Testing Ambient Pollution Instruments with Heterogeneous Agents

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Abstract

This paper investigates the ability of ambient pollution instruments to induce a group of heterogeneous agents to choose a target outcome. Six controlled laboratory sessions were conducted with heterogeneous agents facing ambient pollution instruments with lump sum or proportional fines and bonuses. Sessions are compared with a study of these exogenous targeting instruments and homogenous agents using complete information and certainty [25]. The data show that contracts can indeed be developed that induce heterogeneous groups to choose the target outcome; however, substantial inefficiency and inequality were observed.

Keywords: Nonpoint Source Pollution, Moral Hazard in Groups, Group Decision Making, Experiments

Proposed Running Heading: Testing Ambient Pollution Instruments.

1. Introduction

The theoretical literature on nonpoint source pollution suggests that ambient pollution instruments can be developed to induce polluters to comply with a standard [10, 22, 31, 32]. However, authors such as Shortle and Horan [23], and Weersink, et al. [28] temper this result citing the difficulty of monitoring ambient conditions, political limitations, and suggesting that ambient instruments are only appropriate for simple situations where the number of polluters is small and homogenous. Our paper supports this pessimistic position using empirical evidence from a series of laboratory experiments. The results suggest that ambient pollution instruments can be designed to induce the socially optimal outcome at the aggregate level. However, there are significant inequities in the outcomes of firms with different emissions capacities, which results in inefficiency. This inequality is not apparent in the theoretical studies as individuals are assumed to choose the payoff maximizing decision. However, in the experimental environment presented here, subjects with lower unconstrained emission levels (small capacity polluters) reduce their emissions by less than the optimal amount while subjects with higher unconstrained emissions (large capacity polluters) reduce their emissions by more than the optimal amount. This results in the large capacity polluters shouldering more of the burden of pollution reduction and earning lower payoffs than the small capacity polluters.

More specifically, this paper describes an experiment which is based on the model of nonpoint source pollution problem used by authors such as Segerson [22], Xepapadeas [31], [32], and Horan, et al. [10]. The primary treatment variable is whether or not the group is composed of subjects who have identical unconstrained emission levels (homogeneous sessions) or whether half of the subjects are small capacity polluters and half are large capacity polluters (heterogeneous sessions).[1] Subjects are fully informed of the payoff schedules of all of the members in their group. Subjects choose a decision number which is analogous to a level of emission. They know the private payoff—the cost of reducing their emissions from the unconstrained level—of choosing this action. They are then informed of the aggregate level of emission and the

[1] The homogeneous sessions are discussed more fully in Spraggon [25].

resulting charge as determined by the ambient pollution instrument.[2] Two ambient pollution instruments are tested. The first is the Tax/Subsidy contract suggested by Segerson [22] which induces agents to select values closest to the target level in a previous study with homogeneous payoff functions [25]. This contract involves a proportional bonus if the total of group emissions is below the target and a proportional fine if this group total exceeds the target. As discussed in Spraggon [25], the distinguishing feature of this contract is that it results in the desired individual target being a dominant strategy. The second contract is the Group Fine contract which is similar to the instrument suggested by Holmstrom [11] for the worker effort problem. The Group Fine contract involves a lump sum fine if the total of group emissions is above the target. This contract generates multiple Nash equilibria. Each group of subjects participates in twenty-five repetitions of both contracts. As a result of this within subject design the effects of switching between these types of contracts can be tested.

Moral hazard in groups is a common social dilemma which is applicable to not only the problem of nonpoint source pollution but to problems such as worker effort, common property resources and the provision of public goods. Most of the applicable empirical work has been conducted for the provision of public goods (although, Nalbantian and Schotter [16] provide some evidence against instruments like the Group Fine for the worker effort problem). There are a number of important differences between the standard public good environment and the experiment reported here. Primarily the nonpoint source pollution problem is typically thought of as a public bad. Authors who examine the differences between experiments framed as public goods and those framed as public bad [2, 19, 24, 30], suggest subjects choose the dominant strategy more often when the experiment is framed as a public bad. The Tax/Subsidy instrument is most similar to a non-linear public bad with an internal optimum. However, subjects are not presented with a target in non-linear public bad experiments as they are in this environment. Holt and Laury [12] provide a survey of the results from non-linear public good experiments. They show that decisions are generally more consistent when the dominant strategy is in the interior of the decision space than when it is at a corner or when there are multiple Nash equilibria. However,

[2] We are interested in the incentives provided by the ambient pollution instruments and as a result subjects are not informed that their decisions will be interpreted as the choice of a level of pollution to emit.

none of the studies surveyed involve agents with heterogeneous payoff functions. The Group Fine is most similar to a non-linear threshold public bad with an interior solution. There are many empirical studies of the threshold public good environment, surveyed by Ledyard [14], and Cadsby and Maynes [5] and the threshold common property resource problem by Rapoport and Suleiman [20]. These studies show that if the value of the public good is high enough relative to the required level of individual contribution the public good will be consistently provided [5]. The added complication of heterogeneity in public good environments in general and threshold public good environments specifically, results in the public good being provided less often [7, 8, 12, 14, 21, 29]. Taking the previous results for public bads and heterogeneity together suggests that subjects should be more likely to choose the Nash equilibrium decision which may lead to more compliance with the standard in the environment investigated in this paper.[3]

This study shows that ambient pollution instruments that induce the target decision as a dominant strategy are an effective solution to the problem of group moral hazard with heterogeneous agents. However, there are significant reductions in efficiency when the group is composed of subjects who have different unconstrained emission levels. Further, the effects of switching between the contracts are significant. As in the homogeneous study [25], individual decisions are not adequately described by the Nash equilibrium. Small capacity subjects choose decision numbers which are significantly higher than the Nash prediction and large capacity subjects choose decision numbers which are significantly below the Nash prediction. Thus, this study suggests that the Tax/Subsidy instrument induces the larger capacity subjects to shoulder a greater share of the reduction to the target level than the small capacity subjects. As a result if equity among heterogeneous polluters is an important consideration this study suggests that ambient instruments are not an appropriate regulation device. Thus as Shortle and Horan [23]

[3] The purpose of this paper is not to test the two instruments against each other. Since the Tax/Subsidy instrument results in a unique Nash equilibrium and the Group Fine instrument results in multiple Nash equilibria previous studies of public goods with interior solutions suggest that the Tax/Subsidy instrument will induce more compliance [12]. Instead, both instruments are being tested for the effects of heterogeneity in the individual payoff functions against the case where individuals have homogeneous payoff functions.

suggest these instruments may not be appropriate when the firms responsible for the emissions are heterogeneous.

