EXOGENOUS TARGETING INSTRUMENTS

FOR

ELICITING EFFICIENCY IN GROUPS

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Abstract

When an individual agent's actions are unobservable, there is often an incentive for that agent to act in a way which is not socially optimal. This is the crux of the moral hazard problem and is compounded when there are a group of agents. Moral hazard in groups is a common social dilemma which encompasses situations such as the worker effort problem, contributions to public goods, and the abatement of non-point source pollution. Holmstrom (1982) suggests what is referred to as a forcing contract to induce a group to choose the optimal or target outcome. However, the optimal outcome is only one of many possible Nash equilibria under these forcing contracts. Segerson (1988) suggests the use of exogenous targeting instruments which do implement the optimal outcome as a unique Nash equilibrium.

The purpose of this thesis is to test these different instruments in a controlled laboratory environment to determine whether they are able to induce a group of agents to select the socially optimal outcome. There are many studies which conclude that the target outcome cannot be attained under the Holmstrom (1982) forcing contract. Most notable among these studies is the 1997 paper by Nalbantian and Schotter. They conclude that costly monitoring or competitive teams are required to mitigate the problem of moral hazard in groups in an experiment based on the worker effort problem.

The results from the experiment discussed in this dissertation show that

some exogenous targeting instruments can induce groups of both homogenous and heterogeneous individuals to choose a target outcome. However, significant differences from Nash behaviour are observed at the individual level. It is shown that these differences can be explained by preferences for equity and decision error.

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Preface

Chapters Two, Three and Four of this dissertation were originally drafted as independent papers. Over the last three years different versions of these papers have been presented at various meetings of the Canadian Economics Association, the Economic Science Association, and the Canadian Resource and Environmental Economics Study Group. The content of Chapter Two has been presented under the title "Testing Ambient Pollution Contracts", the content of Chapter Three has been presented under the title "Ambient Pollution Contracts with Heterogeneous Agents" and the content of Chapter Four has been presented as "Individual Decision Making in Exogenous Targeting Instrument Experiments". These essays have a great deal in common and there is considerable overlap between them. There has been substantial integration of these essays which has reduced much of the repetition of material common to the three essays. The common material is introduced in Chapter Two, and while some of it is reiterated in later chapters, these reiterations are in less detail than the descriptions which appear in Chapter Two.

Chapter 1

Introduction

1.1 Background and Motivation

There is a great deal of recent literature which is devoted to markets for tradeable emissions permits. This literature includes a forthcoming paper by Hizen and Saijo (1998), a volume of *Research in Experimental Economics* (Isaac 1999), and a survey article by Muller and Mestelman (1998). All of these papers assume that the emissions of the firms participating in these markets could be perfectly and costly monitored. Moreover, two papers in a recent Symposia on SO_2 trading in the *Journal of Economic Perspectives* (Schmalensse et al. 1998, and Stavins 1998) emphasize the importance of being able to monitor firms on the efficiency of the SO_2 markets which have been implemented.

The assumption that firms can be perfectly and costlessly monitored is in many cases unreasonable. In fact, most of the information that we have on individual firms' emission activities is self reported.[1] As a result, any attempt to implement an emission permit trading program would face a serious moral hazard problem, since firms could just report an amount of emission equal to the number of permits that

[1]John Livernois and C. J. McKenna (1999) state that "Self-reporting is becoming an increasingly common feature of enforcement". The National Pollutant Release Inventory can be found at http://www.ec.gc.ca/pdb/npri/, and Ross McKitrick has a database of environmental data on his website at http://biff.econ.uoguelph.ca/~rmckit/epeq/epeq.html.

they own. There are two papers on the effects of non-compliance on a tradeable permit market. It is clear that it would be in a firm's best interest to report compliance with the standard and surrender the minimum number of permits. In the first paper Malik (1990) shows that non-compliance by any of the firms would have unpredictable results on the market price for permits and as a result equilibrium may not be possible. A second paper by van Egteren and Weber (1996) concludes that "studies which ignore non-compliance when estimating the impact of market power in a permit market tend to underestimate the total social costs."

There is a large environmental economics literature which concerns monitoring and enforcement. The ability of an environmental regulator to monitor the emissions of an individual firm runs from perfect and costless through infeasible. While the perfect and costless monitoring assumption seems extreme, the infeasible monitoring encompasses the case of nonpoint source polluters. Nonpoint sources include agricultural, industrial and municipal runoff which seeps into the ground water and cannot be traced back to its source. Mobile sources are another example where it is impossible to determine the exact source of the pollution (Tietenberg 1996).

Becker (1968) showed that probabilistic monitoring was the best solution for crime and this has been adopted for the case where firms can be monitored at some cost or imperfectly. Subsequently, authors have suggested the use of historical information on the firm's compliance (Russell 1990, Fukuyama, Kilgour, and Hipel

1994) or self reports of the firm's own emission level (Swierzbinski 1994, Malik 1993, Livernois and McKenna 1999). These methods allow a regulator to improve compliance with an environmental standard over what could be attained with probabilistic monitoring for a given budget.

In this thesis, I concentrate on the case where emissions are unobservable and as a result regulation must be based on the ambient level of pollution, which acts as a proxy for the aggregate level of emissions. This problem is referred to as the nonpoint source pollution problem and is fundamentally a group moral hazard problem. The group moral hazard problem is characterized by a principal (in this case an environmental regulator) who would like to induce a group of agents (in this case nonpoint source polluting firms) to choose an action which is not in the agents' best interest (reduce their emissions). The theoretical literature stems from Holmstrom's (1982) "Moral Hazard in Teams" which provides a solution for the problem of moral hazard in groups faced by the owner of a firm (principal) who would like to induce his workers (agents) to choose higher effort levels (an action which is not in the agents' best interest). Holmstrom shows that any solution to this problem must break the budget constraint between the amount of revenue the firm earns on its output and how much the workers receive. If the entire revenue is split between the workers then an individual can free ride on the effort of others, and so to eliminate this problem, Holmstrom suggests the introduction of a regulator who receives all of the revenue if the level of output does not exceed the target. This is referred to as a "forcing contract" (Nalbantian and Schotter 1997) as the workers are only paid if the observed level of output exceeds some target level. These types of contracts are also referred to as exogenous targeting instruments (ETIs) as the target is independent of the agents choices of actions. Segerson (1988) applies this idea to the problem of nonpoint source pollution and suggests a class of exogenous targeting instruments which could be used to mitigate the problem of moral hazard in groups faced by an environmental regulator. These instruments involve fines and bonuses which are lump-sum or proportional to the difference between the observed and the optimal (or target) level of ambient pollution. Xepapadeas (1991) presents a general equilibrium analysis of a class of exogenous targeting instruments that involve the random assignments of fines (scapegoat contract) or bonuses (massacre contract). Xepapadeas (1992, 1995) then provides two papers based on a Tax-Subsidy instrument which combines both taxes and subsidies, and is a special case of the contracts suggested by Segerson (1988). The first of these papers examines the dynamic properties of this contract and the second examines the effects of polluters' emissions having heterogeneous effects on the ambient level of pollution. The second paper suggests that the Tax-Subsidy type contract should be augmented by a Pigouvian tax on self-reported emissions to ensure firms against being fined for high ambient pollution levels which are due to natural randomness. Cabe and Herriges (1992) investigate the Tax-Subsidy contract under geographic asymmetries which result in heterogeneity in how an individual firm's emissions affect the ambient level of pollution and Hoarn, Shortle and Abler (1998) look at the properties of the Tax-Subsidy contract when firms make decisions over many inputs.

This thesis provides an empirical test of the Tax-Subsidy instrument as well as three other instruments, referred to as Tax, Subsidy and Group Fine, in the class of exogenous targeting instruments suggested by Segerson (1988). To the best of my knowledge there are no field implementations of these exogenous targeting instruments. Laboratory methods provide an opportunity to test the incentives provided by these instruments. Experimental economics has a rich tradition of testing similar theoretical institutions (for example Roth 1988, 1995). The experiments presented here are most closely related to public good and common pool resource experiments which involve thresholds such as those surveyed in Cadsby and Maynes (1999) as well as a recent experiment by Nalbantian and Schotter (1997) which investigates the problem of moral hazard in groups. None of these experiments explicitly test the instruments investigated in this dissertation; however, there are some similarities between this study and the others. The experiments presented here use a quadratic payoff function which is similar to the payoff function used in Nalbantian and Schotter (1997). However, Nalbantian and Schotter's environment is more similar to a public good environment where subjects choose how much to contribute to the group good, whereas the environment presented here is more similar to a common pool resource environment where subjects choose to reduce their appropriation of a group good. Andreoni (1995) and Sonnemans et al.

(1998) show that this difference in how the experiment is framed has significant effects on the outcome.

These previous experiments do not provide much basis for optimism that these exogenous targeting instruments will be able to induce the group to choose the target outcome. Cadsby and Maynes (1999) show that agents can be induced to choose the socially optimal outcome but this requires extreme rewards. Further, the Andreoni (1995) and Sonnemans et al. (1998) studies suggest that the socially optimal outcome is even less likely to be achieved when experiments are framed as public bads such as they are in the nonpoint source pollution case rather than the public good environments investigated by Cadsby and Maynes (1999). However, there are two studies one by Keser (1996) and the other by Sefton and Steinberg (1996) which show that groups of subjects can be induced to choose the socially optimal decision in a public good environment with a quadratic payoff function similar to the payoff function investigated here except that they do not involve an exogenous target.

Chapter Two of this thesis presents the results of a controlled experiment designed to evaluate the ability of four exogenous targeting instruments to induce a group of subjects to a target outcome when subjects are homogeneous in that they have identical payoff functions. The results show that contracts with a structure similar to the Tax-Subsidy contract, which is theoretically able to induce the optimal outcome as a unique Nash equilibrium, are able to induce individuals to select the target outcome. Contracts which are similar to the Holmstrom forcing contract, which implement the optimal outcome as one of multiple Nash equilibria are unsuccessful.

Chapter Three of this thesis shows that this result also holds when subjects have heterogeneous payoff functions. Heterogeneity is introduced by assuming that subjects represent different sized firms with different levels of uncontrolled emissions and identical costs of reducing emissions. This results in the dominant strategy no longer being for all of the subjects to choose the same proportion of the target. The results from this chapter suggests that equity plays a role in how subjects make their decisions.

Finally, Chapter Four investigates individual decision making under the Tax-Subsidy contract with both homogeneous and heterogeneous payoff functions. Models of altruism and equity coupled with a decision error model based on either a truncated or censored error distribution are applied to the group moral hazard experiments discussed in chapters 2 and 3 and estimated. It is shown that individual decisions are best described by equity and a decision error model based on a censored distribution.

This thesis provides empirical support for contracts which implement the socially optimal outcome as a unique Nash equilibrium such as the Tax-Subsidy contract. However, this research also suggests some areas for concern in recommending the implementation of such contracts. First, it is clear that care must be taken when using a lump-sum tax or subsidy to ensure that the socially optimal outcome is a unique Nash equilibrium. A lump-sum fine or bonus typically results in multiple Nash equilibria. If the agents believe that they will receive the fine or not receive the bonus no matter what they do, they will choose to not reduce their decision number from the maximum (the uncontrolled level of emission in the nonpoint source pollution case). A second caveat concerns the subsidy portion of the Tax-Subsidy contract. If agents are able to collude, they could extract large subsidies from the regulator by choosing a cooperative action to reduce their emissions below the socially optimal level in the nonpoint source pollution case. A final caveat concerns the inability of any of the contracts tested to eliminate individual free-riding. This results in firms that are choosing the socially optimal action (or an action which is even more cooperative such as reducing their emissions to something below the socially optimal level) to face fines. This issue (the inequity of the Tax-Subsidy instrument) is addressed by Xepapadeas (1995) who suggests the use of a Pigouvian tax on self-reported emission levels. This would not only ensure firms from high ambient levels of pollution due to nature but also from high levels of ambient levels of pollution due to the non-compliance of other firms.

Chapter 2

Exogenous Targeting Instruments as a Solution to Group Moral Hazards

2.1 Introduction

Inducing workers to choose the optimal level of effort, agents to contribute the optimal amount to a public good or reduce their consumption of a common resource, firms to choose the optimal level to pollute, and even countries to reduce their emissions of green house gases are all subject to the "moral hazard in groups" problem. This common social problem is characterized by a difference between socially and individually optimal actions, in combination with non-observability of the individual agents' actions. As a result, some form of regulation or the creation of a new institution is required to induce agents to make socially optimal choices.

