategic incentives in the context of environmental policy remains a critical empirical question.

This study complements the existing theoretical literature on dynamic taxes by providing primary empirical evidence on dynamic tax policies through laboratory experiments. Tax policies, environmental or otherwise, are inherently dynamic and consideration of many important issues such as revenue generation, market impacts, administrative costs, and public opinion of course are at play when imposing and changing tax rates. There are some policies, however, such as the Everglades Forever Act, where tax rate changes are explicitly tied to whether an environmental outcome is achieved (Segerson, 1997). As myriad extant environmental tax policies pass beyond their infancy, and continue to gain political acceptance, it is natural to believe that environmental tax rates will adjust (based on stated rules or otherwise) at least in part due to environmental quality considerations.

Our experimental design employs the simple (linear) and transparent tax rate adjustment rule analyzed theoretically in Karp and Livernois (1994) and Karp (2005), and focuses on potentially important features of policy design, including: the type of tax (individual emissions-based taxes or group, ambient-based taxes); the initial tax rate (above or below the optimal static tax); and the speed at which the tax rate adjusts across decision periods (fast or slow). Our efforts are very much in the spirit of arguments made by Levitt and List on the virtues of laboratory experiments, specifically: "We also view laboratory experimentation as a useful first step in the area of policymaking" in that such efforts provide "qualitative evidence" on policy mechanisms (Levitt and List, 2006, pp. 40–41).

Although both emissions and ambient taxes are applicable in regulating point sources, the ambient tax is better suited for a non-point source pollution setting, such as for the regulation of agricultural runoff into surface waters, where the regulator lacks the ability to effectively monitor emissions on a firm-by-firm basis (see Segerson, 1988). A substantial body of experimental economics research on ambient-based pollution policies for addressing non-point source pollution has emerged over the years (e.g. Alpízar et al., 2004; Cochard et al., 2005; Poe et al., 2004; Spraggon, 2002, 2004; Suter et al., 2008, 2010; Vossler et al., 2006), but 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. By relaxing this assumption, this paper takes an important next step in the experimental pollution tax literature.

As there is no existing empirical evidence to suggest whether all or even some players in a dynamic tax setting will behave strategically, to guide the experimental design and analysis we consider an extension of Karp and Livernois (1994) and Karp (2005) that allows for the regulated group to include both myopic and strategic players. We find experimentally that aggregate emissions are statistically equal to the pollution standard in later decision periods for all the policy settings we consider. This is consistent with the theoretical steady-state equilibrium, which is the same regardless of the number of strategic players. The observed tax rates, however, are found to deviate from the optimal static tax rate. The effects of policy design and treatment conditions on observed tax rates are best organized with a theory that assumes a mix of myopic and strategic players, and further assumes that the decision to play myopically or strategically critically depends upon the corresponding incentives generated by the policy design.

2. Dynamic tax mechanisms

In this section we outline the theoretical properties of the linear dynamic emissions tax mechanism of Karp and Livernois (1994), and the linear dynamic ambient tax of Karp (2005), which form the basis of our experimental design. In the discussion that follows, our intent is to highlight the main findings from the above papers as they pertain to the polar cases where all firms are strategic or all firms are myopic, and provide insight on the intermediary cases.

In the dynamic tax setting, firms have an incentive to consider how their current period abatement influences future tax rates. Strategic firms therefore make abatement decisions by comparing the marginal cost of abatement to the marginal tax savings in the current period as well as the benefit associated with lower tax rates in all future periods. Myopic firms, on the other hand, are assumed to maximize current period profits by focusing solely on marginal benefits and costs in the current period.

Although the profits of the regulated group are maximized when all firms are strategic, there are several reasons why myopic behavior is nevertheless likely to be observed. Our theoretical analysis suggests two drivers. Strategic play serves to lower the (common) tax rate, and thus generates a positive pecuniary externality to the group of regulated firms. Therefore, at least in some cases (including for our experiment parameters), by foregoing costly excess abatement, myopic firms can earn *relatively* higher profits than strategic firms. Further, for certain beliefs regarding group composition (i.e. the number of strategic and myopic players), playing myopically can be profit-maximizing.[2,3]

A firm's type may therefore be determined by nature or be the result of an *ex ante* assessment of the tradeoffs of type choice. For tractability in the theoretical model, we make the assumptions that firms are either strategic or myopic, that firm type does not dynamically adjust and that the ratio of firm types is common knowledge to the regulated industry but unknown to the regulator. These assumptions give rise to a "best-case" scenario under which strategic firms realize the highest net present value of profits, taking as given the number of myopic players.

In the analysis that follows, 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. A myopic firm, denoted as type m, is assumed to maximize current period profits. A strategic firm, denoted as type s, considers all future periods in order to maximize the present value of profits, and in doing so seizes the opportunity to reduce their future tax burden through over-abatement. Let n^m denote the number of myopic firms.

Aggregate emissions by the group are defined as $\sum_{i=1}^{N} x_{it}^k = X_t$. Emissions reductions below a baseline level of emissions, $\bar{x}$, are increasingly costly for a firm so that the pre-tax profit function, $R(x_{it}^k)$, has $R'(x_{it}^k) > 0$ and $R''(x_{it}^k) \le 0$. Critically, information is asymmetric between the firms and the regulator; profit functions are known to firms but not the regulator.

2.1. Dynamic emissions tax

Suppose that the 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 $\tau_t \ge 0$ 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 exogenously. The tax rate evolves over time according to the linear adjustment rule

$$\tau = \max[\tau_t + \alpha(X_t - X^*), 0] \tag{1}$$

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) for the next period. The magnitude of the increase or decrease depends both on the magnitude by which aggregate emissions diverge from the standard and the size of the adjustment parameter. Additionally, the tax rate cannot drop below zero.

After-tax profits to a firm in a given period of the tax policy are simply

$$\pi_{it} = R(x_{it}^k) - \tau_t x_{it}^k. \tag{2}$$

In any period a myopic firm will choose a level of emissions that equates marginal pre-tax profits to the tax rate:

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

If all firms in the market are myopic (i.e. $n^m = N$) 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 that induces myopic firms to achieve the target level of pollution can therefore be defined as

$$\tau^{myopic} = R'\left(\frac{X^*}{N}\right). \tag{4}$$

In the case where one or more firms are strategic, the strategic firm conditions their emissions decisions on the response of the myopic firm(s) to the realized tax in a given period. The maximization problem and associated first-order necessary conditions are provided as Eqs. (A1)–(A3) in the online appendix. The main implications as they pertain to emissions are

[2] The intent of this discussion is to provide some justification for myopic behavior. We address optimal decision making for strategic firms in the presence of myopic players in the next section.