2. Experimental Design

The experiment examines the moral hazard in groups problem in the context of nonpoint source pollution and compares groups of polluters who are homogeneous with those who are heterogeneous in terms of uncontrolled emissions [22, 31].[4] Heterogeneity is introduced to model the situation where firms have different uncontrolled emission levels. Six subjects participated in each session. Half of these subjects took the role of small capacity polluters and the other half took the role of large capacity polluters. In each period the subjects were asked to choose a number. It was explained that their choice resulted in a private payoff and a group payoff. The private payoff was directly related to the decision number, which could be found in a table provided to each subject. The group payoff depended on the subject's own decision as well as the choices of the other subjects and the contract being tested. For consistency with previous studies, subjects had full information as to their payoff structure and the payoff structure of the other participants in their group. Each group participated in both contracts in two twenty-five period phases. The data from these sessions are compared with sessions where all subjects took the role of medium capacity polluters. The sessions where subjects all had the same capacity are referred to as homogeneous and the sessions where subjects had different capacities are referred to as heterogeneous.[5]

[4] As noted previously, the homogeneous sessions were conducted earlier and are discussed extensively in Spraggon (2002) [25]

[5] The sessions were identical except for the differences in capacity of the subjects and four contracts were tested in the homogeneous sessions [25]. The instructions for this experiment are available upon request from the author or from his website at: http://flash.lakeheadu.ca/˜jspragg/.

In the experiment individuals choose their decision numbers without being observed analogous to nonpoint source polluters whose emissions are unobservable.[6] The higher the individual's emission level, the higher the private payoff due to the lower cost of emission abatement. As with the homogeneous case, I identify the efficient choice of individual decision numbers by assuming that society is represented by a social planner who maximizes the benefits from individual decisions $B_n(x_n)$ minus the costs $D(X)$. The joint benefit function is

$$SP = \sum_{n=1}^{6} B_n(x_n) - D(X) \tag{1}$$

where n indexes subjects $n = 1, \ldots, 6$, x_n is the emission level chosen by subject n, and X is the observed total of these emission levels. Aggregate emissions are directly related to ambient level of pollution for a noncumulative (or "flow") pollutant. For simplicity I assume that the social cost of emissions is given by 0.3 times the sum of the individual decisions:

$$D(X) = 0.3 \sum_{n=1}^{6} x_n. \tag{2}$$

Heterogeneity is introduced through the individuals' benefit functions. Individuals represent either small capacity or large capacity firms. Subjects of the small type had an unconstrained emission capacity of 75 units (represented by a maximum decision number of 75) and those of the large type had an unconstrained emission capacity of 125. Subjects from the homogeneous study will be referred to as medium capacity firms as they had a capacity of 100 units. The benefit function for an individual depended on her emission level (x_n) and her unconstrained emission level (x_n^{max}):

$$B_n(x_n) = 25 - 0.002(x_n^{max} - x_n)^2. \tag{3}$$

If we have three individuals of each type, the social planner's problem is to maximize

$$SP = \sum_{n=1}^{6} (25 - 0.002(x_n^{max} - x_n)^2) - 0.3 \sum_{n=1}^{6} x_n, \tag{4}$$

[6] In the paper I will refer to the decisions made by subjects as emission levels for consistency. However, as discussed in the introduction, subjects where told that they were choosing decision numbers and that the aggregate decision number was the group total.

with respect to x_n where $x_n^{max} = 125$ for $n = 1, 2, 3$ and $x_n^{max} = 75$ for $n = 4, 5, 6$. The socially optimal emission level for each individual is found by solving:

$$\partial SP/\partial x_n = 0.004(x_n^{max} - x_n) - 0.3 = 0 \Rightarrow x_n^* = x_n^{max} - 75. \tag{5}$$

Therefore the socially optimal emission level for small types ($x_n^{max} = 75$) is 0, for medium types ($x_n^{max} = 100$) is 25, and for the large types ($x_n^{max} = 125$) is 50.[7] Thus, the socially optimal aggregate emission level is equal to 150 units (as it was for the homogeneous sessions).

3. Contracts

The nonpoint source pollution problem arises because the firm's choice of emission level is unobservable. As a result, the externality they impose cannot be corrected by taxes or subsidies based on individual emissions. The ability of two contracts, referred to as Tax/Subsidy and Group Fine, to mitigate this problem is evaluated herein. These contracts are of the same form as suggested by Segerson [22] for the nonpoint source pollution problem

$$T_n(X) = \begin{cases} t_n(X - X^*) + \tau_n & if\ X > X^* \\ s_n(X - X^*) - \beta_n & if\ X \leq X^*. \end{cases} \tag{6}$$

Where s_n and t_n are a subsidy and a tax respectively, β_n is a bonus and τ_n is a fine. These parameters could differ by agent but this has not been done for this study. The target X^* is exogenous in this model and represents the level of pollution which the social regulator chooses to allow. For the purposes of the experiment X^* is the socially optimal aggregate emission level from the social planner's problem given by equation (4). The Tax/Subsidy contract has $s_n = t_n = 0.3$, and $\beta_n = \tau_n = 0$, and the Group Fine contract has $\tau_n = 24$, and $s_n = t_n = \beta_n = 0$. These parameters are chosen so that the instruments induce the socially optimal outcome as a

[7] This environment differs from the public good environment where subjects contribute tokens. In this environment subjects are asked to choose a decision number rather than to make a contribution. As a result it seems less likely that subjects will feel that choosing zero is equivalent to not participating as they may in a public goods environment.

Nash equilibrium. The Tax/Subsidy contract results in the socially optimal emission level being a dominant strategy, while the Group Fine contract results in multiple Nash equilibria under the assumption of risk neutrality (see Spraggon [25] for details). Xepapades [31] shows that the Tax/Subsidy contract is also an efficient solution to the nonpoint source pollution problem in an infinite-horizon dynamic model.[8]

4. Payoff Maximization

An individual's payoff function is the benefit function (3) minus the value of the contract (6), $\pi_n = B_n(x_n) - T_n(X)$. Thus, the expected payoff function for the Tax/Subsidy contract is

$$\pi_n = 25.00 - 0.002(x_n^{max} - x_n)^2 - 0.3(X - 150). \tag{7}$$

Notice that the socially optimal solution is the unique Nash equilibrium because the first order condition for the subject's payoff function is identical to the first order condition for the social planner's problem.[9] Since this is a dominant strategy, it is also the Nash equilibrium for the repeated game by backwards induction (Osborne and Rubinstien 1994 pp. 157-158) [17].