One well-known solution to the group moral hazard problem, in the context of workers' effort, is the introduction of a principal who receives all of the workers' output if total output is below the optimal level (Holmstrom 1982, Andolfatto and Nosal 1997). These kinds of contracts are often referred to as "forcing contracts". A forcing contract is a type of exogenous targeting instrument (Nalbantian and Schotter 1997). Perhaps surprisingly, a number of recent attempts to implement forcing contracts in laboratory settings have produced quite poor results. For example, Nalbantian and Schotter (1997) provide a laboratory test of Holmstrom's forcing contract and find that it cannot induce workers to supply the optimal level of effort. The Isaac, Schmidtz and Walker (1989) and Suleiman and Rapoport (1992) studies for threshold public goods and common property resources have produced similar results. Taken together, these experiments provide little basis for optimism that effective social institutions can be devised that solve this very common problem in human societies.

In this chapter, I argue that the pessimism that seems to emerge from the above studies may be misplaced. It is misplaced largely because the class of solutions — forcing contracts — that have received the bulk of theoretical and empirical attention to date, share a multiple-equilibrium problem which is not present in all contracts. In particular, in addition to the socially efficient "cooperative" equilibrium, these forcing contracts also have an equilibrium in which all agents choose *individually*, rather than socially optimal actions (Arrow 1985). In contrast, when optimal continuous (indeed linear) contracts are designed, Nash equilibria are efficient and unique (Segerson 1988, McAfee and McMillan 1991). When such contracts are implemented in a controlled laboratory environment, they perform much better than the forcing contracts hitherto examined.

In more detail, this paper describes a controlled laboratory experiment of the kind described by Roth (1988, 1995) as "Speaking to Theorists", that tests the incentives provided by four contracts within a general class of exogenous targeting instruments proposed by Segerson (1988) to induce socially optimal outcomes in a group moral hazard context.[1] If these instruments are not able to induce subjects to select a target outcome in a simple controlled laboratory environment, it calls into question their ability to induce firms to reduce their emissions in the field where benefits and damages as well as the ability to control emissions may be uncertain or even unknown. These contracts use lump sum fines and bonuses, combined with a proportional tax or subsidy on the difference between the actual group outcome and the socially optimal (or target) group outcome. Clearly this general class of contracts encompasses "forcing" contracts. In a laboratory experiment, cast in terms of a non-point source pollution problem, subjects are asked to choose a decision number; penalties and bonuses are then based on the total of these decision numbers (referred to as the group total).[2] A "Tax-Subsidy" contract combines a tax and a subsidy depending upon whether the group total is above or below the optimal level. The "Tax" contract involves only a tax if the optimal level is exceeded. The "Subsidy" (forcing) contract involves a subsidy and a bonus which is provided if the group total is below the optimal level. The "Group Fine" (forcing) contract involves a lump-sum fine if the group total exceeds the optimal level. The effects of

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[1]The details of Segerson's contracts and the contracts presented here are discussed in sections 2.2.2 through 2.2.5.

[2]In contrast to the worker effort case, note that lower group totals are socially preferred in the pollution case. It was however, never suggested to subjects that their decision variables might be interpreted in an environmental or any other context.

uncertainty in measuring the ambient level of pollution are also investigated.

I find that under the non-forcing contracts, the group total is not significantly different from the socially optimal level. Further, this result is robust to both uncertainty and experience with the environment. However, the data show that these contracts do not ensure individual compliance. An additional problem with these contracts is that agents may face substantial fines even though they have chosen the socially optimal action. I conclude that some exogenous targeting instruments are able to mitigate the moral hazard in groups problem but care must be taken in their implementation.

2.2 Experimental Design

As mentioned, the experiment is cast in terms of the non-point source pollution problem where individual decisions cannot be observed. The underlying model is standard in the literature on non-point source pollution (Segerson 1988, Malik 1990, and Xepapadeas 1992) and experimental design decisions were made for consistency with Nalbantian and Schotter (1997). Xepapadeas (1992) investigates the dynamic properties of these types of instruments.

Six subjects (indexed by n=1,..,6) choose a decision number which determines a private benefit and a social cost. These subjects are analogous to firms choosing emissions levels in the non-point source pollution problem. The higher the decision number, the higher the individual private benefit, and the higher the cost to the group.

In the laboratory environment, an individual's private benefit, B_n, is quadratic in the decision number, x_n:

$$B_n(x_n) = 25 - 0.002(100 - x_n)^2 \quad \text{for } n = 1,\ldots,6 \tag{2.2.1}$$

Notice that an agents's benefit is increasing in x_n up to the "maximum" decision number, $x_n^{max} = 100$, which corresponds to an uncontrolled level of emissions. Subjects were provided a table listing the values of $B_n(x_n)$ for each (integer) value of x_n between 0 and 100. The values of this benefit function for each decision number are shown in the first frame of Figure 2.7.1.

The cost to the group depends on the sum of the decision numbers, $X = \sum_{n=1}^{6} x_n$, which will be referred to as the group total. The group total is analogous to the ambient level of pollution in the nonpoint source pollution case. An uncertainty condition is considered to investigate the effects of the ambient level pollution being observed with error. Under the uncertainty treatment, the group total includes a random variable ε, uniformly distributed from -40 to +40, measured in units of the decision number, $X = \sum_{n=1}^{6} x_n + \varepsilon$. For simplicity, the social cost from the decision number choices is defined as a scalar multiple of the group total: $D(X) = 0.3X$.

Assuming that both the agents (firms in the nonpoint source pollution case, subjects in the experiment) and the principal (environmental regulator, experimenter) are risk-neutral, the socially optimal decision number for each agent is found by maximizing the benefits $B_n(x_n)$ minus the expected social cost $D(X)$:

$$\max_{x_1,\ldots,x_6} \sum_{n=1}^{6} [25-0.002(100-x_n)^2]-0.3\sum_{n=1}^{6} x_n. \tag{2.2.2}$$

It is straightforward to show that the socially optimal decision number for each agent is $x_n^* = 25$. The details of this maximization are provided in Appendix C section C.2. The optimal group total is $X^* = \sum_{n=1}^{6} x_n^* = 150$. Notice that the "maximum" group total is 600 which is the outcome that will be selected by profit maximizing agents in the absence of any policy intervention. As a result, there is a role for a principal to penalize the agents if the observed group total is above 150 or reward the agents if the group total is below 150. Because agent's decisions are unobservable, group incentive contracts are utilized (Holmstrom 1982, Segerson 1988, McAfee and McMillan 1991, Xepapadeas 1991 and 1992, Andolfatto and Nosal 1997). Under these contracts each individual faces a profit function which is the benefit from the individual decision minus some function of the measured group total:

$$\Pi_n(x_n) = B_n(x_n) - T_n(X) \qquad \forall\, n = 1,\ldots,6 \tag{2.2.3}$$

where $T_n(X)$ is the incentive scheme or contract imposed by the principal. Assuming that T_n and D are differentiable, profit maximizing agents will choose the socially optimal level of emission when $\dfrac{\partial T_n(X)}{\partial x_n} = \dfrac{\partial D(X)}{\partial x_n}$.

2.2.1 Group Incentive Contracts

All of the contracts considered in this paper are of the form suggested by

Segerson (1988) for the non-point source pollution problem:

$$T_n(X) = \begin{cases} t_n(X-X^*)+\tau_n & \text{if } X > X^* \\ s_n(X-X^*)-\beta_n & \text{if } X \leq X^* \end{cases} \qquad (2.2.1.2)$$

where s_n and t_n are a subsidy and a tax respectively, β_n is a bonus and τ_n is a fine. Since the subsidy, tax, bonus and fine parameters are symmetric across individuals the subscripts can be dropped.

The next sections discuss the Nash equilibria of a stage game for each of the four exogenous targeting instruments. Osborne and Rubinstein (1994, pp. 157-158) show that a unique Nash equilibrium of the stage game is also the unique subgame perfect equilibrium of the finitely repeated game. However, repeated game effects under the instruments with multiple Nash equilibria are ignored. In general, there are multiple non-cooperative Nash equilibria and a unique cooperative outcome which maximizes the group's payoff under each of these instruments. The non-cooperative equilibria may be further divided into symmetric and asymmetric equilibria. There are two types of outcomes which may be symmetric equilibria: *group compliance* where all individuals choose 25 units and *group non-compliance* where all individuals choose 100 units. Asymmetric equilibria are characterized by any combination of individual decisions that sum to the optimal group total (150 units). I will refer to these types of outcomes as *asymmetric compliance*. I will refer to the cooperative outcome which maximizes the total payoff received by the agents as the *group optimal* outcome. Achieving this outcome assumes that subjects can implicitly collude and as a result I do not expect this to be achieved.

The important distinction between the different instruments is whether or not the agent's profit function is continuous at the exogenously targeted decision number. If β_n or τ_n are non-zero, the agent's profit function will be discontinuous. This discontinuity results in both group compliance and group non-compliance being Nash equilibria. Similarly if s_n and t_n are both zero, then asymmetric compliance outcomes are Nash equilibria. This will be discussed in more detail in the following sections.

2.2.2 Tax-Subsidy Contract

The Tax-Subsidy contract provides a subsidy if the group total is below the optimal level and a tax if it is above the optimal level:

$$T(X) = \begin{cases} 0.3*(X - 150) & \text{if } X > X^* \\ 0.3*(X - 150) & \text{if } X \leq X^*. \end{cases} \qquad (2.2.2.1)$$

Under certainty the individual payoff function is continuous:

$$\pi_n = 25 - 0.002(100 - x_n)^2 - 0.3\left(\sum_{i=1}^{6} x_i - 150\right), \qquad n = 1,..,6 \qquad (2.2.2.2)$$

notice that each individual pays the entire damage due to the excess of the group total over the standard. The tax (t) has been chosen to be equal to the marginal damage rate to ensure that the first order conditions for the agent's decision problem are the same as for the social planner's problem (2.2.2). The mathematical appendix

(Appendix C, section C.3.1) provides additional details. An agent's best response is always to choose $x_n = x_n^* = 25$ no matter what the other agents do. The symmetric group compliance outcome ($x_n = 25\ \forall n$), is therefore a unique, dominant strategy Nash equilibrium. However, there is a cooperative equilibrium where everyone chooses zero units. An individual's benefit function, the Tax-Subsidy contract, and the individual's profit function given that all other subjects comply are all depicted in Figure 2.7.1. Table 2.2.2.1 presents the incentives for compliance simplified down to a normal form game between subject n and the rest of the subjects (the total of whose decisions are denoted X_{-n}).

Table 2.2.2.1
Tax-Subsidy Instrument Payoffs under Selected Levels of Compliance (Subject n, Others)

Subject n's E.R. from S.Q.	Group Emission Reduction other than Subject n from Status Quo		
	Over Comply: $X_{-n} = 0$	Comply: $X_{-n} = 125$	Non-compliance: $X_{-n} = 500$
Over Comply: $x_n = 0$	50.00, 50.00	12.50, 21.25	-100, -80.00
Comply : $x_n = 25$	51.25, 42.50	13.75, 13.75	-98.75, -87.50
Non-compliance: $x_n = 100$	40.00, 20.00	2.50, -8.75	-110, -110

The first thing to notice in Table 2.2.2.1 is that compliance ($x_n = 25$) dominates the other strategies. The second thing to notice is that the taxes paid by the agents could be quite high even when they choose to comply. Consider the case were everyone chooses 100 units. In this case the profits for all of the firms are -110 lab dollars. If one of the agents were to choose to comply they would earn -98.75 and everyone else would earn -87.50 and if one of the agents choose to over comply they would earn -100 and everyone else would earn -80.00 lab dollars. Uncertainty does not effect the predictions of theory for this instrument.[3]

2.2.3 Tax Contract

If agents can coordinate on the cooperative solution under the Tax-Subsidy contract, the group total will be inefficiently low and the principal will be forced to pay a large amount to the agents. In contrast, under the Tax contract, agents are taxed if the group total is above the optimal but no subsidy is provided when the group total is below.

$$T(X) = \begin{cases} 0.3*(X - 150) & \text{if } X > X^* \\ 0 & \text{if } X \le X^* \end{cases} \tag{2.2.3.1}$$

Thus an individual's payoff function is

$$\pi_n = \begin{cases} 25 - 0.002(100 - x_n)^2 - 0.3(\sum_{i=1}^{6} x_i - 150) & \text{if } X > X^* \\ 25 - 0.002(100 - x_n)^2 & \text{if } X \le X^*. \end{cases} \tag{2.2.3.2}$$

It is clear that this instrument leads an agent to the socially optimal decision if $X > X^*$,

[3]See the mathematical appendix section C.3.1, specifically equation C.3.1.2 for details.

since the first order conditions are the same as for the social planner's problem.[4] However, if the group total (X) is less than the optimal level (X^*) an agent's best response is to choose $x_n = 100$. This results in a contradiction as the group total would exceed the optimal level and an individual's best choice would be to choose $x_n = 25$. Thus, this contract also results in symmetric compliance ($x_n^* = 25$) being a unique Nash equilibrium. Figure 2.7.2 depicts an individual's benefit function, the graph of the Tax contract and the graph of the agent's payoff for each decision number, assuming that all other agents choose the optimal level of emission ($x_n^* = 25$). Table 2.2.3.1 presents the incentives for compliance; notice that symmetric group compliance is the only Nash equilibrium.