[3] There are other behavioral explanations for myopic behavior, including income smoothing, narrow framing (e.g. making decisions based on a short time horizon), and cognitive limitations (e.g. "bounded rationality"). A rational firm may also choose to behave myopically if it perceives the payoff difference between strategic and myopic play to be low (i.e. decision rewards provide insufficient incentive to invest the necessary cognitive resources or "decision costs"; see Smith and Walker, 1993).

that: (1) the steady-state emissions of strategic and myopic firms differ; and (2) the emissions standard is exactly met in steady-state. Turning to steady-state tax rates, the strategic firm's first-order necessary conditions imply

$$\tau = Max\left[R'(x^s) - \frac{\alpha x^s}{\delta - \alpha n^m x^{m'}(\tau)}, 0\right], \tag{5}$$

where δ denotes the discount rate and $x^{m'}(\tau) \leq 0$ is the marginal change in emissions for a myopic firm associated with a marginal increase in the tax rate. In the special case where all firms are strategic (i.e. $n^m = 0$), $x^s = X^*/N$ and Eq. (5) yields an explicit solution for τ:

$$\tau_E^{strategic} = Max\left[R'(X^*/N) - \frac{\alpha X^*}{N\delta}, 0\right]. \tag{6}$$

Eqs. (5) and (6) together imply that, when at least some firms are strategic, the steady-state tax does not depend on the initial tax rate, τ_0, and is decreasing in α. The adjustment parameter result requires an additional assumption of positive discounting when there is a mix of types. Higher values of the adjustment parameter allow strategic firms to gain a more immediate benefit from over-abatement, and thus increase the discounted benefits of reducing the tax below static levels. Assuming that $\delta \geq 0$, $\alpha > 0$ and $X^* \geq 0$, comparison of (6) with (4) reveals that the steady-state emissions tax rate is at least as high in the case where all firms behave myopically relative to the case when all firms behave strategically, i.e. $\tau^{myopic} \geq \tau_E^{strategic}$. From Eq. (5) it is straightforward to show that the steady-state tax rate is increasing in the number of myopic firms.

2.2. Dynamic ambient tax

We next consider a dynamic ambient tax, which is better suited for a setting where it is prohibitively costly to measure firm-level emissions, as in the case of non-point source pollution. Under the ambient tax each firm pays the tax rate, τ_t, on each unit of *aggregate* emissions. Under this scheme, the after-tax profits to a firm in a given period of the tax policy are

$$\pi_{it} = R(x_{it}^k) - \tau_t\left[\sum_{i=n^m+1}^{N} x_{it}^s + \sum_{i=1}^{n^m} x_{it}^m(\tau_t)\right], \tag{7}$$

where the second term on the right-hand side is simply the sum of all emission from both myopic and strategic players multiplied by the tax rate. Basing tax payments on aggregate emissions as opposed to individual emissions does not alter the myopic firm's marginal incentives in a given period, and Eq. (3) continues to hold in the dynamic ambient tax setting.

If a firm behaves strategically, the incentives for abatement are different than in the dynamic emissions tax case, given that the firm's tax payment in a particular period is the product of the period-specific tax rate and *aggregate* emissions. The current-value Hamiltonian and first-order necessary conditions are provided as Eqs. (A4)–(A5) in the online appendix. Similar to the dynamic emissions tax, the emissions standard continues to be exactly met in steady state. The first order necessary conditions imply that the steady-state tax rate satisfies

$$\tau = Max\left[R'(x^s) - \frac{\alpha}{\delta}[R'(x^s)n^m x^{m'}(\tau) + X^*], 0\right] \tag{8}$$

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

$$\tau_A^{strategic} = Max\left[R'\left(\frac{X^*}{N}\right) - \frac{\alpha X^*}{\delta}, 0\right]. \tag{9}$$

Eqs. (8) and (9) show that – as in the case of the dynamic emissions tax – the steady-state tax rate is invariant to the choice of τ_0. Additionally, α is inversely related to the steady state tax, under the assumption of positive discounting.

When all firms are strategic, a comparison of (6) with (9) reveals an important difference between the two instruments. Specifically, the negative, second term of the steady-state dynamic ambient tax equation is no longer divided by N. This implies that in steady state the ambient tax rate is *lower* than the emissions tax rate, i.e. $\tau_A^{strategic} \leq \tau_E^{strategic}$. For the parameters used in the experimental design, this relationship holds in the mixed-type case as well.

2.3. Incentives for myopic behavior

The analysis above demonstrates that strategic and myopic firms have different emissions in steady state, and hence different profits. These profits are further influenced by policy design. As it is reasonable that players may view strategic or myopic play as a "choice", we briefly provide intuition as to how the incentives for myopic or strategic play are affected by the policy design variables. Specifically, we evaluate the incentives for strategic play by considering how the treatment variables influence the marginal benefits and costs of reducing emissions below the myopic level.

The incentives for strategic play are weakly decreasing in the initial tax rate, τ_0. Due to the assumption that the marginal cost of abatement is non-decreasing, a higher tax rate implies weakly lower myopic emissions. The non-decreasing marginal cost of abatement also implies that the cost of marginal reductions in emissions below the myopic level is weakly higher for lower levels of myopic emissions. The marginal benefit of emissions reductions, however, in terms of lower future tax rates, is constant. Therefore, the net benefit of emissions reductions below the myopic level is weakly lower when the initial tax rate is higher and as such, we expect the number of strategic firms to be inversely related to the initial tax rate.

Intuitively, the incentives for strategic play are increasing in the level of the adjustment parameter. A faster rate of adjustment means that each unit of abatement will have a larger effect on reducing future tax rates and therefore the net benefits of strategic over-abatement are higher. Similarly, the incentives for strategic relative to myopic play are higher under the dynamic ambient tax compared to the dynamic emissions tax. The intuition for this is that any given tax rate has a more negative impact on firm-level net benefits under the ambient tax, since the total tax bill that each firm must pay is equal to the tax rate multiplied by aggregate – rather than individual – emissions. As such, reductions in the tax rate have a larger impact on future net benefits and therefore the net benefits to marginal reductions in emissions below the myopic level are higher under the ambient tax than under the emissions tax.

To summarize, we predict that the number of firms that choose to behave myopically will be weakly increasing in the initial tax rate, decreasing in the rate of adjustment parameter, and lower under the dynamic ambient tax relative to the emissions tax.