An individual's expected payoff function under the Group Fine contract depends on the probability that the sum of the emission levels is less than the target level $Prob(X < 150)$ or $Prob(X_{-n} \leq 150 - x_n)$ where X_{-n} is the sum of all individuals' emission levels except subject n ($X_{-n} = \sum_{j \neq n} x_j$). Then $T_n(X)$ for the Group Fine contract is $T_n(X) = 24(1 - Prob(X_{-n} \leq 150 - x_n))$ for agent n. Thus, for a large capacity subject the expected profit function under the Group Fine contract is

$$\pi_n = 25 - 0.002(x_n^{max} - x_n)^2 - 24[1 - Prob(X_{-n} \leq 150 - x_n)]. \tag{8}$$

Clearly it is in an agent's best interest to choose x_n so that $X = 150$ or, if the fine cannot be avoided, to choose x_n equal to its maximum value. As a result there are two types of

[8] Xepapadeas' [31] dynamic version of the contract includes the firm's discount rate, the rate of pollution decay and possibly a term which depends on the other firms' adjustments depending on the information structure.

[9] $\partial \pi_n / \partial x_n = 0.004(x_n^{max} - x_n) - 0.3$ which is identical to the first order condition of the social planner's problem (5).

Nash equilibrium. These equilibria can be described as socially optimal when the group total is equal to 150 and individually optimal when each subject chooses their maximum emission level. Multiple equilibria in the one-shot game suggests that there may be repeated game effects in the experiment. The Group Fine contract, however, is discussed for comparison with the threshold public good literature [5, 14, 20] and the analysis of the repeated game effects are beyond the scope of this paper.

Subjects may use simple heuristics to determine how to choose their emission level, as suggested by Rapoport and Suleiman [21] and Hackett, Schlager and Walker [9]. Such heuristics might be based on notions of equity. Subjects could choose to select emission levels which are equal, an equal proportion of their unconstrained emission level, an equal reduction from their unconstrained emission level or an equal proportional reduction from their maximum. In this study these heuristics lead to different results, whereas for the homogeneous study all of the subjects had the same payoff function and as a result they all lead to the optimal outcome. For equal absolute emission levels, the six subjects in this study, with a target of 150, would each choose $x_n = 25$. If the subjects reach the target of 150 by either reducing their unconstrained number by the same proportion or by selecting a number which is the same proportion of their maximum, large capacity and small capacity subjects will choose 31 and 19 respectively.[10] The optimal outcome (large capacity subjects choose 50, and small capacity subjects choose 0) is an equal absolute reduction. These predictions as well as the predictions of Nash equilibria are summarized in Table I.

5. Results

The results from the sessions with heterogeneity in the payoff functions are based on data collected from thirty-six subjects who were recruited from the student population at McMaster

[10] Let p be the proportion that subjects reduce their emissions by, or the proportion of their emissions which they choose. For the decision to be a Nash equilibrium, the group total must be 150. Therefore $150 = 3(75)p + 3(125)p$ which implies that $p = 1/4$.

Table I. Theoretical Predictions

Contract	Subject Capacity	Nash Equilibrium		Simple Heuristics		
		Optimal	Sub-Optimal	Abs. Dec.	Prop. Dec.	Abs. Red.
Tax/Subsidy	Large	50	None	25	31	50
	Medium	25	None	25	25	25
	Small	0	None	25	19	0
Group Fine	Large	Multiple	125	25	31	50
	Medium	Multiple	100	25	25	25
	Small	Multiple	75	25	19	0

Notes: Sub-Optimal refers to the solution where all subjects choose their maximum decision number, Abs. Dec. refers to subjects choosing equity in the absolute decision number, Prop. Dec. refers to subject choosing equity in the proportion of their maximum, and Abs. Red. refers to subjects choosing equity in the absolute reduction from their maximum decision number

University. Six sessions were conducted in which subjects participated in twenty-five periods of either the Tax/Subsidy or Group Fine contract and then twenty-five periods where subjects participated under the other contract. Groups participating in the first twenty-five periods are referred to as inexperienced, while those participating in the second twenty-five periods are referred to as experienced. Bankruptcies[11] were handled by excusing the subject from the phase of the experiment in which the bankruptcy occurred. On average subjects earned twenty-five dollars Canadian for sessions that lasted about an hour and a half. These sessions are compared with data from six sessions which were conducted in an identical manner except that the subjects all had homogeneous payoff functions.

Each group of six subjects participated in one session which consisted of twenty-five periods with both of the contracts. Only the first phase of each session provides an independent

[11] It was possible for subjects to earn negative payoffs in each period. Each subject was given an initial endowment of five dollars Canadian and if their cumulative payoff fell below zero in any period, they were removed from the rest of that phase of the experiment. Everyone in the group was informed that there had been a bankruptcy and that the group total was now the sum of the remaining subjects' emission levels. Bankruptcies occurred in three sessions which were used in the data analysis. All of these sessions involved experienced subjects and the effects of the bankruptcies will be discussed in the analysis presented below.

observation. Regression analysis bases the standard errors on the variance in the data from the whole experiment. It therefore exploits the factorial design to provide more powerful tests to determine whether the mean emission level totals and mean emission levels by subject capacity are consistent with the theoretical predictions. Since the sessions with experienced and inexperienced subjects are not independent, tests are initially calculated separately for these groups.

The experiment has been repeated for twenty-five periods for consistency with previous experimental studies [14, 16]. Typically this is done to allow for learning. However, in the nonpoint source pollution context if these instruments were implemented in a field setting it would presumably involve a number of firms choosing their emission levels for a period of time, then being fined or rewarded depending on the ambient level of pollution and then choosing their emission levels again. I argue that it is the mean outcomes over the twenty-five periods that are of interest to us. This provides some indication of the average level of compliance over the period where individuals are learning and once they understand the environment.[12]

The efficiency of the instrument in this environment can be thought of in terms of the value of the Social Planner's problem. The closer the value of (4) to the optimal value (where all of the firms emit the optimal level of pollution) the more efficient the instrument. As a result, efficiency in this environment is defined as $\epsilon = \frac{SP_{ACTUAL} - SP_{STATUSQUO}}{SP_{OPTIMAL} - SP_{STATUSQUO}}$ where SP_{ACTUAL} is the value of the social planner's problem (4) for the actual decision number chosen by the agents, $SP_{STATUSQUO}$ is the value of the social planner's problem when the agents choose their unconstrained emission levels and $SP_{OPTIMAL}$ is the value of the social planner's problem when the agents choose the optimal emission levels. Efficiency is interesting because it not only takes into account whether or not the target is achieved but also the cost at which the target is achieved. For example, the least efficient case for the target to be achieved is for all of the large type subjects and one of the small type reduce their decision numbers to zero, and the other two small type subjects choose their unconstrained levels of emission (75). The aggregate level of emission would be 150 but the efficiency is only 44.4 percent.