Table 2.2.3.1
Tax Instrument Payoffs under Selected Levels of Compliance
(Subject *n*, Others)

Subject n's E.R from S.Q.	Group Emission Reduction other than Subject *n* from Status Quo		
	Over Comply: $X_{-n} = 0$	Comply: $X_{-n} = 125$	Non-compliance: $X_{-n} = 500$
Over Comply: $x_n = 0$	5.00, 5.00	5.00, 13.75	-100, -80.00
Comply : $x_n = 25$	13.75, 5.00	13.75, 13.75	-98.75, -87.50
Non-compliance: $x_n = 100$	25.00, 5.00	2.5, -9.25	-110, -110

[4]See the mathematical appendix, section C.3.2 for details.

Notice that as was the case with the Tax-Subsidy contract, it is again possible for subjects to earn significantly negative profits even if they choose to comply or over comply.

Under uncertainty the Tax contract is weaker because there is some probability that agents will not be fined even if group total exceeds 150. An individual's profit function is the same as before except for the random variable which is added into the ambient level of pollution:

$$\pi_n = \begin{cases} 25-0.002(100-x_n)^2-0.3(\sum_{i=1}^{6} x_i+\epsilon-150) & \text{if } X > X^* \\ 25-0.002(100-x_n)^2 & \text{if } X \leq X^* \end{cases} \tag{2.2.3.3}$$

The only Nash equilibrium under this instrument is a symmetric outcome where everyone chooses 28 units.[5]

2.2.4 Subsidy Contract

Both the Tax and Tax-Subsidy contracts assume that agents can be held collectively liable for the damages caused by their decisions. If agents are not liable for their decisions, they must be subsidized for any reduction. A pure subsidy contract provides subsidies if the optimal group total is attained. Notice however that a marginal subsidy (s_n) alone cannot induce compliance with the standard because the ambient pollution subsidy (s_n) does not change the slope of the firm's

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[5]See mathematical appendix section C.3.2 equation C.3.2.10 for details.

profit function for emission levels above 25 units (assuming all of the other agents comply). To induce compliance, the payoff for choosing 25 units must be increased above the payoff for choosing 100 units (given that all other agents comply). As a result, a bonus (β_n>0) is included in the subsidy contract. The Subsidy contract shares the real social benefit due to the reduction among the agents if the standard is attained.

$$T(X) = \begin{cases} 0 & \text{if } X > X^* \\ 0.3*(X - 150) - 22.50 & \text{if } X \leq X^* \end{cases} \tag{2.2.4.1}$$

where 22.50 represents an equal share of the real social benefits from an optimal reduction in the group total. This instrument is equivalent to the Holmstrom forcing contract with the revenue being split among the agents if the optimal level of effort is provided.

Under certainty, an individual's payoff is given by a discontinuous function:

$$\pi_n = \begin{cases} 25 - 0.002(100 - x_n)^2 & \text{if } X > X^* \\ 25 - 0.002(100 - x_n)^2 - [0.3[\sum_{i=1}^{6} x_i - 150] - 22.50] & \text{if } X \leq X^* \end{cases} \tag{2.2.4.2}$$

In this case the individual's decision problem provides the same incentives as the social planner's problem when the group total is below the optimal level ($X \leq X^*$) and as a result each agent choosing $x_n = 25$ is a Nash equilibrium. However, if $X > X^*$ then it is in an agent's best interest to maximize her private benefits (choose $x_n = 100$) as the subsidy is not going to be received. As a result, non-compliance (each agent choosing $x_n = 100$) is also a Nash equilibrium under this instrument. Thus, there may be many Nash equilibria to the stage game. Details are provided in the mathematical appendix section C.3.3. Figure 2.7.3 depicts an individual's benefit function, the graph of the subsidy instrument and the graph of the agent's profits for each decision number assuming that all other agents choose the optimal decision ($x_n^* = 25$). Table 2.2.4.1 presents the incentives for compliance. Notice that it is in agent *n*'s best interest to comply with the standard (choose $x_n = 25$) as long as everyone else chooses to comply (or over comply $x_n < 25$). Notice also that agents maximize the payoff to the group if everyone chooses 0 units. Thus, this instrument is undesirable as the principal is likely to face capital constraints which would make subsidising agents' decisions infeasible if the group is able to coordinate.

Table 2.2.4.1
Subsidy Instrument Payoffs under Selected Levels of Compliance
(Subject *n*, Others)

Subject n's E.R. from S.Q.	Group Emission Reduction other than Subject *n* from Status Quo		
	Over Comply: $X_{-n} = 0$	Comply: $X_{-n} = 125$	Non-compliance: $X_{-n} = 500$
Over Comply: $x_n = 0$	72.50, 72.50	35.00, 43.75	5.00, 25.00
Comply : $x_n = 25$	73.75, 65.00	36.25, 36.25	13.75, 25.00
Non-compliance: $x_n = 100$	62.50, 42.50	25.00, 13.75	25.00, 25.00

Under uncertainty an individual's profit is given by a discontinuous function:

$$\pi_n = \begin{cases} 25-0.002(100-x_n)^2 & \text{if } X > X^* \\ 25-0.002(100-x_n)^2-[0.3(\sum_{i=1}^{6} x_i+\varepsilon-150)-22.50] & \text{if } X \leq X^* \end{cases} \qquad (2.2.4.3)$$

In this case only group non-compliance is a Nash equilibrium. Group compliance is no longer a Nash equilibrium because even if all agents comply, there is some probability that the subsidy will not be provided. As a result, an individual increases her expected profit by increasing her decision number. As with the certainty case there are no asymmetric Nash equilibria, and the group payoff is maximized if everyone chooses 0 units.[6]

2.2.5 Group Fine Contract

The final instrument is a forcing contract when the group total is above the optimal level as opposed to the subsidy contract which is forcing when the level is below optimal. Under the Group Fine contract all of the agents pay a lump sum fine if the group total is above the optimal level:

$$T(X) = \begin{cases} -24 & \text{if } X > X^* \\ 0 & \text{if } X \leq X^* \end{cases} \qquad (2.2.5.1)$$

The value of the fine (-24) is chosen so that the marginal expected value of the

[6]See mathematical appendix section C.3.3 equation C.3.3.3.

contract is equal to the marginal damage at the optimum under uncertainty.[7] Under both certainty and uncertainty an individual's profit function is discontinuous:

$$\pi_n = \begin{cases} 1-0.002(100-x_n)^2 & \text{if } X > X^* \\ 25-0.002(100-x_n)^2 & \text{if } X \leq X^* \end{cases} \qquad (2.2.5.2)$$

Under certainty, any set of decision numbers which sum to 150 is a Nash equilibrium. An agent's best response to this contract is to choose a decision number, x_n, which makes the group total just equal to 150, if $50 < X_{-n} \leq 150$, and to choose $x_n = 100$ if $X_{-n}<50$ or $X_{-n}>150$. Again there are many possible Nash equilibria to the stage game. For both the certainty and uncertainty case group compliance, group non-compliance and asymmetric compliance are Nash equilibria. Group compliance is the group optimal outcome for this contract. Additional details are provided in the mathematical appendix section C.3.4.

Figure 2.7. 4 shows the individual's benefit function, the Group Fine contract and an individual's profit function given that everyone else complies and Table 2.2.5.1 presents the incentives for compliance or non-compliance for the individual. Notice that the potential for large losses is not as severe under this contract as it is under the Tax-Subsidy and Tax contracts.

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[7]See the mathematical appendix section C.3.4 for details.

Table 2.2.5.1
Group Fine Instrument Payoff under Selected Levels of Compliance
(Subject *n*, Others)

Subject n's E.R. from S.Q.	Group Emission Reduction other than Subject *n* from Status Quo		
	Over Comply: $X_{-n} = 0$	Comply: $X_{-n} = 125$	Non Compliance: $X_{-n} = 500$
Over Comply: $x_n = 0$	5.00, 5.00	5.00, 13.75	-19.00, 1.00
Comply : $x_n = 25$	13.75, 5.00	13.75, 13.75	-10.25, 1.00
Non-compliance: $x_n = 100$	25.00, 5.00	1.00, -10.25	1.00, 1.00

2.2.6 Theoretical Outcomes

Table 2.2.6.1 summarizes the potential outcomes under certainty (C) and uncertainty (U) for the four different contracts. Notice that the Tax contract has one potential outcome, the Tax-Subsidy has two, the Subsidy contract has three and the Group Fine has multiple potential outcomes. Thus the Tax and Tax-Subsidy are the simplest of the four contracts. Moreover, the Subsidy and Group Fine contracts present coordination problems. If all of the other subjects choose the socially optimal outcome it is player *n*'s best response to choose the socially optimal outcome. However, if one subject deviates from the socially optimal decision, it is in everyone's best interest to deviate. As a result, it is more likely that the subjects will choose the socially optimal outcome (group compliance) under the Tax-Subsidy and Tax contracts.

Table 2.2.6.1
Potential Outcomes under the Four Instruments

Contract		Symmetric	Asymmetric	Cooperative
Tax-Subsidy	C	150*	None	0
	U	150*	None	0
Tax	C	150*	None	150*
	U	168*	None	168*
Subsidy	C	150*, 600*	None	0
	U	600*	None	0
Group Fine	C	150*, 600*	150*	150*
	U	150*, 600*	150*	150*

Note: C and U identify certainty and uncertainty. An asterisk (*) identifies Nash equilibrium.

2.2.7 The Experiment

Twenty-four sessions were conducted at the McMaster Experimental Economics Laboratory during the winter term of 1997. Each session involved one group of six subjects who participated in twenty-five periods for each of two different contracts. Subjects were recruited from the university population and earned on average twenty-four dollars for a session which lasted between 1 and 2 hours.

In each period the subjects were asked to choose a decision number between

0 and 100.[8] They were told that their total payoff in each period was the sum of a private payoff and a group payoff. The private payoff was found by looking up their decision number on a payoff table. The group payoff depended on the group total. They were informed that the group total was the sum of the decision numbers of all of the subjects, and in the uncertainty condition, a uniform random variable between -40 and +40. The group payoff was described using one of the four contracts (Tax-Subsidy, Tax, Subsidy, or Group Fine).

To control for group effects it would be best to have each subject participate in each contract. Unfortunately, this was not feasible as it would have made the sessions too long. In each session 25 periods of each of two contracts were presented. Each contract was paired with each other contract for twelve pairings under certainty and uncertainty. As a result there are three replications of each contract under certainty and uncertainty in both the first and second positions.

2.3 Testable Hypotheses

Three theories are used to predict the outcomes from the sessions: non-cooperative game theory, non-cooperative game theory with equilibrium selection, and cooperative game theory. Non-cooperative game theory in this case just appeals to the concept of Nash equilibrium. There are unique Nash equilibria under the Tax-Subsidy and Tax contracts but not under the Subsidy or Group Fine contracts. To

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[8] A copy of the instructions as presented to the subjects is included in appendix A, section A.1.

predict results for the Subsidy and Group Fine contracts we need an equilibrium selection mechanism. A common choice is payoff dominance, which predicts that the group compliance equilibrium will be chosen for both of these contracts. Cooperative game theory suggests that under the Tax-Subsidy and Subsidy contracts individuals will be able to coordinate on the group optimal outcome where each agent chooses zero units. These predictions are summarized in Table 2.3.1.

Table 2.3.1
Predicted Outcomes under the Four Instruments

	Contract			
	Tax-Subsidy	Tax	Subsidy	Group Fine
Non-Cooperative Game Theory				
Certainty	SC	SC	None	None
Uncertainty	SC	SC*	None	None
Non-Cooperative Game Theory and Equilibrium Selection				
Certainty	SC	SC	SC	SC
Uncertainty	SC	$SC^{(28)}$	None	SC
Implicit Coordination				
Certainty	GO	SC	GO	SC
Uncertainty	GO	$SC^{(28)}$	GO	SC

Note: SC represents Symmetric Compliance (25,25,25,25,25,25), $SC^{(28)}$ represents Symmetric Compliance for the Tax instrument under uncertainty (28,28,28,28,28,28), and GO represents the Group Optimal (0,0,0,0,0,0) outcome.

All of the instruments have symmetric compliance, the socially optimal outcome, as a Nash equilibrium. The first question is whether these instruments are able to induce the group to choose this socially optimal outcome. This can be tested in two ways. The first is to compare the group total to the socially optimal level of 150, the second is to calculate the efficiency of each session. Efficiency is defined in terms of the share of the potential gains that are realized by the introduction of the exogenous targeting instrument. Using equation (2.2.2) the value of the social planner's problem can be measured in the status quo state ($x_n = x_n^{\max}, \forall n$), in the actual state, and in the optimal state ($x_n = x_n^*, \forall n$).

$$\epsilon = \frac{SP_{ACTUAL} - SP_{STATUS\ QUO}}{SP_{OPTIMAL} - SP_{STATUS\ QUO}} \tag{2.3.1}$$

This is independent of the fines and taxes paid by the subjects.