3. Experimental design

One hundred and sixty University of Tennessee undergraduate students participated in an experiment conducted at the UT Experimental Economics Laboratory. These individuals came from a pool of roughly 1400 students representing over 70 majors who had previously registered to be potential participants in economics experiments. About 60% of participants were male, and had spent an average of 2-1/2 years in college. On average participants had taken one economics course and 39% had participated in a previous (unrelated) experiment. 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 are asked to choose a level of “output” between 0 and 24. Although this choice is synonymous to emissions (x), and we use an environmental context in our discussion of the experimental design and results in this paper, the experiment uses neutral framing (see the online appendix). Paired with each emissions choice is a level of (pre-tax) profit, generated from the profit function $R(x)=M-150(20-x)^2$. In the absence of taxes, profits are maximized with $x=20$, which corresponds with the value of $\bar{x}$ in Section 2. The parameter M varies across tax instruments in order to roughly equate expected earnings while maintaining consistent marginal incentives ($M=75{,}000$ for dynamic emissions tax; $M=110{,}000$ for dynamic ambient tax). 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 participants make an emissions choice in the absence of the tax mechanism. This is followed by a set of tax policy decision rounds, wherein participants face one of the dynamic tax mechanisms. To implement the underlying theoretical framework of a dynamic game, with an eye toward steady-state behavior, participants are told that the number of tax policy rounds is indefinite. In particular, they are told that the number of tax policy periods was randomly determined (prior to the session) to be between 20 and 30. In the analysis that follows, we evaluate the results of the first 20 tax policy periods (i.e. 25 periods in the overall experiment) so as to minimize end-of-game effects.

Participants are anonymously placed in groups of four, which remain intact for the duration of the experiment, and it is common knowledge that all participants have identical payoff functions. The dynamic tax mechanism is described in two stages. First, participants are told how payoffs are determined for a particular period. Second, participants are informed the tax rate (i.e. marginal or per-unit tax) in the first tax period and how this rate adjusts 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 are provided a “Tax Rate Adjustment Sheet” which maps all possible levels of aggregate emissions (referred to in the experiments as “group output”) to the resulting change in the next period’s tax rate.

As part of the instructions, participants are asked to go through two calculation exercises to help understand how payoffs and the tax rate are determined. Calculations are based on hypothetical decisions made by the participants, and this is done to avoid possible cues stemming from experimenter-provided decision choices. Participants are paid $1 on each exercise for undertaking calculations without error. Also to help facilitate learning, there are three unpaid practice periods after the no-policy periods and prior to the first actual tax period, whereby the experiment moderator stated verbally how changes in the tax rate are determined and how profits are calculated. Decisions are made via networked computers using software programmed with *z*-Tree (Fischbacher, 2007). The software collects all decisions and makes all relevant earnings calculations. Written instructions are provided to each participant, an example of which is included in the online 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 instrument (emissions or ambient tax), initial tax rate (low or high), and tax adjustment parameter (fast or slow). Each participant faced the same tax treatment during all tax periods of the experiment and each treatment was comprised of four groups of four participants each. 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

Table 1
Experiment treatments.

Treatment	Regulatory instrument	Initial tax, τ_0	Tax adjustment parameter, α
1	Dynamic emissions tax	1200 (low)	75 (fast)
2	Dynamic emissions tax	3600 (high)	75 (fast)
3	Dynamic emissions tax	1200 (low)	12.5 (slow)
4	Dynamic emissions tax	3600 (high)	12.5 (slow)
5	Dynamic ambient tax	1200 (low)	75 (fast)
6	Dynamic ambient tax	3600 (high)	75 (fast)
7	Dynamic ambient tax	1200 (low)	12.5 (slow)
8	Dynamic ambient tax	3600 (high)	12.5 (slow)

values for the tax rate are $\tau = 1200$ (low) and $\tau = 3600$ (high). Given four identical players with the marginal profit function $R'(x) = 300(20 - x)$, the aggregate marginal profit function is $Z'(X) = 75(80 - X)$. With the aggregate emissions standard of $X^* = 48$, if the regulator had complete information on the profit function the optimal static tax would be $Z'(48) = \tau = 2400$. As such, the low and high initial values used represent 50% deviations from the efficient 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. Table 1 summarizes the experiment treatments.

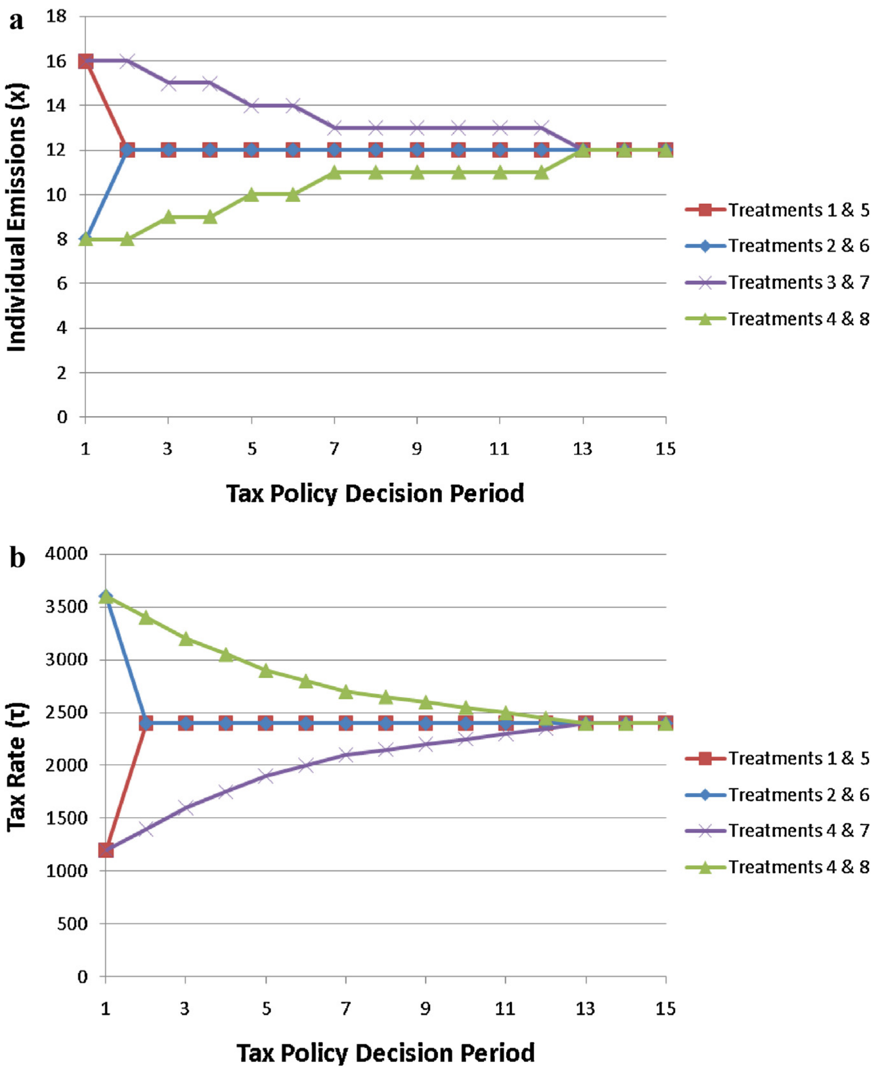

Fig. 1. Dynamic tax predictions when all players are myopic: (a) individual emissions; (b) tax rates.