[12] Subjects were surveyed as to how long it took them before they felt that they understood the experiment and the typical response was five periods.

To summarize, the data shows that the Tax/Subsidy instrument is able to induce both homogeneous and heterogeneous groups to choose the target outcome at the aggregate level. Moreover, there is no significant difference between the homogeneous and heterogeneous groups at the aggregate level. Experience does not have significant effects on these observations. However, there seem to be systematic differences between sessions with experience and without. Tax/Subsidy sessions which follow Group-Fine sessions tend to have higher aggregate emission levels than the Tax/Subsidy sessions run without experience. Similarly, Group Fine sessions which follow Tax/Subsidy sessions tend to have lower aggregate emission levels than the Group Fine sessions run without experience. The first two results concern inexperienced subjects, while the third result concerns experienced subjects. Result four compares the outcomes at the individual level.

Result 1: Under the Tax/Subsidy instrument there are no significant differences between groups of inexperienced subjects with homogeneous and heterogeneous payoff functions at the aggregate level.

Notice in Table II that under Tax/Subsidy the mean group emission levels are not significantly different from 150 for both homogeneous and heterogeneous groups. Table III presents the analysis of variance for the entire sample controlling for treatment (Tax/Subsidy versus Group Fine), whether or not subjects had heterogeneous payoff functions, whether or not they had experience and the interaction between these three variables.[13] Notice that only the p-values for the Model, Group Fine and the interaction between Group Fine and Experience are below 0.10. Mean efficiency (Table II) for the homogeneous treatment is higher than the efficiency for the heterogeneous treatment. Figure 1 (the mean group totals for the Tax/Subsidy instrument with inexperienced subjects by period) shows that part of the explanation for this difference is that the aggregate emission level for heterogeneous groups is higher than for the homogeneous groups in many periods. The other part of the explanation is due to the individual level decision making and will be discussed in the final result.

[13] Analysis of Variance conducted only for the inexperienced subjects provides the same results.

Table II. Mean Group Emission Levels and Mean Group Efficiencies by Treatment for Inexperienced Subjects.

Treatment	Mean Group Emission	Confidence Interval Lower Bound	Confidence Interval Upper Bound	Mean Group Efficiency
Tax/Subsidy, Homogeneous, Inexperienced Subjects	158.44 (7.702) [3]	125.3	191.58	96.3 (1.09) [3]
Tax/Subsidy, Heterogeneous, Inexperienced Subjects	170.47 (6.62) [3]	141.99	198.95	85.1 (4.88) [3]
Group Fine, Homogeneous, Inexperienced Subjects	358 (105.73) [3]	-96.9	812.9	53.5 (22.46) [3]
Group Fine, Heterogeneous, Inexperienced Subjects	509.47 (14.47) [3]	447.2	571.73	22.2 (3.63) [3]

Standard errors are provided in parenthesis and number of observations are provided in square brackets.

Table III. Anova on Group Total, by Session, Full Sample

Number of Observations: 24 — Root MSE: 105.02
R-squared: 0.6335 — Adj R-squared: 0.4732

Source	Partial SS	df	MS	F	Prob > F
Model	305029.92	7	43575.71	3.95	0.0108
Group Fine	186025	1	186025	16.87	0.0008
Homogeneity	14737.16	1	14737.16	1.34	0.2647
Experience	29979.63	1	29979.63	2.72	0.1187
Interactions					
Group Fine*Homogeneity	12450.64	1	12450.64	1.13	0.3038
Group Fine*Experience	52117.44	1	52117.44	4.73	0.0451
Homogeneity*Experience	6215.89	1	6215.89	0.56	0.4637
Group Fine*Homogeneity*Experience	3504.17	1	3504.17	0.32	0.5808
Residual	176467.26	16	11029.2		
Total	481497.19	23	20934.66		

Result 2: The Group Fine instrument is consistent with previous studies for both groups of inexperienced subjects with homogeneous and heterogeneous payoff functions at the aggregate level.

Table II shows that the aggregate emission levels for the Group Fine instrument with both Homogeneous and Heterogeneous inexperienced groups are well above the target and highly variable. Table II also shows that the efficiencies are very low. Figure 2 confirms this, showing that the aggregate emission levels are well above the target in all periods and indeed for the heterogeneous groups seem to be converging towards the maximum aggregate emission level of 600. This is consistent with previous studies of threshold public goods [5] which suggest that groups will converge to zero contributions if the reward is not high enough. This suggests that a higher penalty in this environment may have resulted in more efficient results. However, such a large fine may not be politically feasible as if even one participant deviates slightly from the optimal decision a huge penalty is imposed on all of the participants including those who are reducing their emissions to the optimal level.

Result 3: The effect of experience in the environment is insignificant; however, there are significant effects of switching between the instruments.

Table IV shows that the group totals are again closer to the target level and the efficiencies are higher for the Tax/Subsidy than for the Group Fine instrument with experienced subjects.[14] Notice in Figures 3 and 4 that the results are very similar for homogeneous and heterogeneous agents across each instrument. There is one notable difference between the inexperienced and experienced subjects: For the Tax/Subsidy instrument the mean group total for heterogeneous experienced groups is less than that for homogenous groups where it was higher for inexperienced subjects. However, notice that efficiency is higher for the homogeneous rather than the heterogeneous groups. The Anova for all of the treatment variables on group total (Table III)

[14] Since some of the sessions with experienced subjects were affected by bankruptcies the mean group decision numbers may be lower for these sessions as the maximum possible aggregate emission level falls from 600 to 500. Each of the treatments with experienced subjects except for the Group Fine with heterogeneous agents experienced bankruptcies in one of the three sessions.

Table IV. Mean Group Emission Levels and Mean Group Efficiencies by Treatment for Experienced Subjects.

Treatment	Mean Group Emission	Confidence Interval Lower Bound	Confidence Interval Upper Bound	Mean Group Efficiency
Tax/Subsidy, Homogeneous, Experienced Subjects	188.87* (4.00) [3]	171.78	206.17	89.1 (5.40) [3]
Tax/Subsidy, Heterogeneous, Experienced Subjects	184.96* (7.51) [3]	152.63	217.29	76.3 (6.89) [3]
Group Fine, Homogeneous, Experienced Subjects	250.47* (102.63) [3]	-191.11	692.04	74.82 (21.67) [3]
Group Fine, Heterogeneous, Experienced Subjects	289.23 (85.53) [3]	-78.77	657.22	63.94 (17.78) [3]

Standard errors are provided in parenthesis and number of observations are provided in square brackets.

suggests that instrument and instrument interacted with experience are the only treatment variables which have significant effects (at both the 5% and 10% levels).