The effect of uncertainty on each of the contracts can also be tested. Since uncertainty complicates the environment, we might expect to see the subjects choosing the socially optimal outcome even less often and the efficiencies being lower. This is even more likely for the Tax and Subsidy instruments as symmetric compliance at the socially optimal level is no longer a Nash equilibrium.

As people become more experienced with the environment, they should be better able to coordinate on the payoff dominant Nash equilibrium. This implies that the group totals for the Subsidy and Group Fine contracts conducted in the second phase should be closer to the socially optimal outcome and the efficiencies should be higher than those conducted first.

2.4 Results

The outcome of the experiment is organized into four overall results. The first two results are that the Tax-Subsidy and Tax contracts are better able to induce groups to choose the target aggregate outcome. The third result is that individuals do not always choose the socially optimal decision number even when it is a dominant strategy and the fourth result is that bankruptcies are observed, which suggests that these instruments may not be equitable. The experiment provides three independent observations in each of the sixteen treatment cells (four contracts by two orders of presentation by the presence or absence of uncertainty). The results presented here are based on the means of the group totals (aggregate decisions) over the three sessions in each cell although sometimes results based on all of the data are discussed.

Result 1: The Tax-Subsidy and Tax instruments are better able to enforce the standard than the Subsidy and Group Fine instruments with inexperienced subjects under certainty.

The first question is whether these instruments are able to induce the group to the socially optimal outcome (or enforce the standard) in the simplest case. Figure 2.7.5 shows the group totals in each period for each of the three sessions in each contract with inexperienced subjects under certainty.[9] Notice that the group totals under the Tax-Subsidy contract are much more consistently close to the target of 150

[9]Figure 2.7.6 shows the group totals by session for each treatment.

than the other three contracts and that the group totals under the Group Fine and Subsidy contracts tend towards the symmetric non-compliance outcome in two out of the three cases. Table 2.4.1 shows the mean and standard deviations of the group totals across all three twenty-five period phases. Notice that the group totals for the Tax-Subsidy and Tax contracts are closer to 150 (the optimal outcome) and that the standard deviations are lower than the group totals from the subsidy and Group Fine contract. Also notice that the efficiencies for the Tax-Subsidy and Tax are much higher than those for the Subsidy and Group Fine instruments (Table 2.6.1).

Table 2.4.1
Mean Group Totals for Inexperienced Subjects under Certainty

Instrument	Tax-Subsidy	Tax	Subsidy	Group Fine
Mean	158.44	209.99	351.45	358.00
Standard Deviation by Session(n=3)	(13.34)	(10.85)	(188.83)	(183.13)

Analysis of variance on the twelve observations (the four different instruments with three observations, see Table 2.4.2) suggests that there is no significant difference between the group totals by instrument (a categorical variable for the different instruments has a p-value of 0.23). Despite this regression analysis (Table 2.4.3) suggests that the coefficients on dummy variables for Tax-Subsidy and Tax are not significantly different from 150 (p-values from a test of whether the coefficients in Table 2.4.3 are significantly different from 150 are 0.91 and 0.45 respectively) and that the coefficients for the Subsidy and Group Fine instruments are (p-values of 0.0257 and 0.0294 respectively).

Table 2.4.2
Anova on Group Total, by Session with Inexperienced Subjects under Certainty

Number of Observations: 12 R-squared: 0.3964
Root MSE: 131.804 Adj R-squared: 0.1701

Source	Partial SS	df	MS	F	Prob > F
Model	91274.27	3	30424.76	1.75	0.2339
Instrument	91274.27	3	30424.76	1.76	0.2339
Residual	138979.37	8	17372.42		
Total	230253.65	11	20932.15		

Table 2.4.3
Regression on Group Total by Session with Inexperienced Subjects and Certainty

Variable	Coefficient	Standard Error	P-Value
Tax-Subsidy	158.44	76.10	0.071
Tax	209.99	76.10	0.002
Subsidy	351.45	76.10	0.002
Group Fine	358	76.10	0.025

Group $\text{Total}_s = \beta_1 \text{tax-subsidy}_s + \beta_2 \text{group fine}_s + \beta_3 \text{subsidy}_s + \beta_4 \text{tax}_s + \varepsilon_s$, where s indexes sessions

It is clear from these results that the Tax-Subsidy and Tax contracts are more consistently able to induce groups to choose aggregate decision numbers which are closer to the target level than the Subsidy and Group Fine contracts. The box-and-whisker diagram presented in Figure 2.7.7 shows this result quite clearly.[10]

Result 2: Result 1 is robust to uncertainty and experience

Tables 2.6.1, 2.6.2 and 2.4.4, and figures 2.7.8 through 2.7.10 show that neither uncertainty nor order of presentation make much difference to the observed results.[11] In Table 2.6.1 notice that the efficiencies are much higher for the Tax-Subsidy and Tax instruments. Further, in Table 2.4.4 notice that the group totals for the Tax-Subsidy and Tax instruments are always lower than the group totals for the subsidy and Group Fine instruments.[12] Figures 2.7.8 through 2.7.10 also support this hypothesis. They show the average group total by period for each instrument for each of the different certainty and experience conditions. Notice that in all cases the group totals for the Tax-Subsidy and Tax instruments are close to the optimal level of 150 while the group totals for the Subsidy and Group Fine instruments are far more variable and also far more likely to tend towards the non-compliance outcome of 600.

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[10]The box depicts the interquartile range, the line through the box the mean, and the whiskers the upper and lower adjacent values (StataCorp 1999b).

[11]Figures 2.7.11, 2.7.12, and 2.7.13 present the mean group totals by session, treatment and period.

[12]Table 2.6.2 depicts the same data except that the standard deviations are calculated from the variance between sessions and periods.

Table 2.4.4
Mean Group Totals by Session (n=3 per cell)

Contracts	Certainty		Uncertainty		Totals
	First	Second	First	Second	
Tax- Subsidy	158.44 (13.34) 3	188.97 (6.92) 3	211.19 (19.35) 3	158.92 (29.49) 3	179.38 (28.32) 12
Tax	209.99 (10.85) 3	183.72 (26.03) 3	201.27 (18.68) 3	169.19 (21.57) 3	191.04 (23.75) 12
Subsidy	351.45 (188.83) 3	232.48 (118.55) 3	233.91 (52.83) 3	294.52 (157.15) 3	278.09 (128.13) 12
Group Fine	358.00 (183.13) 3	250.47 (177.76) 3	366.12 (176.07) 3	379.93 (98.60) 3	338.64 (148.79) 3

Note that the numbers in brackets are standard deviations calculated over the three sessions.

Anova analysis (Table 2.4.5) conducted on the mean group totals in each of the forty-eight sessions with a categorical variable for instrument confirms that order and uncertainty are not significant ($p>.36$ for order and $p>0.75$ for uncertainty). Regression analysis by treatment (Tables 2.6.3 through 2.6.6) show that the group total is only significantly different from the target (150) for the Group Fine contract with inexperienced subjects and uncertainty, and both the Group Fine and the Subsidy instruments with uncertainty and experience. The box-and-whisker diagrams (Figures 2.7.14 through 2.7.16) summarize this result by treatment showing that the means for the Group Fine and Subsidy instruments are higher and more variable than the Tax-Subsidy and Tax instruments.

Table 2.4.5
Anova on Group Total, Full Sample

Number of observations: 48 R-square: 0.42
Root MSE: 107.86 Adj R-square: 0.15

Source	Partial SS	df	MS	F	Prob >F
Model	274546.47	15	18303.10	1.57	0.14
Treatment	204797.36	3	68265.79	5.87	0.0026
Uncertainty	1246.03	1	1246.03	0.11	0.75
Order	10105.93	1	10105.93	0.87	0.36
Interactions					
Treatment Uncertainty	16054.06	3	5351.35	0.46	0.71
Treatment Order	1943.58	3	647.86	0.06	0.98
Uncertainty Order	8452.46	1	8452.46	0.73	0.40
Treatment Order Uncertainty	31947.06	3	10649.02	0.92	0.44
Residual	372270.15	32	11633.44		
Total	646816.614	47	13762.06		

As a result, I claim that not only are the Tax-Subsidy and Tax contracts able to induce a group to the social optimum, but that this result is robust to uncertainty and experience with the environment.

Result 3: Individual free-riding is not eliminated

Figures 2.7.17 through 2.7.20 present the distributions of individual decision numbers by instrument and certainty condition. These pictures show that agents choose non-compliance to a greater extent under the discontinuous contracts (Group Fine and Subsidy) contracts than they do under the continuous contracts (Tax and Tax-Subsidy). It is also clear that the variance in the decision numbers is higher under uncertainty than under certainty except under the Group Fine contract where the percentage of decision numbers in the 90 to 100 range is approximately 50 percent. This suggests that individuals choose the socially optimal outcome less than 50 percent of the time even for the Tax-Subsidy and Tax instruments for which this choice is a dominant strategy.

Result 4: Bankruptcy is important

The Tax-Subsidy, Tax, and Group Fine instruments investigated in this paper are in a sense extreme. If one person chooses a non-socially optimal action all of the subjects are punished. As a result, agents who choose the socially optimal action may earn significantly negative payoffs (see Tables 2.2.2.1, 2.2.3.1 and 2.2.5.1). Subjects in the experiment were endowed with an opening balance to reduce the likelihood of bankruptcy. Despite this, bankruptcy was observed under all of these contracts (see Table 2.4.6).

Table 2.4.6
Number of Sessions in which Bankruptcy was Observed, by Treatment

Contracts	Certainty		Uncertainty	
	First	Second	First	Second
Tax-Subsidy	0	1	1	0
Tax	0	1	1	0
Group Fine	0	1	0	1

The fact that agents who are in compliance are penalized for the non-compliance of others may provide an incentive for these agents to find ways to credibly report their actions. This type of ambient pollution contract with self-reporting is shown to be theoretically optimal by Xepapadeas (1995). Self-reporting is an important issue in the environmental compliance literature (Malik 1993, Swierzbinski 1994, and Livernois and McKenna 1999).

2.5 Conclusions and Extensions

In a simple environment where moral hazard would result in non-compliance, exogenous targeting instruments are theoretically able to induce compliance with a standard. Four specific different exogenous targeting instruments: Tax-Subsidy, Tax, Subsidy, and Group Fine have been tested in a controlled laboratory environment. Of these, the two "forcing" contracts, proposed by Holmstrom (1982) are unable to consistently enforce the standard. In contrast, the two continuous contracts, (Tax-Subsidy and Tax) are effective without the need to resort to (costly) monitoring of individual performance or to set up multiple, competing "teams" (Nalbantian and Schotter 1997). I find that these results are robust to uncertainty as well as to experience with the environment.

The results observed in this study are consistent with the results of similar experiments in the literatures on worker effort and public goods. Nalbantian and Schotter (1997) find that forcing contracts are not able to induce subjects to choose efficient levels of effort. Cadsby and Maynes survey the threshold public good literature and suggest that if the incentives are strong enough, group contributions will exceed the threshold level. However, as Andreoni (1995) and Sonnemans (1998) find, it is less likely that the group's aggregate appropriation in public bad environments, such as the one investigated here, will fall below the target level than the group's contribution in a public good environment will exceed the target. The results for the Tax-Subsidy and Tax contracts are consistent with the public good experiments conducted by Keser (1996) and Sefton and Steinberg (1996). These authors investigate an environment which is similar to the one discussed here in that it has a dominant strategy Nash equilibria and a quadratic payoff function, but differs in that it is a public good environment and there is no target.

It seems clear that a key explanation behind the inability of "forcing" contracts to induce compliance with a standard can be attributed to the coordination problem that arises under these contracts. Under the continuous instruments, the marginal incentives induce agents to the socially optimal outcome, whereas under discontinuous instruments, the group needs to coordinate on one of many possible Nash outcomes. There is an extensive literature on coordination failures which shows that even groups of two players have trouble coordinating when there are as few as two possible equilibria.[13] Further, sessions were conducted in which subjects were allowed to communicate and they were consistently able to coordinate on the group optimal outcome (Childs et al. 1997).

While cast in terms of a non-point source pollution problem, it is clear that the results of this experiment — that "continuous" penalties and rewards, based on the difference between the value of the observed statistic and the desired value work well — have implications for the optimal design of contracts in other situations. For example, an analogous contract to the Tax-Subsidy contract in the worker effort case would imply that workers could be paid some proportion of the firm's profits such that the groups reward is below the firm's profit if the workers produce less than the target level and the reward is above the firm's profit if they produce more. Alternatively, the firm's profits could be distributed among the workers and a proportional fine could be charged if the target is not met and a proportional bonus provided otherwise. Isaac, Schmidtz, and Walker (1989) and Bagnoli and McKee (1991) address alternate renumeration schemes in their threshold public good papers.

[13]For an example see the battle of the sexes games studied by Cooper, DeJong, Forsythe, and Ross (1990).