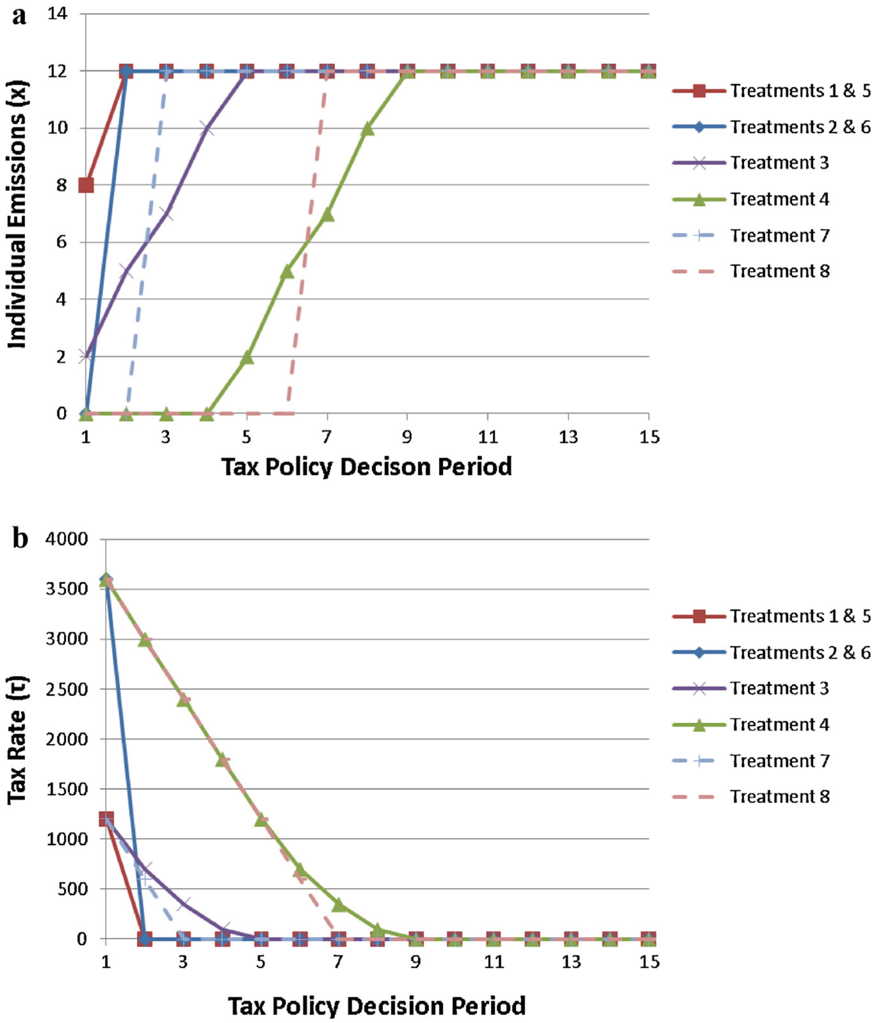

Fig. 2. Dynamic tax predictions when all players are strategic: (a) individual emissions; (b) tax rates.

Fig. 1a and b depicts the predicted individual emissions and tax rate paths, for the dynamic tax periods, for the eight treatments when all players are myopic.[4] Under myopic play both tax instruments generate identical marginal incentives. The steady-state equilibrium has $\tau = 2400$ and $x = 12$. With the fast adjustment parameter, convergence to steady state occurs in the second dynamic tax period. With the slow adjustment parameter, convergence occurs in the 13th dynamic tax period (or the 18th period of the overall experiment).

Under strategic play, the optimal tax rate and individual emissions paths depend on the discount rate and the number of myopic players. For purpose of illustration, Fig. 2a and b depicts the predicted outcomes for the eight treatments in the extreme case where all players are strategic and the discount rate is zero. This extreme case gives rise to the lowest steady-state tax rate ($\tau = 0$) under all treatments. Further, for each treatment, this represents the fastest approach to steady state. Thus, increasing the number 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.

To provide some guidance on predicted outcomes for other group compositions – i.e. the number of myopic and strategic players, as well as provide insight on the payoffs associated with myopic and strategic play, Table 2 provides theoretical predictions for the dynamic emissions and dynamic ambient tax instruments in the case of the fast adjustment and low initial tax rate.[5] As suggested by theory, we see that (a) the steady-state tax rate is non-decreasing in the number of myopic

[4] Dynamic optimization solutions presented in this article were generated using Microsoft Excel's Solver, subject to the additional choice constraints introduced by the experimental design – namely, that only integer values between and including 0 and 24 were included in the choice space. This integer restriction on emissions underlies the stepwise structure of the solutions presented in Figs. 1a and 2a.

[5] As suggested by theory, the steady-state emissions and tax rates for other dynamic emissions (ambient) tax treatments are identical. Although there are some differences in profit levels, the qualitative relationships regarding profits we highlight in the text characterize the other treatments as well.

Table 2
Theoretical predictions conditional on group composition (dynamic tax periods only).

Group composition	Tax rate	Myopic emissions	Strategic emissions	Myopic player profit	Strategic player profit	Group profit
Dynamic emissions tax, Treatment 1 ($\alpha = 75$; $\tau_0 = 1200$; $\delta = 0$)						
All strategic	0	–	12	–	$21.44	$85.76
1 myopic, 3 strategic	240	19.2	9.6	$23.14	$18.54	$78.76
2 myopic, 2 strategic	1680	14.4	9.6	$15.49	$14.34	$59.66
3 myopic, 1 strategic	2160	12.8	9.6	$13.42	$12.91	$53.17
All myopic	2400	12	–	$12.48	–	$49.92
Dynamic ambient tax, Treatment 5 ($\alpha = 75$; $\tau_0 = 1200$; $\delta = 0$)						
All strategic	0	–	12	–	$32.63	$130.52
1 myopic, 3 strategic	0	20	9.33	$35.99	$30.08	$126.23
2 myopic, 2 strategic	0	20	4	$35.99	$22.87	$117.72
3 myopic, 1 strategic	1600	14.67	4	$9.89	−$1.42	$28.25
All myopic	2400	12	–	−$4.17	–	−$16.68

Notes: Tax rate and emissions numbers correspond to steady state. Profit numbers are totals across the twenty periods of the dynamic tax game, in US$.

players; (b) the steady-state dynamic emissions tax rate is greater than or equal to the dynamic ambient tax rate; and (c) the steady-state emissions choice of myopic players is non-increasing with the number of myopic players.