That the Group Fine and experience interaction term in the full sample Anova (Table III) is significant suggests that subjects' experience with one instrument affected their decisions under the other. The effect can also be clearly seen in the efficiencies when the aggregate data are plotted (Figure 5). This suggests that there are systematic differences in behavior between groups who have experience with the Group Fine instrument before they are exposed to the Tax/Subsidy instrument. Indeed it seems that the experienced groups under the Tax/Subsidy instrument are more likely to choose higher emission levels after participating in the Group Fine instrument and experienced groups under the Group Fine instrument choose lower decisions after participating in Tax/Subsidy. This resulted in bankruptcies being observed under the Tax/Subsidy contract with experienced subjects where no bankruptcies were observed with inexperienced subjects.

The effect of experience also shows up in the individual decisions (Table V). Large capacity subjects chose on average higher numbers under the Tax/Subsidy instrument and lower numbers

Table V. Confidence Intervals for Mean Individual Emission Levels by Treatment.

Treatment	Mean Individual Emission	Confidence Interval Lower Bound	Upper Bound
Tax/Subsidy, Large Capacity, Inexperienced Subjects	35.29 (3.75) [3]	19.16	51.43
Tax/Subsidy, Small Capacity, Inexperienced Subjects	21.53* (3.83) [3]	5.07	37.99
Tax/Subsidy, Large Capacity, Experienced Subjects	41.58 (11.65) [3]	-8.56	91.70
Tax/Subsidy, Small Capacity, Experienced Subjects	20.08 (11.14) [3]	-27.85	68.00

* Indicates that the mean individual emission level is significantly different from the Nash prediction. Standard errors are provided in parenthesis and number of observations are provided in square brackets

under the Group Fine instrument with experience than they did without. Small capacity subjects chose about the same level of emissions under the Tax/Subsidy instrument and lower under the Group Fine with experience than they did without. This is consistent with the bankruptcies which were observed under the Tax/Subsidy instrument when subjects were experienced (see Table IV). The large capacity subjects choose larger numbers resulting in larger taxes to each member of the group which results in subjects who are choosing lower numbers earning negative payoffs in each period and eventually going bankrupt.

This effect can also be observed in the distributions of individual decisions. Figures 6 and 7 depict these distributions for large capacity subjects for periods 11-20, and small capacity for periods 11-20 respectively.[15] Notice that under the Tax/Subsidy instrument for both the large and small capacity subjects there are more decisions concentrated at the high and low limits when subjects have experience, while for the Group Fine there are less decisions concentrated

[15] The first 10 periods and last four periods have been excluded to eliminate learning and end game effects. However, the graphs where all of the data is used are almost identical.

at the end points when subjects have experience. This suggests that the outcome subjects coordinate on under the first contract affects the outcome of the second contract. Comparing Tables II and V shows this result clearly.

Result 4: Large capacity subjects reduce their emission levels by more than small capacity subjects under the Tax/Subsidy contract.

Nash equilibrium does a good job in predicting the aggregate emission levels. Table V shows that the mean decision number is significantly different from the Nash prediction only for the small capacity subjects with no experience. Further, the data does not provide support for any of the simple heuristic hypotheses. Recall that if a subject decides that all subjects should choose an equal proportion of their unconstrained level (or an equal reduction from their unconstrained level) small capacity subjects will choose 19 and large capacity subjects will choose 31, and if they decide that all subjects should choose the same emission level they will choose 25. However, there does not seem to be any significant coordination on any of these outcomes as shown in Figures 6 and 7. For both inexperienced and experienced small capacity subjects the top left and right panels of figure 7 show that the dominant strategy (zero) is played with the highest frequency. Moreover this strategy is played more frequently among the experienced subjects. For the large capacity under the Tax/Subsidy the inexperienced subjects choose numbers between twenty-five and forty-five. Whereas, with experience the distribution of decisions for these subjects shows more decisions above forty-five but also a larger percentage at zero. Thus, although Nash equilibrium does a good job of predicting average decisions, it does not do a good job predicting individual decisions particularly for the large capacity subjects under the Tax/Subsidy instrument.

Overall large capacity subjects are reducing their decision numbers by more than small capacity subjects. This shows up in the final payoffs. Table VI shows that small capacity subjects earn much more than large capacity subjects under the Tax/Subsidy. Small capacity subjects earn on average 6.63 Canadian dollars (C$) more than large capacity subjects for inexperienced groups and C$ 6.14 more for experienced groups under the Tax/Subsidy contract. Under the Group Fine small capacity subjects earn C$ 0.71 more for inexperienced groups and C$ 4.12 more for experienced groups. Table VII presents the Anova for payoff on all of the

Table VI. Mean Payoffs for Heterogeneous Treatments

Contract	No Experience		Experience	
	Large	Small	Large	Small
	7.28	13.91	4.55	10.69
Tax/Subsidy	(3.26)	(2.71)	(5.29)	(3.24)
	[9]	[9]	[9]	[9]
	5.25	5.96	4.40	8.52
Group Fine	(1.57)	(0.71)	(3.44)	(4.03)
	[9]	[9]	[9]	[9]

Table VII. Anova on Payoff, Full Sample by Individual

Number of Observations: 72 — Root MSE: 3.31
R-squared: 0.5010 — Adj R-squared: 0.4464

Source	Partial SS	df	MS	F	Prob > F
Model	702.06	3	100.29	9.18	0.0000
Group Fine	170.06	1	170.06	15.56	0.0002
Large Capacity	348.17	1	348.17	31.87	0.0000
Experience	20.4	1	20.4	1.87	0.1766
Interactions					
Group Fine*Large Cap.	70.69	1	70.69	6.47	0.0134
Group Fine*Experience	66	1	66	6.04	0.0167
Large Cap.*Experience	9.61	1	9.61	0.88	0.3519
Group Fine*Large Cap.*Experience	17.13	1	17.13	1.57	0.2151
Residual	699.27	64	10.93		
Total	1401.33	71	19.74		

treatment variables. Notice that the dummy variables for Group Fine, Large Capacity, and the interactions for Group Fine and Large Capacity, and Group Fine and Experience are all significant. Using regression analysis (Table VIII), capacity, experience and the instrument crossed with experience are significant. This again illustrates the effect of switching between the instruments and the differences in payoffs between capacities are significant.