Bagnoli and McKee (1991) investigate a full money back guarantee as well as a partial (fifty percent) money back guarantee if the public good is not provided. They find that the full money back guarantee does increase compliance with the target but the partial money back guarantee has no affect whatsoever. They conclude that a full money back guarantee must be offered to induce compliance. However, the results from this study suggest that if the guarantee was proportional to the difference between the observed contribution and the target, compliance would be induced.

Finally, it should be noted that even the Tax-Subsidy and Tax instruments are not without problems. For example, while group compliance is realized, individuals choose the socially optimal decision number less than fifty percent of the time. Chapter 4 of this thesis appeals to recent work done on bounded rationality (Anderson, Goeree, and Holt 1998) and alternate preference functions to determine if better explanations can be provided for the observed results. Another potential concern is that Tax-Subsidy, Tax, and Group Fine contracts may result in agents facing large fines or taxes even when they are in compliance with the standard. Further, the Tax-Subsidy and Subsidy contracts may result in significant costs to the regulator if firms are able to collude. Thus, some of these contracts may not be politically feasible. Still, I believe my results provide a basis for renewed optimism regarding the possibility of designing simple but practical and effective social institutions to control problems of moral hazard in groups.

2.6 Supplemental Tables

Table 2.6.1
Efficiency by Treatment

Contracts	Certainty		Uncertainty		Total
	First	Second	First	Second	
Tax-Subsidy	98.12% (2.96) 3	91.34% (1.54) 3	86.40% (4.30) 3	98.02% (6.55) 3	93.47% (6.29) 12
Tax	86.67% (2.41) 3	92.51% (5.79) 3	88.61% (4.15) 3	95.74% (4.79) 3	90.88% (5.28) 12
Subsidy	55.23% (41.96) 3	81.67% (26.35) 3	81.35% (11.70) 3	67.88% (34.92) 3	71.53% (28.70) 12
Group Fine	53.78% (40.70) 3	77.67% (39.50) 3	51.97% (39.13) 3	48.90% (21.91) 3	58.08% 33.07% 12

Mean efficiency, standard error, number of observations

Table 2.6.2
Mean Decision Number Totals by Treatment

Contracts	Certainty		Uncertainty		Totals
	First	Second	First	Second	
Tax-Subsidy	158.44 (34.44) 75	188.97 (60.30) 75	211.19 (50.71) 75	158.92 (51.17) 75	179.38 (54.50) 300
Tax	209.99 (53.76) 75	183.72 (40.80) 75	201.27 (77.93) 75	169.19 (37.96) 75	191.04 (56.89) 300
Subsidy	351.45 (178.42) 75	232.48 (137.23) 75	233.91 (121.42) 75	294.52 (158.60) 75	278.09 (159.61) 300
Group Fine	358.00 (179.29) 75	250.47 (161.55) 75	366.12 (171.52) 75	379.93 (169.22) 75	338.64 (175.70) 300

Means, standard deviations, and number of observations

Table 2.6.3
OLS - Full Sample

Variable	Coefficient	Standard Error	P-Value
Constant	163.4	62.41	0.01
Group Fine	217.8	88.26	0.02
Subsidy	130.15	88.26	0.15
Tax	8.23	88.26	0.93
Certainty	25.57	88.26	0.77
First	46.95	88.26	0.6
Group Fine & Certainty	-156.31	124.83	0.22
Subsidy & Certainty	-86.64	124.83	0.49
Tax & Certainty	-13.48	124.83	0.92
Group Fine & First	-61.63	124.83	0.63
Subsidy & First	-106.13	124.83	0.4
Tax & First	-14.31	124.83	0.91
Certainty & First	-77.48	124.83	0.54
Group Fine, Certainty & First	199.69	176.53	0.27
Subsidy, Certainty & First	254.76	176.53	0.16
Tax, Certainty & First	71.11	176.53	0.69

Group $\text{Total}_s = \beta_1\text{tax-subsidy}_s + \beta_2\text{group fine}_s + \beta_3\text{subsidy}_s + \beta_4\text{tax}_s + \beta_5\text{order}_s + \beta_6\text{uncertainty}_s +$ interactions $+ \varepsilon_s$, where s indexes sessions

Table 2.6.4
Regression on Group Total by Session with Experienced Subjects and Certainty

Variable	Coefficient	Standard Error	P-Value
Tax-Subsidy	188.97	62.17	0.016
Tax	183.72	62.17	0.018
Subsidy	232.48	62.17	0.006
Group Fine	250.47	62.17	0.004

Group $\text{Total}_s = \beta_1\text{tax-subsidy}_s + \beta_2\text{group fine}_s + \beta_3\text{subsidy}_s + \beta_4\text{tax}_s + \varepsilon_s$, where s indexes sessions

Table 2.6.5
Regression on Group Total by Session with Experienced Subjects and Uncertainty

Variable	Coefficient	Standard Error	P-Value
Tax-Subsidy	158.92	54.58	0.020
Tax	169.19	54.58	0.015
Subsidy	294.52	54.58	0.001
Group Fine	379.93	54.58	0.000

Group $\text{Total}_s = \beta_1\text{tax-subsidy}_s + \beta_2\text{group fine}_s + \beta_3\text{subsidy}_s + \beta_4\text{tax}_s + \varepsilon_s$, where s indexes sessions

Table 2.6.6
Regression on Group Total by Session with Inexperienced Subjects and Uncertainty

Variable	Coefficient	Standard Error	P-Value
Tax-Subsidy	211.19	53.63	0.004
Tax	201.27	53.63	0.006
Subsidy	233.91	53.63	0.002
Group Fine	366.12	53.63	0.000

Group $\text{Total}_s = \beta_1\text{tax-subsidy}_s + \beta_2\text{group fine}_s + \beta_3\text{subsidy}_s + \beta_4\text{tax}_s + \varepsilon_s$, where s indexes sessions