The type-specific profit levels in Table 2 illustrate the tension between myopic and strategic play. At the group level, there are strong incentives for strategic play. A group consisting of all myopic players leaves $35.84 (or $8.96/person) on the table in the dynamic emissions tax case and $147.20 ($36.80/person) in the dynamic ambient tax case.[6] At the individual level, as expected, myopic player profits are higher than for a strategic player regardless of group composition. Furthermore, comparing strategic and myopic player profits in adjacent rows of Table 2 paints a picture of whether myopic or strategic play, conditional on beliefs regarding others' types, is congruent with profit-maximization. For the dynamic emissions tax, conditional on the belief that all others will play strategically, a player is expected to earn $21.44 if she too plays strategically (profit for strategic player in an "all strategic" group) or $23.14 if she plays myopically (profit for myopic player in a group with one myopic player); hence in this case, myopic play is consistent with profit maximization. On the other hand, when a player in the dynamic emissions tax game believes there to be two strategic players, she is expected to earn $18.54 from strategic play but only $15.49 from myopic play. For all dynamic emissions tax treatments, beliefs that all other players are strategic yields myopic play as a best-response. For the dynamic ambient tax treatment, myopic play is profit maximizing under the belief that two or three others are strategic.[7] If instead a player has diffuse priors (i.e. she places equal probability on being grouped with 0, 1, 2 or 3 strategic players), then playing strategic maximizes expected profit in all treatments.

3.1. Testable hypotheses

There are several testable hypotheses pertaining to steady-state emissions and tax rates based on our experimental design. As a basic guide, we state as formal hypotheses the theoretical predictions corresponding to the case when all players are myopic, and then discuss predictions as they relate to the hypotheses for other situations.

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

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

Hypothesis 3. The tax rate is invariant to instrument choice (ambient or emissions tax).

Hypothesis 4. The tax rate is invariant to the speed of adjustment parameter, α.

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

Hypothesis 1 is expected to hold in all cases as the pollution standard is theoretically met in steady state regardless of group composition or policy design. With one or more strategic types, given that strategic play reduces the steady-state tax rate, we expect to reject Hypothesis 2. With one or more strategic players, Hypothesis 3 is also expected to be rejected. In particular, holding the number of strategic players fixed, the tax rate is lower for the dynamic ambient tax. Allowing group composition to vary is not expected to alter this prediction. In particular, if we use as a reasonable assumption that players have diffuse beliefs, then implementing an ambient tax decreases the incentive to play myopically, which leads similarly to a predicted decrease in the steady-state tax rate.

Holding group composition fixed, Hypotheses 4 and 5 are expected to hold even when some players are strategic.[8] Otherwise, a higher initial tax rate or a slower speed of adjustment increases the incentives to play myopically and thus, if

[6] The difference in profit levels across instruments is partially due to the instrument-specific profit function intercepts used. Within-instrument comparisons are not altered by this design choice.

[7] Of course, there exist other probability weights regarding others' types that would support myopic play as profit maximizing.

[8] Here, and throughout the analysis, we assume zero discounting. This appears to be a palatable assumption given that the experiment was reasonably short and participants were paid in cash at the end of the session.

group composition is affected by the initial tax rate, we expect to observe that the steady-state tax rate decreases with α and increases with τ_0. In order to carefully interpret the data in the analysis that follows, we examine how policy design influences emissions choices and corresponding tax rates, as well as the number of myopic (strategic) players.

4. Results

We begin with a simple graphical representation of the mean time series of individual-level emissions decisions by treatment in Fig. 3a, and the mean time series of tax rates by treatment in Fig. 3b. Fig. 3a illustrates that the tax policy reduces emissions relative to the no-policy setting as expected and that decisions across all treatments cluster close to 12 (the theoretical prediction) by the later periods of the experiment. Fig. 3b, however, reveals considerable variation in tax rates across treatments, even in later periods of the experiment. The tax rate in treatments with a high initial tax parameter drops quite quickly on average, while the tax rate in treatments with a low initial tax parameter increases modestly in some treatments and decreases in others.

To formally test the first two hypotheses we use the emissions and tax rate data to estimate separate econometric models. 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

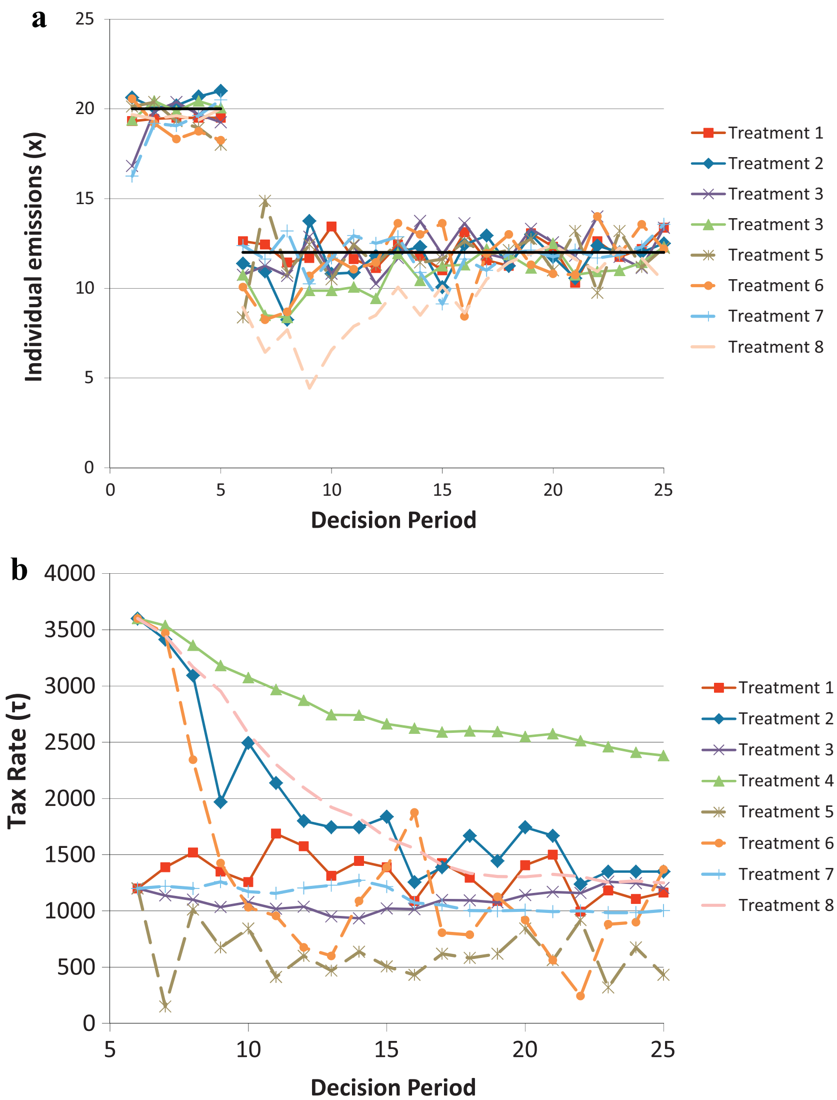

Fig. 3. (a) Observed average emissions levels by treatment, individual emissions. (b) Observed average tax levels by treatment.

Table 3
Individual emissions model.