Table VIII. Regression on Payoff by Individual, Full Sample

Variable	Coefficient	Standard Error	p-Value
Constant	10.69	1.10	0.000
Group Fine	-2.17	1.56	0.169
Large Capacity	-6.14	1.56	0.000
Experience	3.22	1.56	0.043
Group Fine*Large Capacity	2.01	2.20	0.364
Group Fine*Experience	-5.78	2.20	0.011
Large Capacity*Experience	-0.49	2.20	0.821
Group Fine*Large Capacity*Experience	3.90	3.12	0.215

$Payoffs = \beta_1 + \beta_2 groupfine_s + \beta_3 Homogeneity_s + \beta_4(groupfine * Hom)_s + \beta_5(groupfine * order)_s$ $+\beta_6(Hom * order)_s + \beta_7(groupfine * Hom * order)_s + \epsilon_s$, where s indexes individual.

It seems as if the large capacity subjects are reducing their levels to offset or avoid the fines which must be paid due to the high emission levels chosen by the small capacity subjects. They do this despite the fact that this results in lower payoffs themselves and higher payments for those subjects who are choosing higher than Nash emission levels. By reducing their emission levels below the Nash equilibrium level, the large capacity subjects offset the fines paid by the small capacity subjects, which reduces the incentive for the small capacity subjects to choose the Nash emission levels. The debriefing surveys which were conducted after each session, and which asked the subjects to describe how they chose their emission levels, suggest that large capacity subjects were behaving in their own self-interest rather than altruistically.

6. Conclusions

This study exacerbates the concern that many researchers (see Shortle and Horan [23]) have regarding the ability of ambient pollution instruments to effectively control the nonpoint source pollution problem through the use of a series of controlled laboratory experiments. We point out a number of areas of concern for the implementation of these instruments. It is shown that the Tax/Subsidy instrument is less effective after the group has some experience under the

Group Fine instrument which typically converged to the non-cooperative equilibrium where individuals choose their unconstrained level of emission. This suggests that implementing a Tax/Subsidy instrument in an environment where the polluters are accustomed to not controlling their emissions may be problematic. The primary area of concern, however, is that the Tax/Subsidy instrument is less able to induce individuals to choose the target outcome with heterogeneous agents. This problem is tied to the observation that small capacity subjects reduce their emissions by less than the optimal amount and large capacity subjects reduce their emissions by more than the optimal amount. Once the small capacity subjects have realized that the large capacity subjects will reduce their emission levels by more, they can force the large capacity subjects to accept more of the burden of the emissions reduction by keeping their emissions high.

However, If we were only concerned with the aggregate level of emission, then a Tax/Subsidy instrument of the form suggested in Segerson [22] can induce individuals to reduce their emission levels, thus mitigating the problem of moral hazard in groups. This suggests that these instruments may be able to induce nonpoint source polluters to reduce their emissions. Indeed the reductions found in the laboratory environment were of the order of sixty-nine percent reducing emissions to within twenty-five percent of the target level.[16]

This study highlights the importance of allowing firms to be exempt from the emissions tax if they can credibly show that they are reducing their emissions appropriately [32]. This would eliminate the ability of some agents to force other agents to reduce their emissions below the optimal level in order to avoid the emissions tax. In future work I intend to investigate an environment with both an ambient pollution instrument and a self-reporting instrument. Moreover, further investigation is required to see whether this behavior (smaller subjects not reducing their emissions by enough and larger subjects reducing by too much) is consistent with different hypotheses on individual preferences or with a decision error model as suggested by Palfrey and Prisbrey [18] and Anderson, et al. [1].

[16] These percentages are calculated using the mean group emission level for the Tax/Subsidy instrument from Table IV.

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Appendix

A. Symbols

Symbol	Description
SP	Joint benefit function, Social Planner's Problem
n	indexes individuals 1 to 6
x_n	individual n's emission level
$B_n(x_n)$	individual n's private benefit function
X	sum of all individual's emission levels
$D(X)$	damage costs from aggregate individual emissions
x_n^{max}	individual n's unconstrained emission level
$T_n(X)$	ambient pollution Instrument
s_n	proportional subsidy
t_n	proportional tax
β_n	lump sum subsidy
τ_n	lump sum tax
X^*	exogenous target
π_n	individual n's payoff function
$Prob()$	probability
X_{-n}	the sum of all individuals' emission levels except subject n
p	the proportion of subjects
ϵ	efficiency

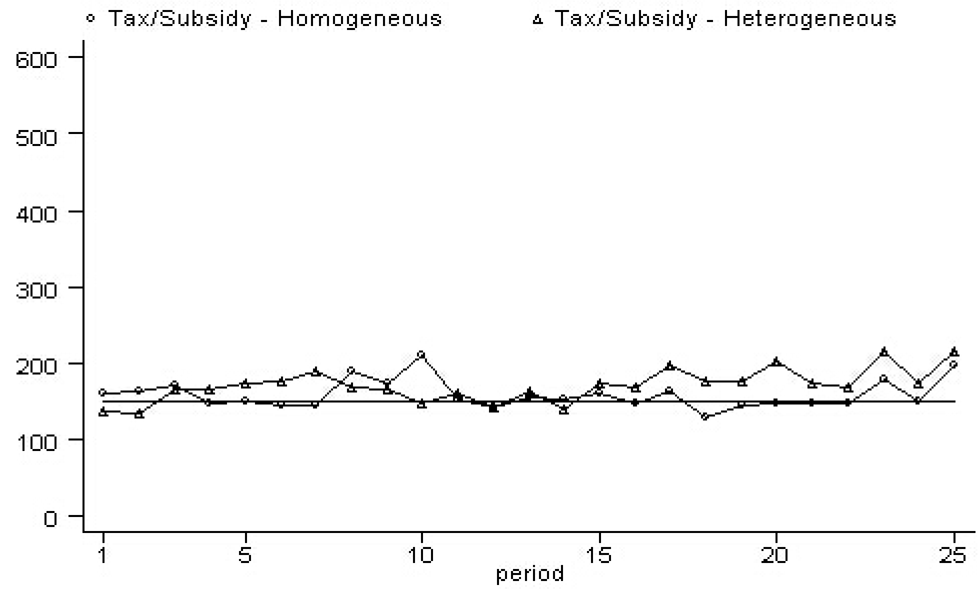

Figure 1: Mean Group Totals by Period for the Tax/Subsidy Instrument with Inexperienced Subjects.