2.7 Supplemental Figures

Figure 2.7.1: Tax-Subsidy Instrument

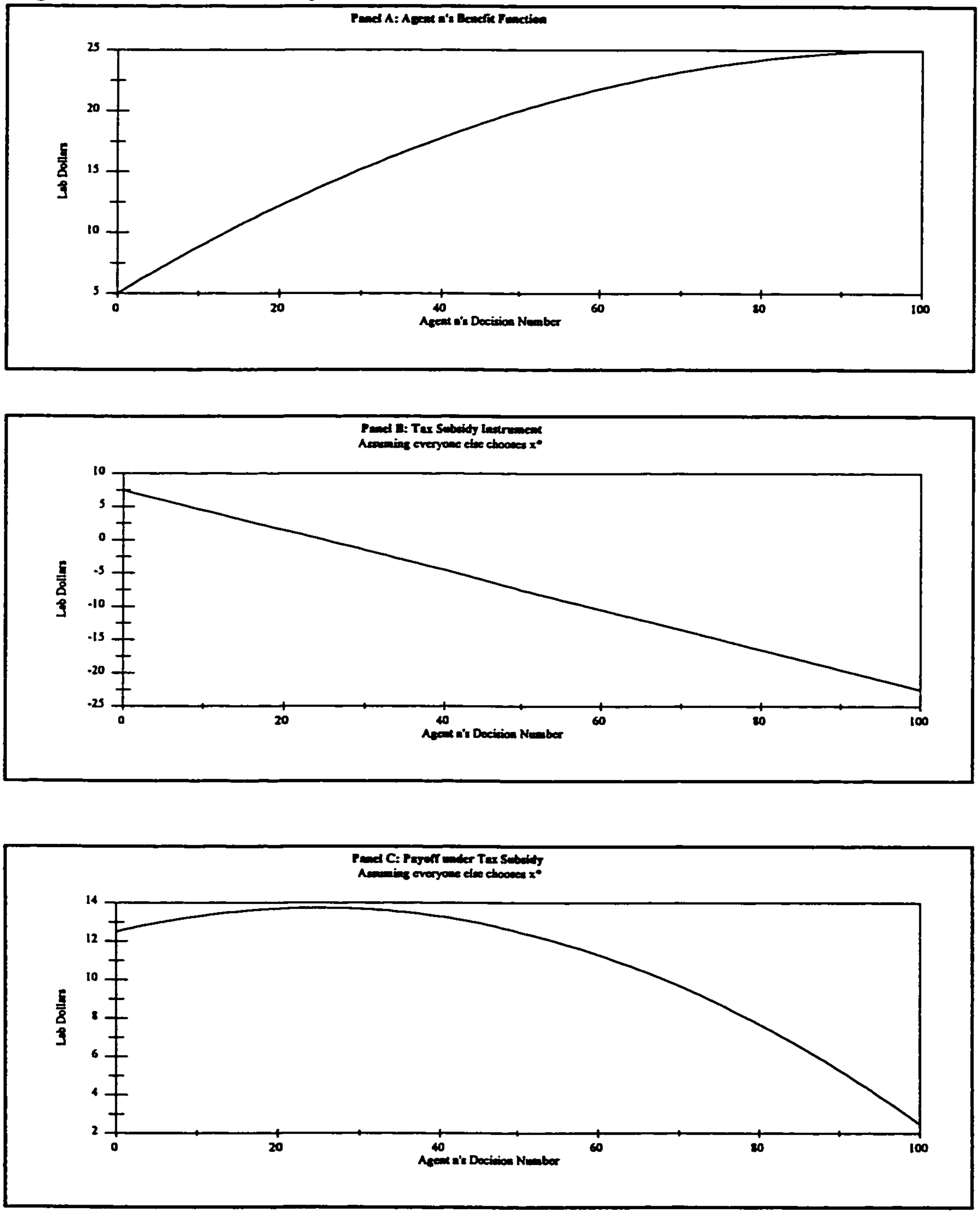


Figure 2.7.2: Tax Instrument

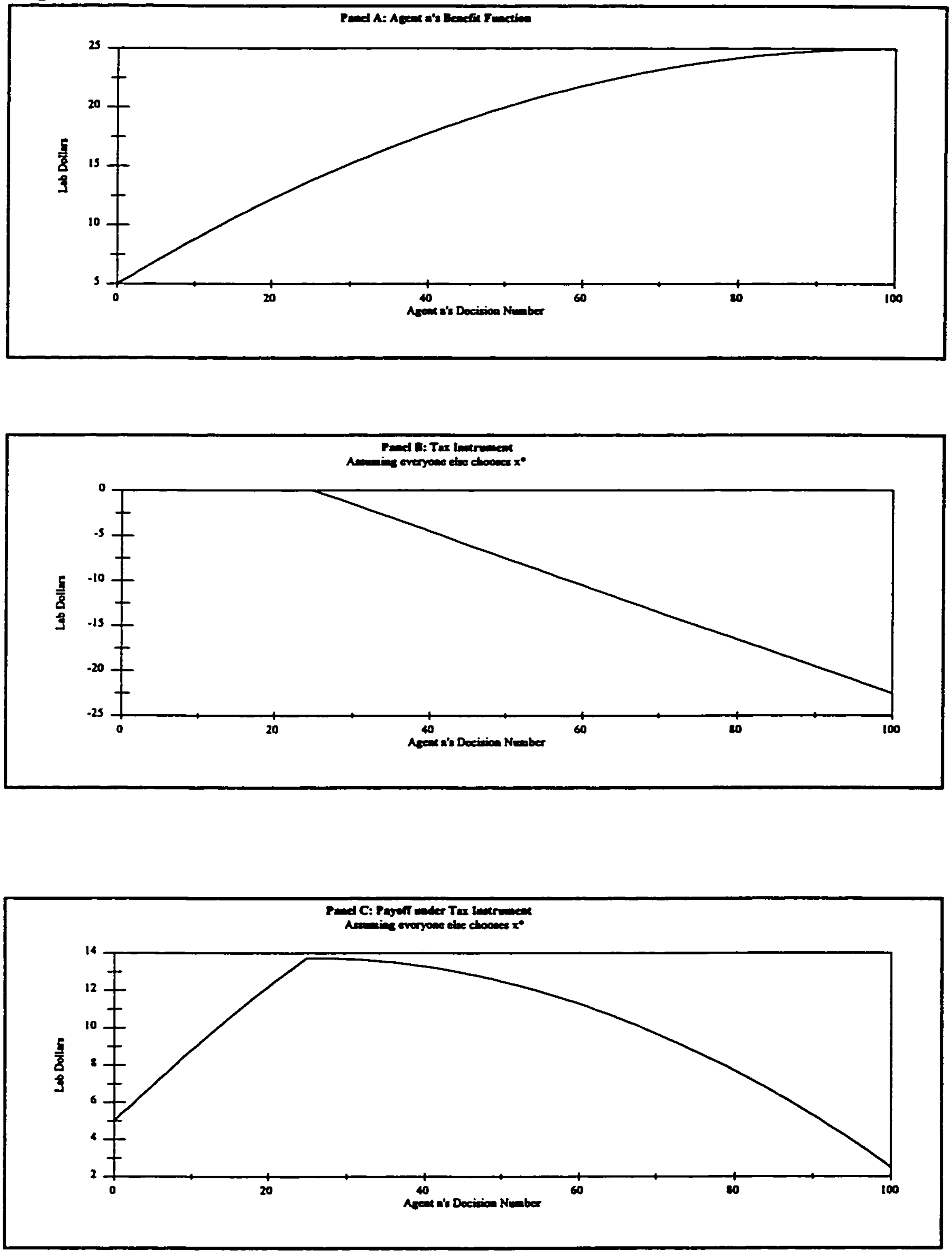


Figure 2.7.3: Subsidy Instrument

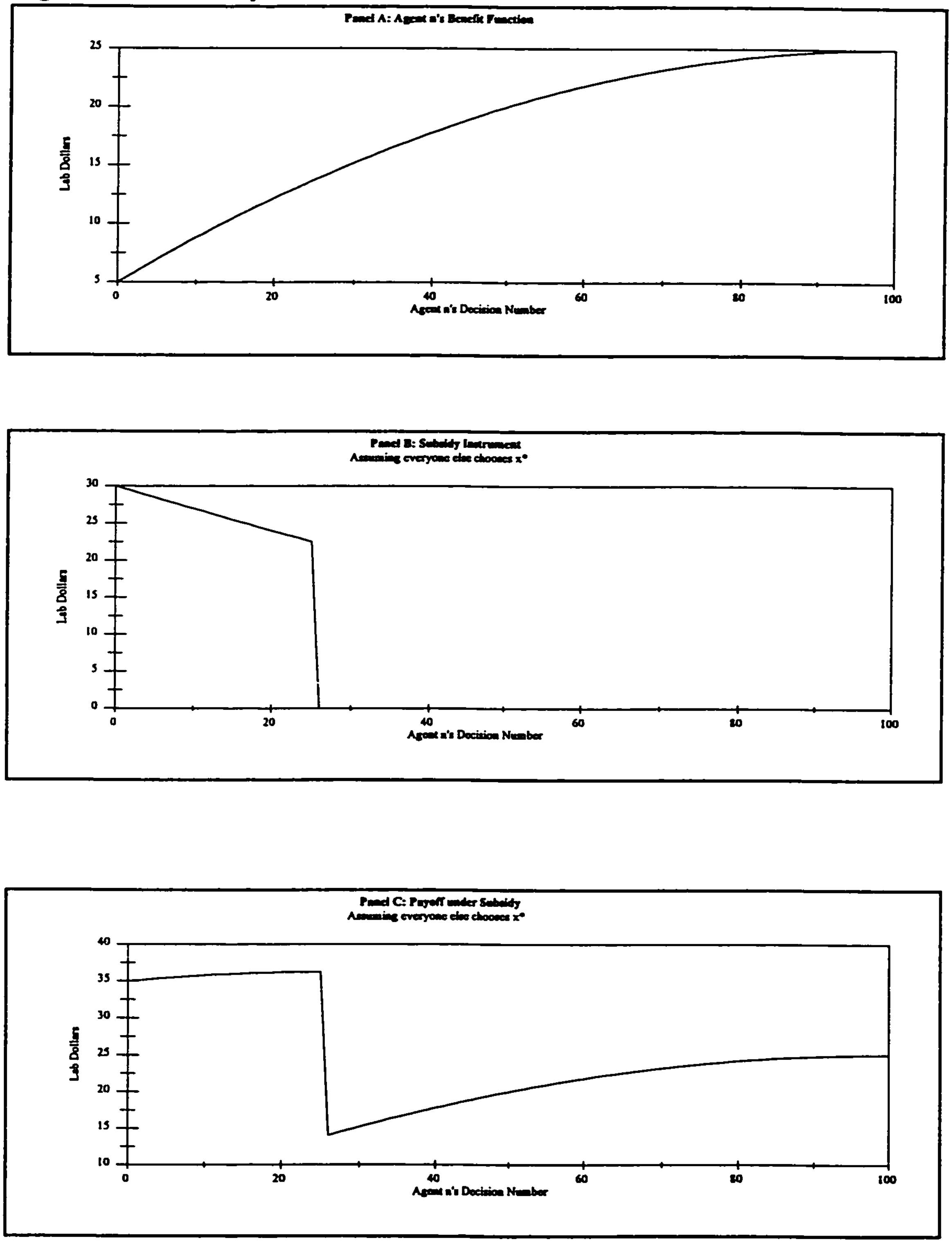


Figure 2.7.4: Group Fine Instrument

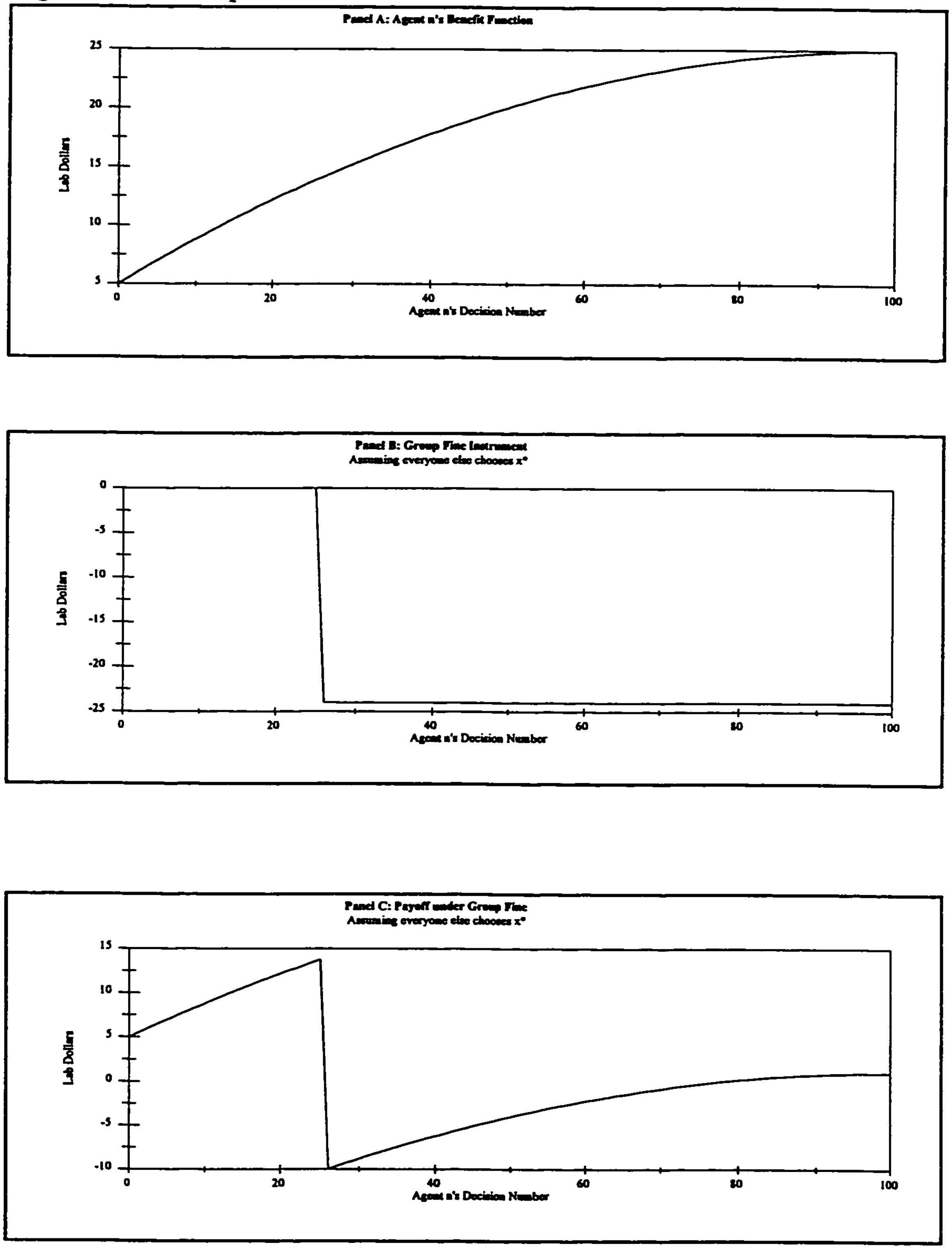


Figure 2.7.5: Mean Group Totals by Instrument, Inexperienced Subjects, Certainty

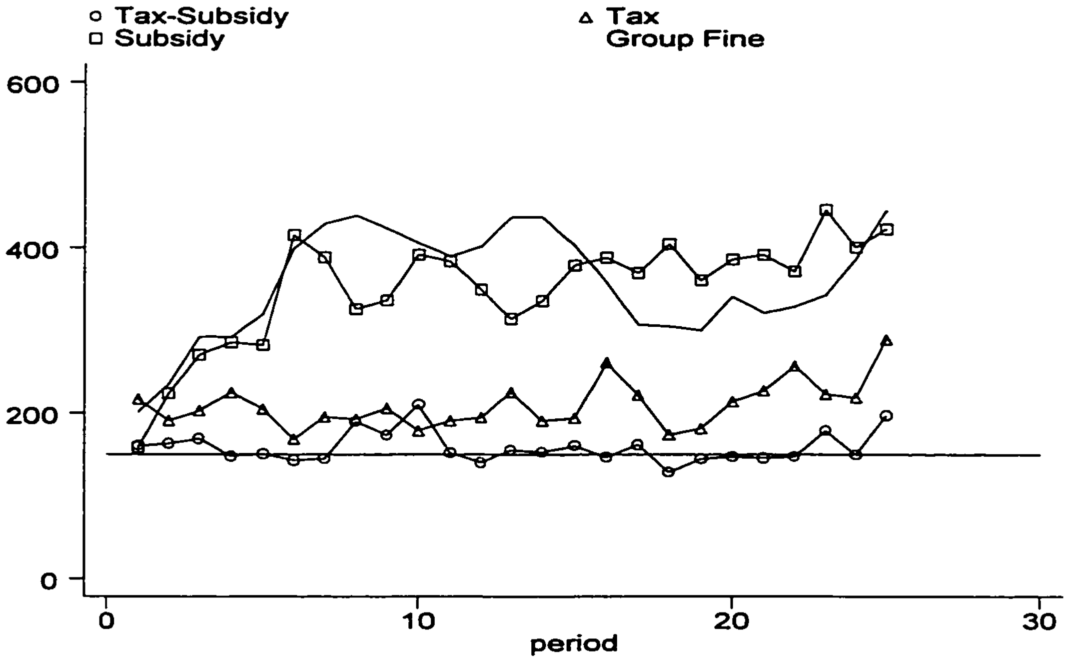


Figure 2.7.6: Group Totals by Period, Inexperienced Subjects, Certainty

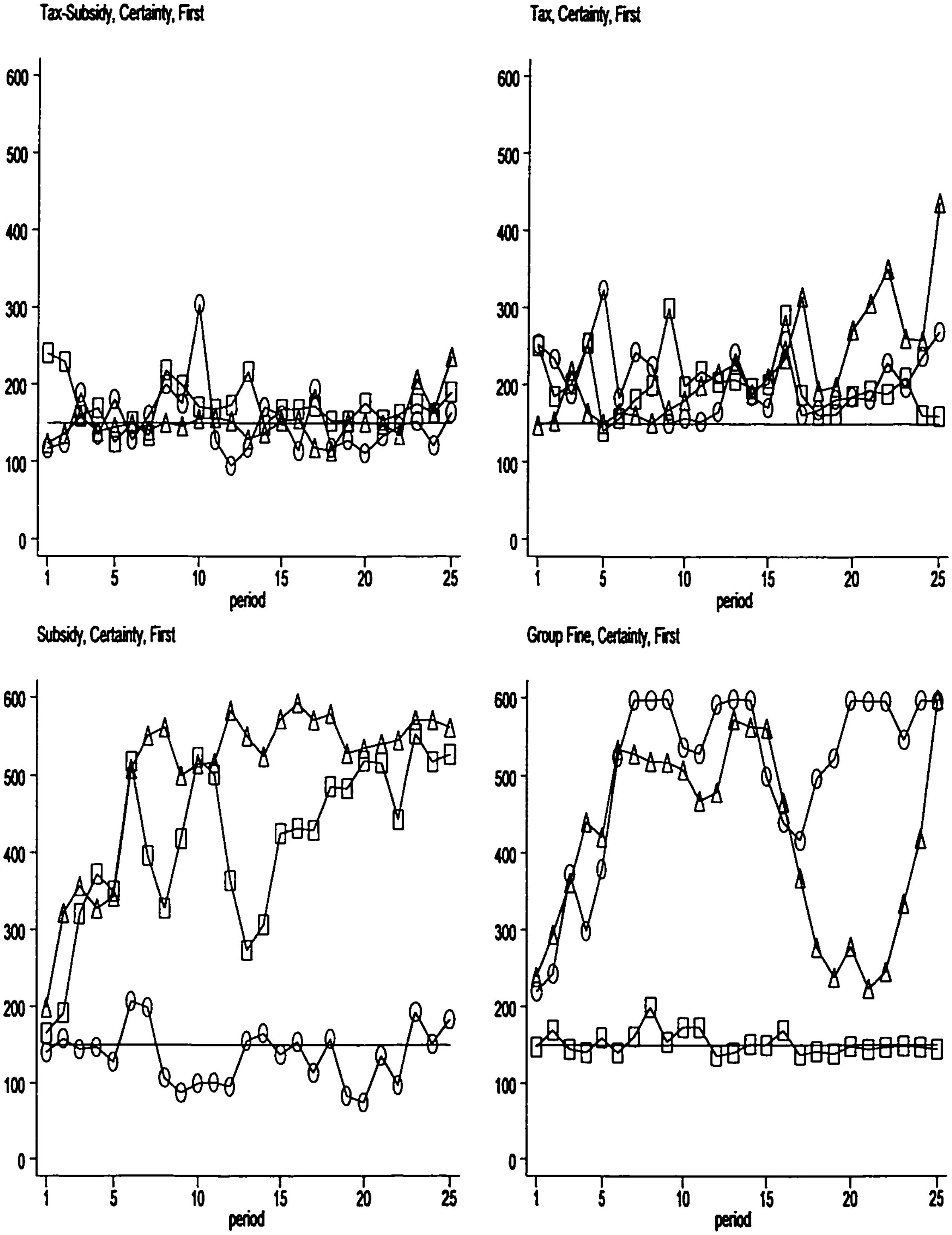


Figure 2.7.7: Box-and-Whisker Plot, Group Totals for Inexperienced Subjects under Certainty