Dependent variable: individual emissions choice Number of observations: 3200		$R^2 = 0.89$				
Treatment		No policy (Pds 1–5)	Tax policy (Pds 6–25)			
			Period 6	Period 7	Pds 8–17	Pds 18–25
Dynamic emissions tax	1. $\alpha = 75$; $\tau_0 = 1200$	19.45 (0.57)	12.63 (0.97)	12.44 (0.94)	11.93 (0.56)	12.11 (0.70)
	2. $\alpha = 75$; $\tau_0 = 3600$	20.51 (0.53)	11.38 (2.08)	10.94 (1.95)	11.53 (0.78)	11.93 (1.00)
	3. $\alpha = 12.5$; $\tau_0 = 1200$	19.20 (0.59)	10.75 (1.11)	11.25 (1.14)	11.99 (0.67)	12.45 (0.55)
	4. $\alpha = 12.5$; $\tau_0 = 3600$	20.04 (0.23)	10.75 (1.32)	8.50* (1.19)	10.48* (0.41)	11.49 (0.29)
Dynamic ambient tax	5. $\alpha = 75$; $\tau_0 = 1200$	19.35 (0.79)	8.38* (1.22)	14.88* (1.22)	11.77 (0.63)	11.93 (0.49)
	6. $\alpha = 75$; $\tau_0 = 3600$	19.01 (0.69)	10.06 (1.86)	8.25* (1.64)	11.43 (0.88)	12.19 (0.95)
	7. $\alpha = 12.5$; $\tau_0 = 1200$	18.93 (0.66)	12.38 (1.30)	11.63 (1.42)	11.61 (1.01)	12.17 (1.14)
	8. $\alpha = 12.5$; $\tau_0 = 3600$	19.63 (0.25)	8.94 (2.08)	6.44* (1.66)	8.28* (1.44)	11.59 (1.14)

Notes: Numbers in parentheses are cluster-robust standard errors.
* No policy (tax policy) mean emissions is statistically different than 20 (12) at the 5% level.

treatment, to vary across no-policy periods 1–5 and policy periods 6–25.[9] For tests of equilibrium behavior in the tax policy setting, mean emissions are further allowed to vary across period 6, period 7, and two policy-period groupings, periods 8–17 and 18–25. Formally, the estimating equation is

$$x_{it} = \left(\sum_{m=1}^{8} \sum_{k=1}^{5} \beta_{mk} \cdot D_{it}^{m} I_{it}^{k} \right) + \varepsilon_{it}, \tag{10}$$

where x_{it} is the emissions choice for participant i in period t; the D_{it}^{m} are indicator variables that equal 1 for treatment m; the I_{it}^{k} are indicator variables that equal 1 for observations corresponding with period grouping k; the β_{mk} are estimable parameters; and ε_{it} is a mean-zero error term.

Evaluating results in the first two dynamic tax periods allows us to compare the initial decisions observed to the theoretical predictions under myopic and strategic behavior. However, as theoretical predictions on the path to steady state depend heavily on the (unknown) number of myopic players, we mainly focus on mean outcomes corresponding with periods 18–25, which we will refer to as the "equilibrium" outcomes. This time-period grouping is chosen based on empirical as well as theoretical considerations, as the steady state is theoretically reached at or before period 18 in all treatments with groups composed of purely myopic or purely strategic players.[10]

We use an estimating equation similar to (10) for tax rate outcomes. For the tax rate model, however, the data are necessarily at the group-level. Further, given that participant decisions have no impact on the observed tax rate in the no-policy periods, or the first period of the tax policy, these data are excluded from the model.

To undertake valid hypothesis testing under conditions of unspecified heteroskedasticity and autocorrelation, we use robust standard errors adjusted for clustering (i.e. "cluster-robust" standard errors). In particular we use the heteroskedasticity-autocorrelation consistent (HAC) covariance estimator of White (1984) and Arellano (1987).[11] Monte Carlo evidence suggests that this estimator performs well for panel dimensions and data-generating processes typical of lab experiments (Vossler, 2013). When analyzing emissions, errors are clustered at the level of the individual, whereas errors are clustered at the group-level for the analysis of tax rates.

Table 3 presents the parameter estimates of the Individual Emissions Model, whereas Table 4 presents the Tax Rate Model. Given that the covariates in these linear regressions are simply interactions of time and treatment dummy variables, and further that there is no overall model intercept (i.e. full sets of indicators are included) each coefficient is simply an estimate of mean emissions (or mean tax rate) for a particular treatment and time period (grouping).[12] For ease of interpretation we organize the regression coefficients by rows, where each row corresponds to a particular treatment, and columns, where each column represents a time period (grouping).

Similar to previous emissions and ambient tax experiments that include 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. Using a 5% significance level, mean emissions in the baseline, no-tax setting are not statistically different from the theoretical prediction of $\bar{x} = 20$ for any treatment or jointly across all treatments [$F = 1.44$; $p = 0.18$].[13] This can be taken as evidence

[9] We also analyzed aggregate (i.e. group-level) emissions, which lead to the same conclusions.
[10] All of our conclusions remain if we instead base these hypothesis tests on outcomes from any particular period between 18 and 25, or from any grouping of these periods. Participants are not observed to systematically increase emissions in the final few periods, which implies that beliefs regarding continuation probabilities do not significantly impact decision-making.
[11] This is implemented in Stata using the "cluster" option for the "regress" command.
[12] Since no intercept is included in the regressions, we note that R^2 no longer has the standard interpretation.
[13] Throughout the paper, unless otherwise noted, a 5% significance level is used.

Table 4
Tax rate model.

Dependent variable: group-level tax rate Number of observations: 608		$R^2 = 0.86$			
Treatment		Tax policy (Pds 6–25)			
		Period 6	Period 7	Pds 8–17	Pds 18–25
Dynamic emissions tax	1. $\alpha = 75$; $\tau_0 = 1200$	–	1387.5* (196.5)	1404.4* (212.5)	1216.4* (181.7)
	2. $\alpha = 75$; $\tau_0 = 3600$	–	3412.5 (699.9)	1946.3*,† (283.1)	1476.6*,† (106.7)
	3. $\alpha = 12.5$; $\tau_0 = 1200$	–	1137.5* (100.0)	1028.8* (255.2)	1168.4* (306.3)
	4. $\alpha = 12.5$; $\tau_0 = 3600$	–	3537.5* (73.6)	2882.2*,† (37.3)	2510.2† (182.9)
Dynamic ambient tax	5. $\alpha = 75$; $\tau_0 = 1200$	–	150.0*,† (83.0)	620.6*,† (173.2)	618.8*,† (238.6)
	6. $\alpha = 75$; $\tau_0 = 3600$	–	3468.8* (118.6)	1218.8*,† (161.5)	848.4*,† (201.6)
	7. $\alpha = 12.5$; $\tau_0 = 1200$	–	1218.8* (40.6)	1183.1* (186.9)	996.9* (291.3)
	8. $\alpha = 12.5$; $\tau_0 = 3600$	–	3446.9* (154.8)	2145.9*,† (457.0)	1293.0*,† (499.2)

Notes: Numbers in parentheses are cluster-robust standard errors.
* Mean tax rate is statistically different than 2400 at the 5% level.
† Parameter is statistically different than τ_0 at the 5% level.

that participants understand the decision-making framework and that financial incentives are salient enough to motivate identification of the profit-maximizing outcome.