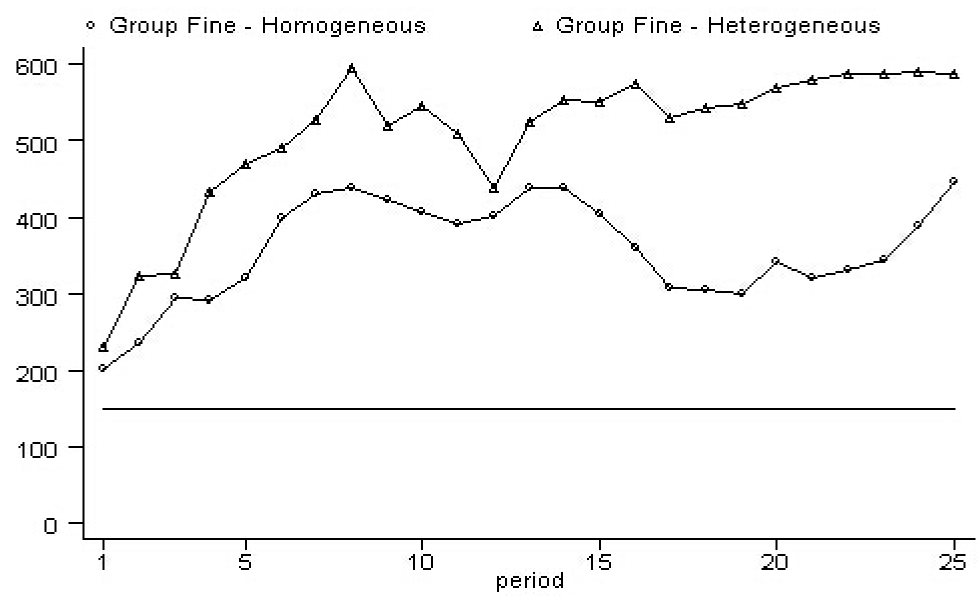

Figure 2: Mean Group Totals by Period for the Group Fine Instrument with Inexperienced Subjects.

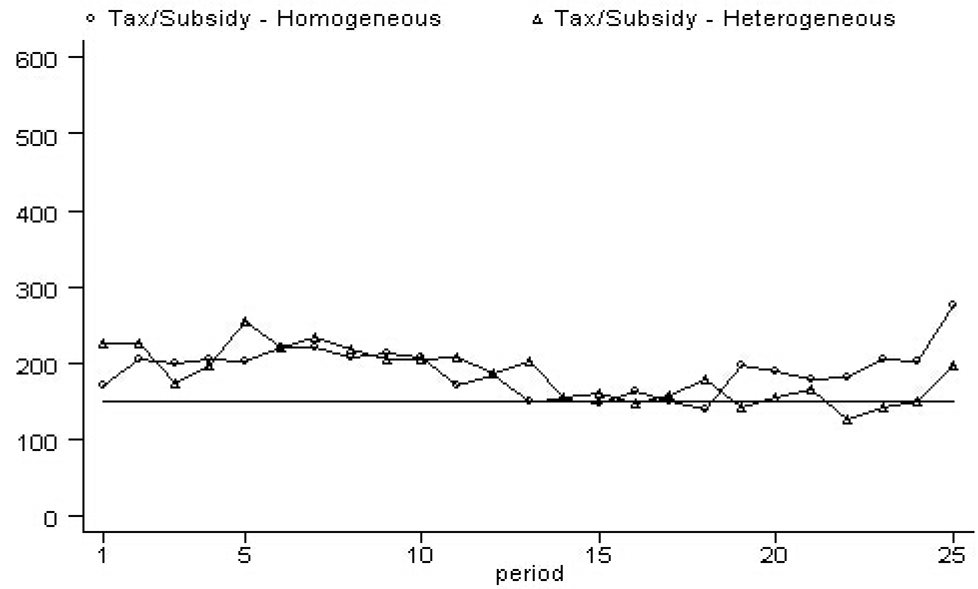

Figure 3: Mean Group Totals by Period for the Tax/Subsidy Instrument with Experienced Subjects.

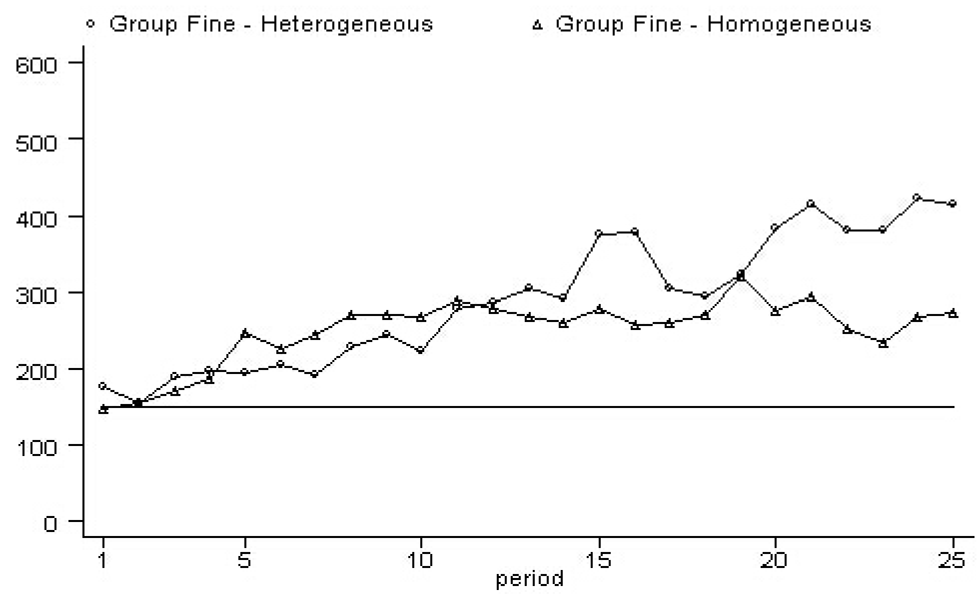

Figure 4: Mean Group Totals by Period for the Group Fine Instrument with Experienced Subjects.