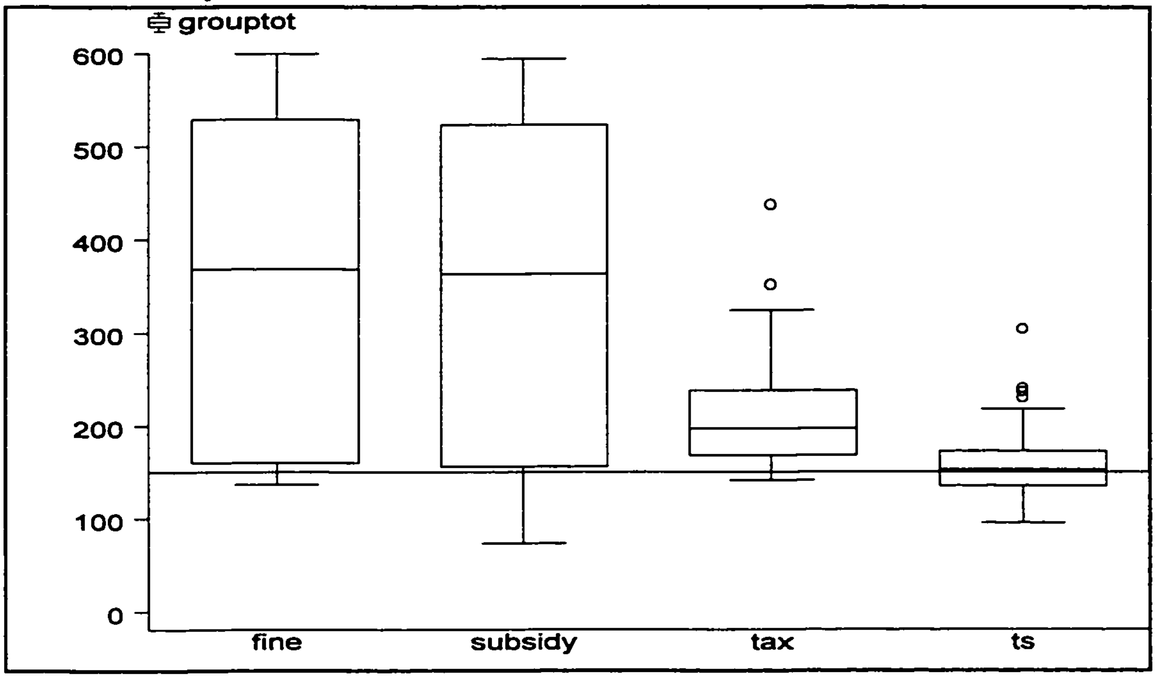


Figure 2.7.8: Mean Group Totals by Instrument, Experienced Subjects, Certainty

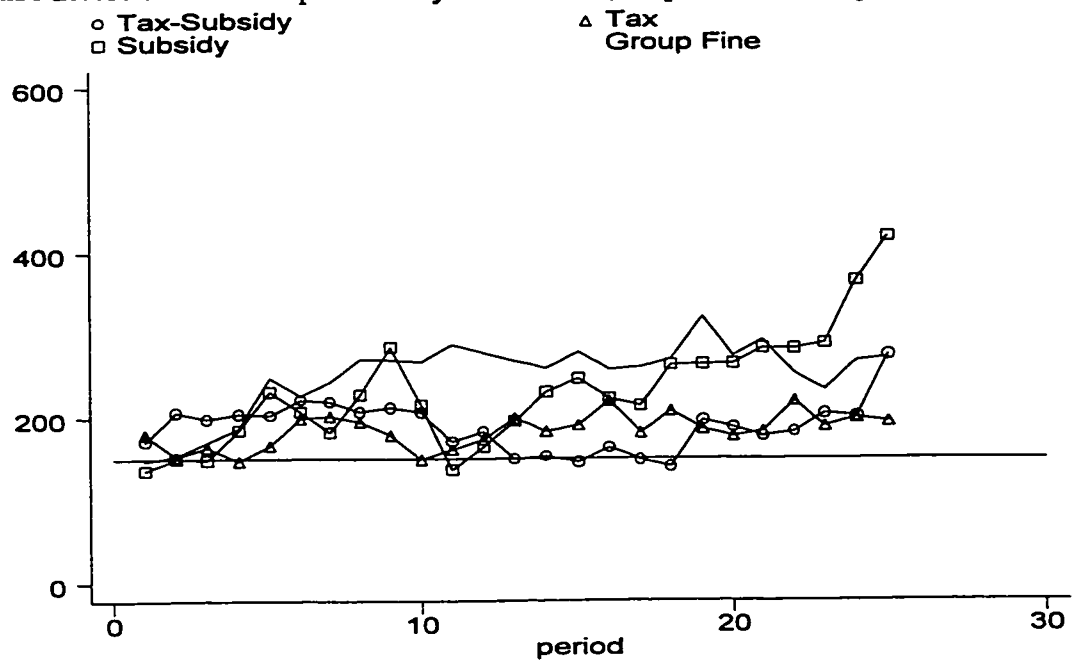


Figure 2.7.9: Mean Group Totals by Instrument, Inexperienced Subjects, Uncertainty

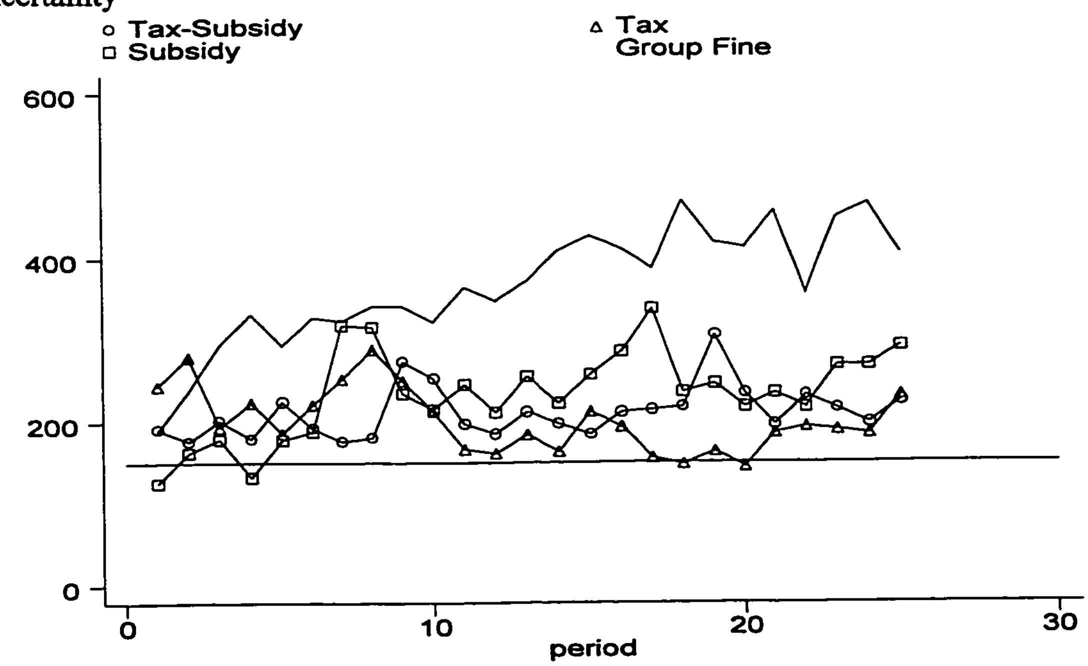


Figure 2.7.10: Mean Group Totals by Instrument, Experienced Subjects, Uncertainty