Turning to analysis of the tax policy, we begin by analyzing the initial policy period outcomes and then focus on equilibrium behavior. We note that, aside from the initial tax policy period (period 6), it is difficult to construct meaningful tests of point predictions or comparisons across treatments for pre-steady state periods.[14] Mean emissions in period 6, for treatments with a low initial tax, are predicted to be 16 when all players are myopic. Mean emissions across this set of treatments is 11.04, and based on treatment-specific *t*-tests we reject this prediction of 16 in each case. Turning to the high initial tax treatments, the theoretical prediction is 8 for the all-myopic case. We fail to reject this all-myopic hypothesis in all cases. Thus, this evidence suggests that policy design may influence the decision to play myopic or strategic, and in particular that a low initial tax encourages strategic play.

With respect to the effects of the other treatment variables on emissions decisions in period 6, there are no clean directional predictions without making assumptions regarding the number of strategic players. If we make the assumption that the number of strategic players is fixed, theory suggests that emissions under the dynamic ambient tax should be relatively lower than under the dynamic emissions tax. Although emissions appear to work in the hypothesized direction – mean emissions are 11.38 and 9.94, across dynamic emissions tax and dynamic ambient tax treatments, respectively – this difference is not statistically significant. Further, theory predicts that – for a particular instrument – emissions are higher with the fast speed of adjustment parameter. There is some support for this with the dynamic emissions tax (12.00 for fast adjustment versus 10.75) but not the dynamic ambient tax (9.22 for fast adjustment versus 10.66). For either case the difference is not statistically significant. However, the evidence regarding the influence of the initial tax on strategic play casts doubt on the assumption that the number of strategic players is invariant to policy design.

We now turn to our analysis of equilibrium (i.e. periods 18–25) outcomes. Below we summarize our results with respect to the first two of our main hypotheses from Section 3.1, regarding equilibrium outcomes.

Result 1. In all treatments, average emissions are equal to the standard in equilibrium.

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

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 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 equilibrium, 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. Despite the statistical equivalence, there is still some variance around the optimal individual abatement level. Hence, while our experimental results suggest that the application of a dynamic tax does not affect the desired pollution standard, the standard is not necessarily reached at least cost.

Tax rate outcomes are theoretically dependent upon the proportion of myopic players, although in the special case that 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 suggestive of some degree of strategic behavior. In particular, the average tax rate in steady

[14] As can be gleaned from Figs. 1 and 2, theoretical predictions on the approach path depend heavily on the assumed number of myopic players and the tax policy period. This limits the number of useful tests of point predictions. Further, comparisons across treatments are problematic as even the direction of the theoretical treatment effect varies across periods and is ambiguous for any particular period without assumptions regarding the (unknown) number of myopic players.

Table 5
Policy design effects model I.

Variable	Description	Coefficient (robust std. err.)
Dependent variable: group-level tax rate		
Ambient policy	=1 if dynamic ambient tax; =0 if dynamic emissions tax	−653.6* (209.6)
Fast adjustment	=1 if $\alpha = 75$; =0 if $\alpha = 12.5$	−452.1* (209.6)
Low initial tax	=1 if $\tau_0 = 1200$; =0 if $\tau_0 = 3600$	−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.
* Estimate is statistically significant at the 5% level. Only data from periods 18–25 of the experiment are analyzed in this model.

state 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 the efficient static tax rate of 2400.

4.1. Effects of policy design on tax rates

Hypotheses 3–5 correspond with the effects of policy design on the tax rate, i.e. treatment effects. To test these hypotheses, we draw data from the equilibrium periods 18 to 25 to estimate the Policy Design Effects Model I presented in Table 5.[15] The policies we explore have three attributes (regulatory setting, speed of adjustment, and 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 with an ambient tax, a fast adjustment parameter, and a low initial tax.

As illustrated in Table 5, the marginal effect of the fast adjustment parameter, the ambient version of the dynamic tax, or the low initial tax rate reduces the equilibrium tax by approximately 500. The magnitude of these effects is apparent when looking at two ends of the policy design spectrum. For Treatment 4 (slow adjustment, dynamic emissions tax, high initial tax) the estimated equilibrium tax based on this model is 2510, whereas for Treatment 5 (fast adjustment, dynamic ambient tax, low initial tax) the estimate is 619. The policy variables alone explain 32% of the overall variation in tax rates.

Thus, the results from Policy Design Effects Model I allow us to reject the null Hypotheses 3–5. Rejection of Hypothesis 3 is consistent with the comparative statics of the dynamic model with (one or more) strategic players, but is in contrast to completely myopic behavior. Rejection of Hypotheses 4 and 5 is not theoretically supported if firm types are fixed, but may be explained if the initial tax or speed of adjustment parameter influences the choice of type. We explore this below.

4.2. Effects of policy design on player type

Changing the policy design theoretically alters the steady-state tax by dynamically influencing emissions choices, when one takes as given a player's type. Further, policy design influences the incentives to choose a particular type, which can in turn influence the steady-state tax. Thus, an empirical investigation into the influence of policy design on the propensity to choose a type is essential to carefully interpreting the observed treatment effects regarding steady-state tax rates.

To facilitate this investigation, we use two approaches for identifying player types. The first is based on average behavior in the experiment. Regardless of the number of strategic players in the group (based on beliefs or in actuality), a myopic player deterministically equates marginal profits to the tax rate. Based on our experimental design this implies the following linear relationship between emissions choice and the tax rate: $x^m(\tau) = 20 - \tau/300$.[16] To statistically identify myopic players, for each individual we ran a regression of the emissions choice on the tax rate. Given the data are time-series, we assume the disturbance follows an AR(1) process and estimate the model using FGLS. The test for myopic play is a joint test that the slope of the emissions choice function is $-1/300$ and the intercept is 20.

As a second approach, we identify myopic players based on their emissions choice in the first tax policy period. Theoretically, the emissions choice of a myopic player in this period is dependent on the initial tax but independent of group composition. The emissions choice of a strategic player in the initial period is dependent on group composition, but is theoretically lower than for a myopic player. As a rule of thumb, we characterize myopic players as those who make an emissions choice equal to or higher than the theoretical prediction for a myopic player.

Overall, 67 players are identified as myopic, with 14 identified based on average behavior only, 33 based on initial tax period behavior only, and 20 based on both criteria. To investigate the effects of policy design we estimate a probit model.