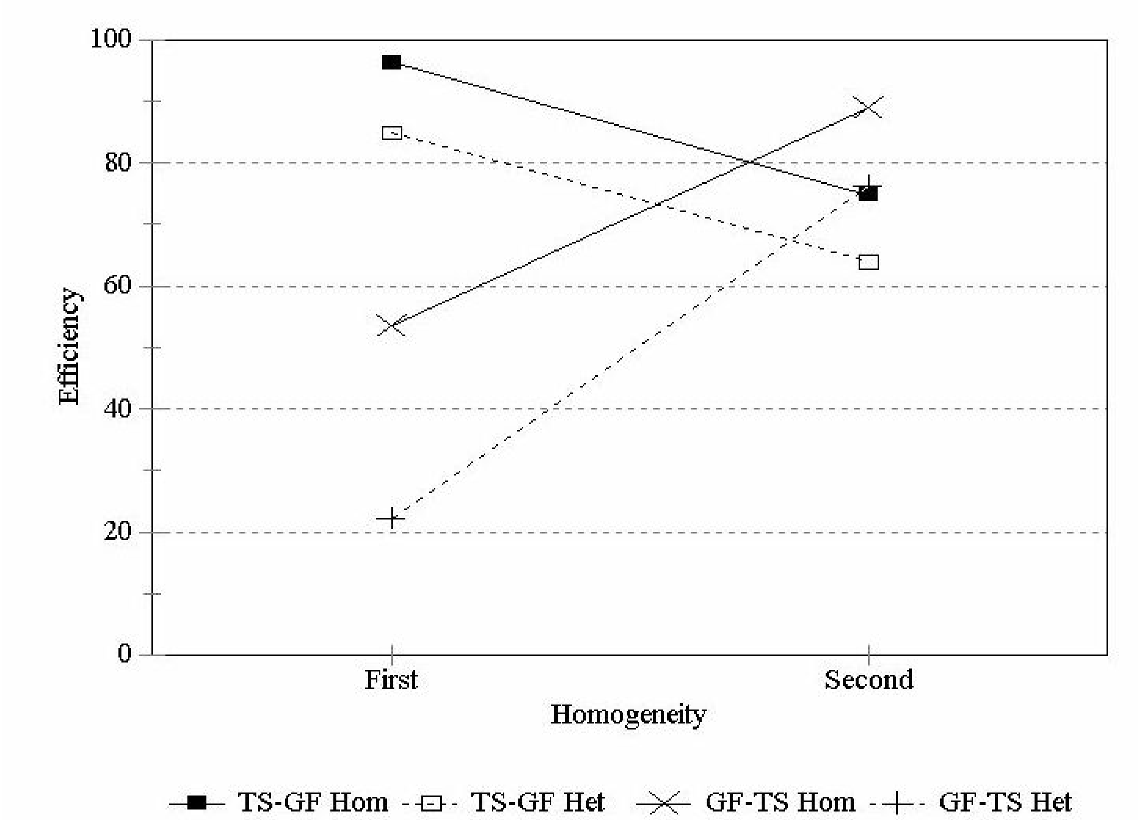

Figure 5: Efficiency: Order Effects, Homogeneity versus Heterogeneity

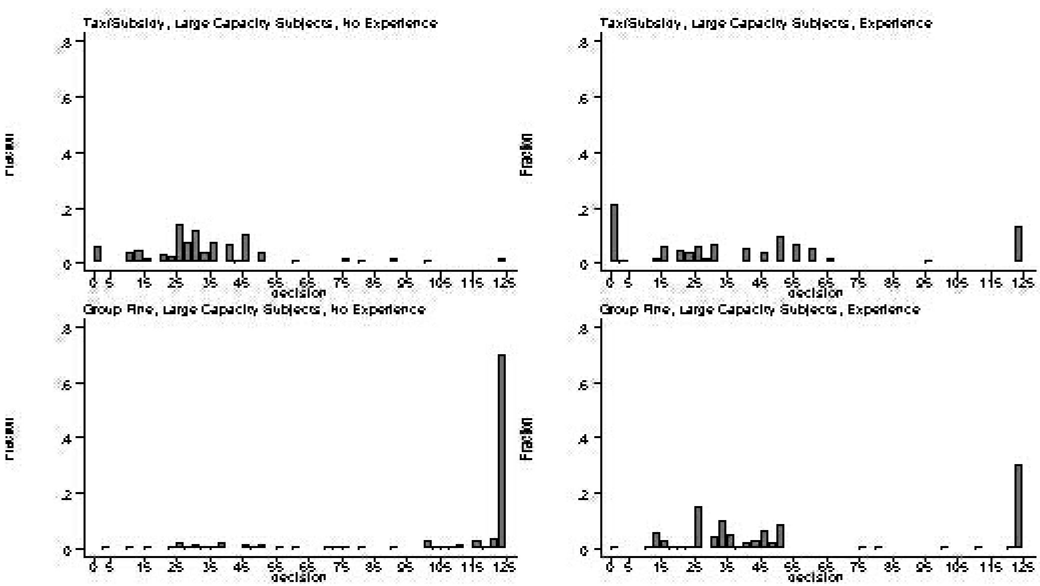

Figure 6: Distributions of Individual Decisions, Large Capacity Subjects, Periods 11-20.

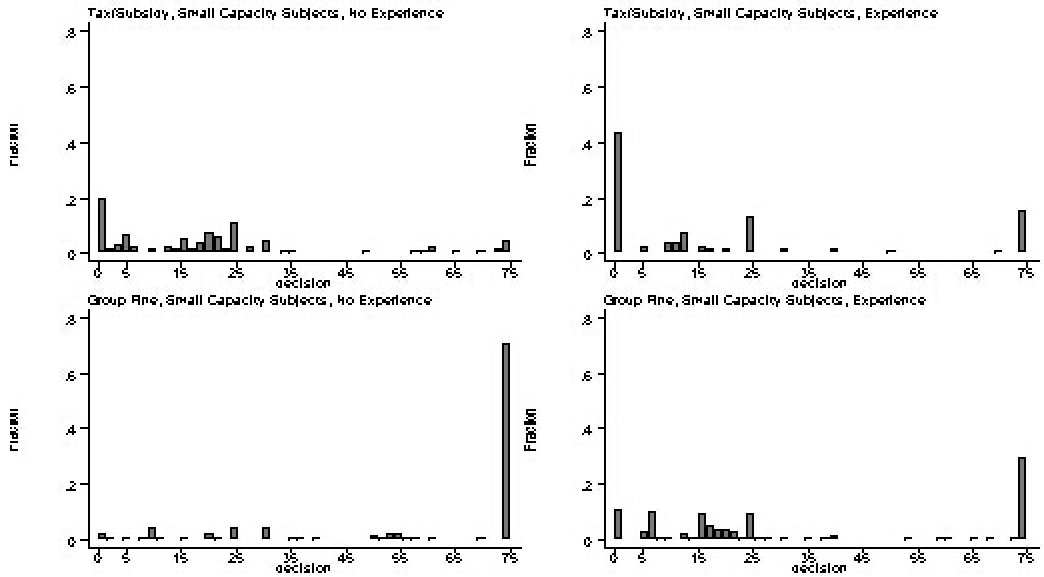

Figure 7: Distributions of Individual Decisions, Small Capacity Subjects, Periods 11-20

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