[15] We have estimated a similar model using individual emissions choice data, which is 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 mean emissions across any pair of treatments.

[16] We note that it is difficult to devise a formal test for strategic play given that updating rules depend on first identifying the number of myopic players in the group and further varies dramatically with respect to policy parameters.

Table 6
Policy design effects model II.

Dependent variable: =1 if myopic player; =0 otherwise			
Variable	Description	Coefficient (std. err.)	Marginal effect
Ambient policy	=1 if dynamic ambient tax; =0 if dynamic emissions tax	−0.271 (0.242)	−0.087
Fast adjustment	=1 if $\alpha = 75$; =0 if $\alpha = 12.5$	−0.448* (0.242)	−0.144*
Low initial tax	=1 if $\tau_0 = 1200$; =0 if $\tau_0 = 3600$	−1.254** (0.243)	−0.402**
Constant		1.063** (0.264)	
Log-likelihood = −72.676			
McFadden's $R^2 = 0.18$			
$\chi^2 = 31.81$**			
$N = 128$			

* Estimate is statistically significant at the 10% level.
** Estimate is statistically significant at the 5% level.

In particular, the Policy Design Effects Model II uses as the dependent variable an indicator that equals 1 if the player is identified as being myopic (based on either metric), and the independent variables are indicator variables that correspond with the policy design parameters. The estimated model is presented in Table 6.

Result 4. The propensity to play myopically decreases with a fast adjustment parameter and the low initial tax.

We find that coefficient signs match theoretical expectations, assuming players have diffuse beliefs regarding others' types, although the effects are not always significant. The largest effect, which is statistically significant, is that the low initial tax decreases the propensity to play myopically by 40%.[17] As a decrease in myopic players theoretically leads to a lower steady-state tax, this finding provides an explanation for why we observe that the low initial tax is associated with a decrease in the equilibrium tax, an effect not predicted when player types are assumed to be fixed. The fast adjustment setting decreases myopic play by 14%, and this effect is marginally significant ($p = 0.06$). Thus, the rejection of Hypotheses 4 and 5, which is not consistent with the assumption that player types are invariant to treatment, can instead be explained by the incentives for myopic play generated through the policy design.[18]

5. Discussion

The results from our experimental investigation 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. In addition, some participants seize the opportunity to strategically over-abate in order to reduce their own long-term tax burden, which leads to observed tax rates roughly 50% below those which would stem from purely myopic behavior. When the polluter group consists of both myopic and strategic players, they exercise different strategies in equilibrium, which implies that the standard is not being met at minimum cost.

The observed effects of policy design changes on long-run tax rates can be reconciled with a theory that allows for a mix of strategic and myopic firms, along with the recognition that the incentives generated by the policy design can influence whether an agent plays myopically or strategically. In particular, the results reveal significantly lower (ceteris paribus) tax rates in settings with an ambient tax, fast rate of adjustment parameter, and low initial tax rate. These settings are congruent with relatively larger financial incentives for strategic over-abatement. Based on an identification strategy for myopic players, we find statistical support that the fast adjustment parameter and low initial tax rate decreased the propensity to play myopically. The values for the adjustment and initial tax rate parameters are presumably at the discretion of regulators, and can be used to design a policy that is potentially more politically palatable in the sense that it reduces the long-run tax burden.

Although the recent economics literature has focused on the development of ambient-based taxes for regulating non-point source pollution, it has been argued that these instruments are only practical for regulating watersheds with a small number of reasonably homogenous polluters (Weersink et al., 1998). Our experimental design reflects this setting, and the evidence we present on the dynamic ambient tax suggests especially strong promise for using such a mechanism to control non-point source pollution. A key concern about static ambient tax mechanisms is that extant incentives for collusion reduce pollution below the standard (see, for example, Hansen, 1998). With the dynamic tax, incentives to cooperate would seem both self-serving and socially desirable. The coalition can drive the tax rate expediently down to the group-profit maximizing

[17] In addition, we ran probit models based on average and initial period behavior criterion separately. For the average behavior criterion, we find that the low initial tax decreases the propensity to play myopic by 13% ($p = 0.09$). For the initial tax period behavior criterion, the estimated decrease is 38% ($p < 0.01$).

[18] As additional evidence of emissions heterogeneity resulting from different player types, we compared the variance of within-group emission decisions between the dynamic tax treatments and comparable static tax treatments not reported in this paper. From this comparison, we generally find a higher variance in the dynamic treatments, including the later periods of the experiment.

level through over-abatement. However, once the equilibrium tax rate is achieved there are no longer incentives to over-abate but instead correct incentives to exactly meet the standard.

It remains an open question whether the implications from our experiments, which involved student participants and small regulated groups, generalize to naturally-occurring policy settings. Accumulated evidence does however suggest that the qualitative findings based on student experiments are consistent with those from representative participant groups (Ball and Cech, 1996; Krause et al., 2003; Suter and Vossler, 2013; Vossler et al., 2009). Further, as highlighted by Normann and Riccuiti's (2009) review article, there are prominent examples where laboratory experiments on market-based mechanisms have been used to inform policy. With respect to the issue of group size, we acknowledge that industry size may influence the decision to behave strategically.[19] In the extreme, a single firm out of thousands may simply perceive itself as having no possible influence on future tax rates. Working in the opposite direction is the effect of formal or informal cooperative agreements (i.e. collusion). Although the gains from coordination theoretically remain strong with a large industry, transaction costs make this less likely. Coordination may nevertheless have an important role in small industries, or large industries where a handful of firms represent a considerable share of overall emissions.

On a final note, although regulators have embraced the use of cap-and-trade approaches over taxes in many instances, uncertainty over the benefits and costs of possible climate change policies has reinvigorated academic and policy interest in pollution taxes (e.g. Fischer et al., 2003; Pizer, 1999; Quirion, 2004). This study provides some input to this discussion. While the linear dynamic tax can serve to reduce the costs of regulation to important industries, the ability to coordinate behavior to achieve a low tax rate may also be seen as unfavorable. For example, although the relative incentives for technological innovation under (static) tax and permit policies is in general ambiguous (Fischer et al., 2003), the dynamic tax approach serves to increase the level of uncertainty with regard to future payoffs because the price of emissions has the potential to vary over time, thus increasing the risk of investment in abatement technologies. Additionally, a low steady-state tax rate could further serve to dampen incentives for innovation. In fact, undertaking costly over-abatement 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 focused on comparing price versus quantity instruments.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at http://dx.doi.org/10.1016/j.jebo.2013.07.017.

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[19] We note that for the dynamic tax (ambient or emissions), the incentives for strategic play are independent of industry size conditional on holding fixed the intensity of the policy (pollution standard divided by the number of players). Of course, holding the standard fixed while increasing the industry size has the effect of reducing strategic incentives.

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