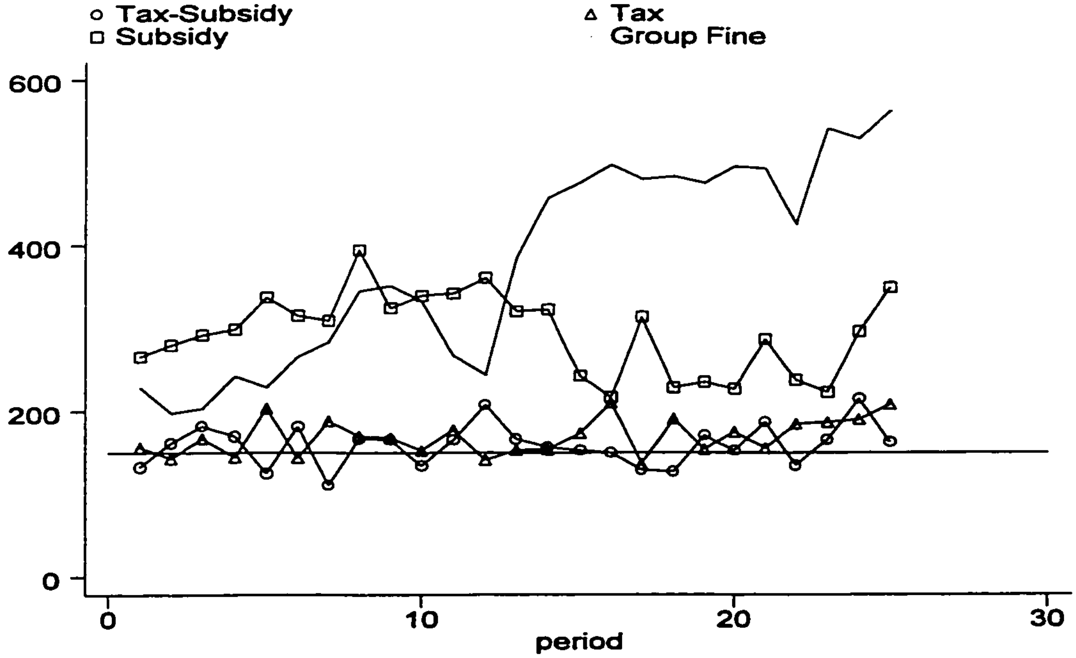


Figure 2.7.11: Group Totals by Period Experienced Subjects, Certainty

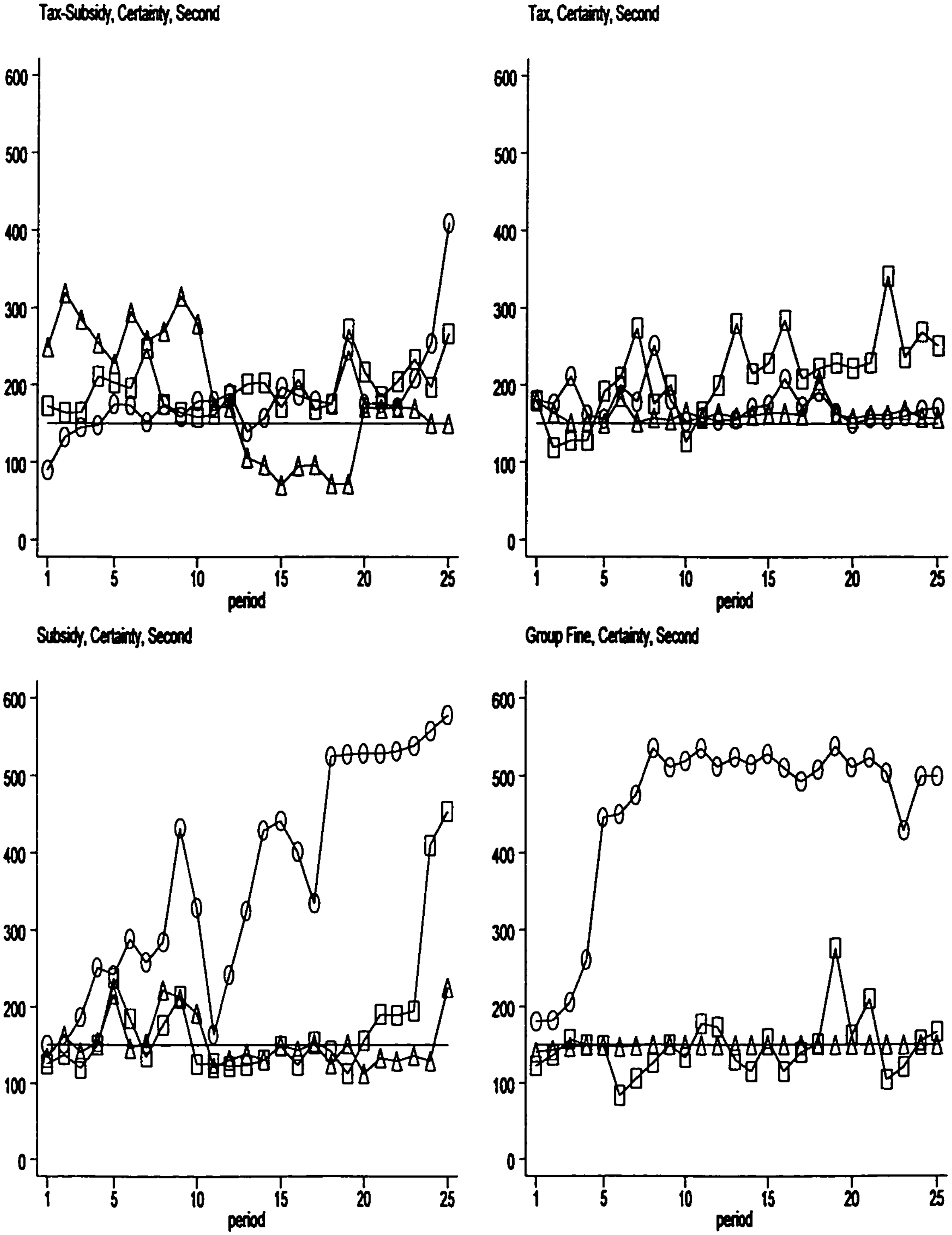


Figure 2.7.12: Group Totals by Period Inexperienced Subjects, Uncertainty

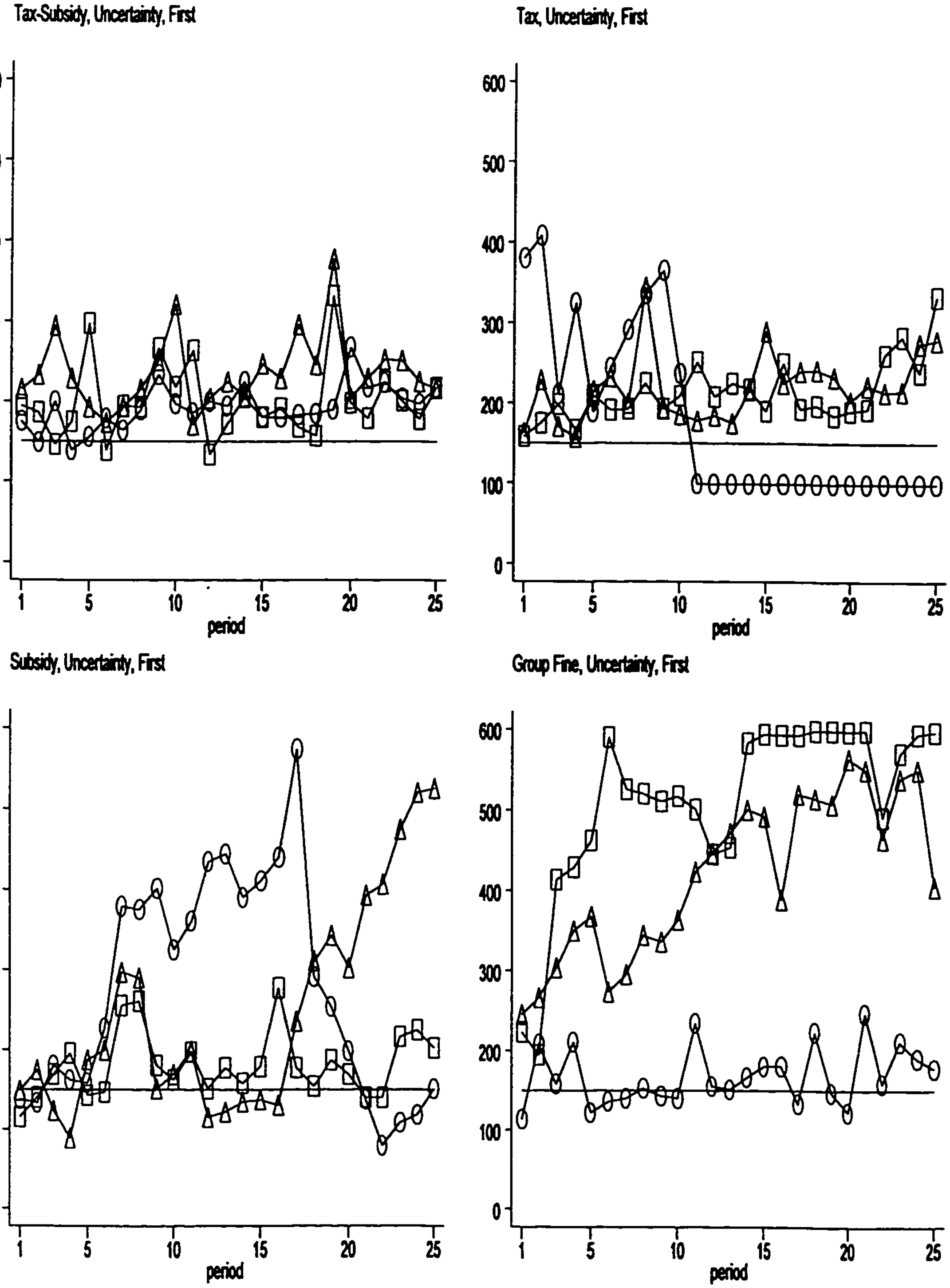


Figure 2.7.13: Group Totals by Period, Inexperienced Subjects, Uncertainty

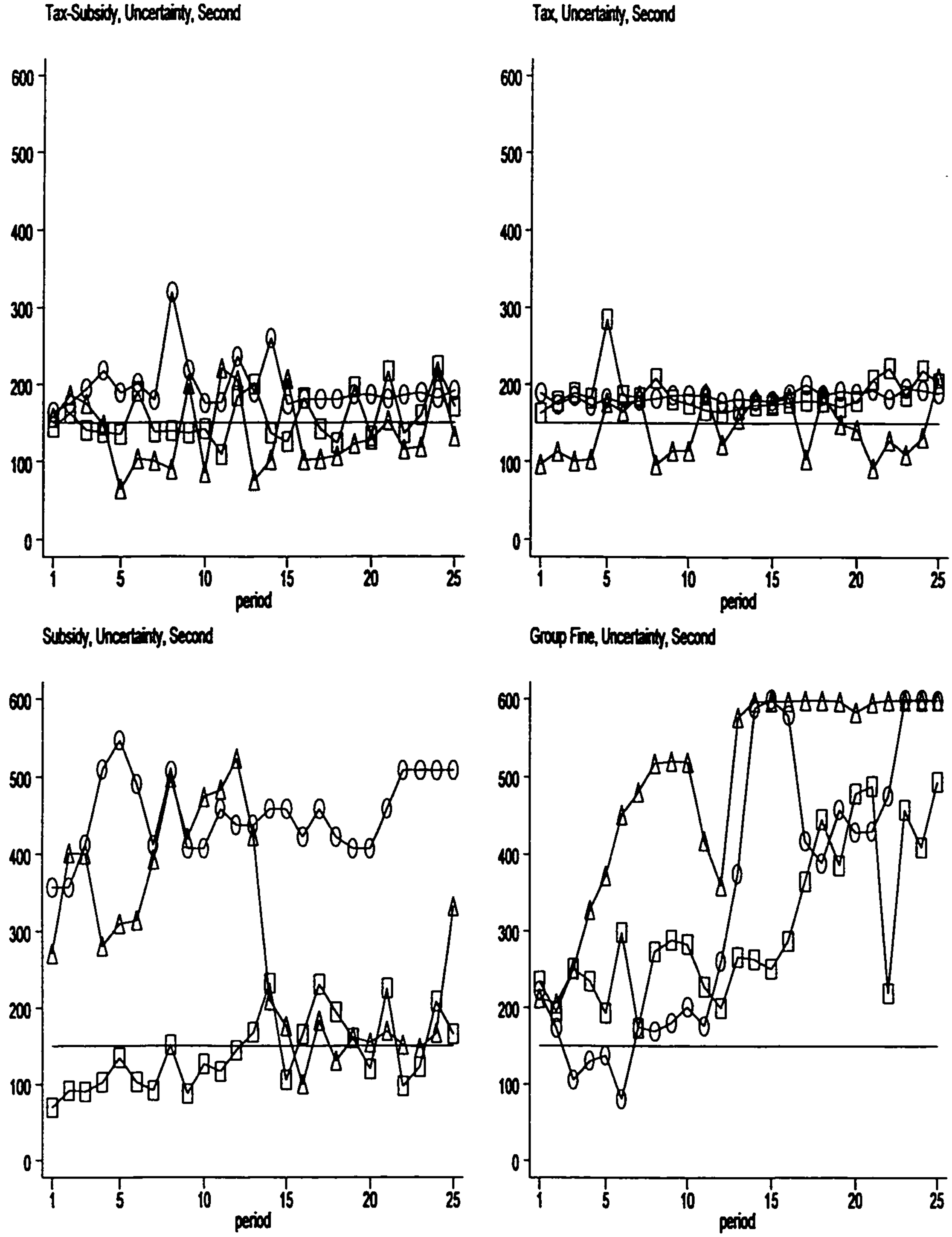


Figure 2.7.14: Box-and-Whisker Plot, Group Totals for Inexperienced Subjects under Uncertainty

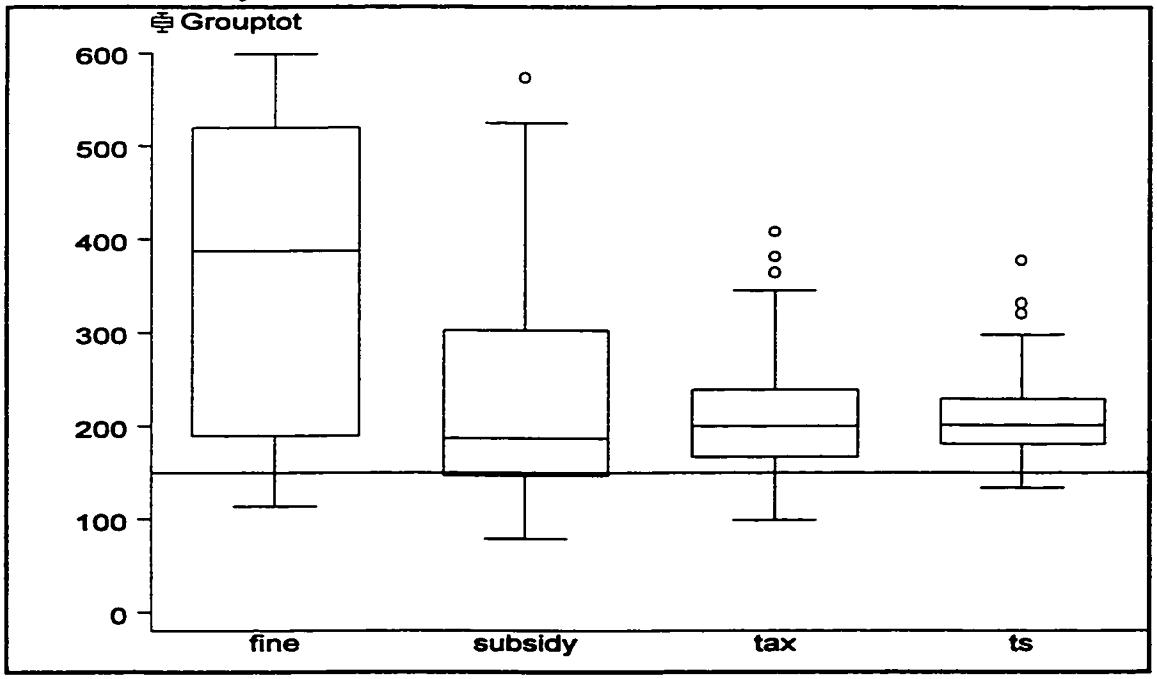


Figure 2.7.15: Box-and-Whisker Plot, Group Totals for Experienced Subjects under Certainty

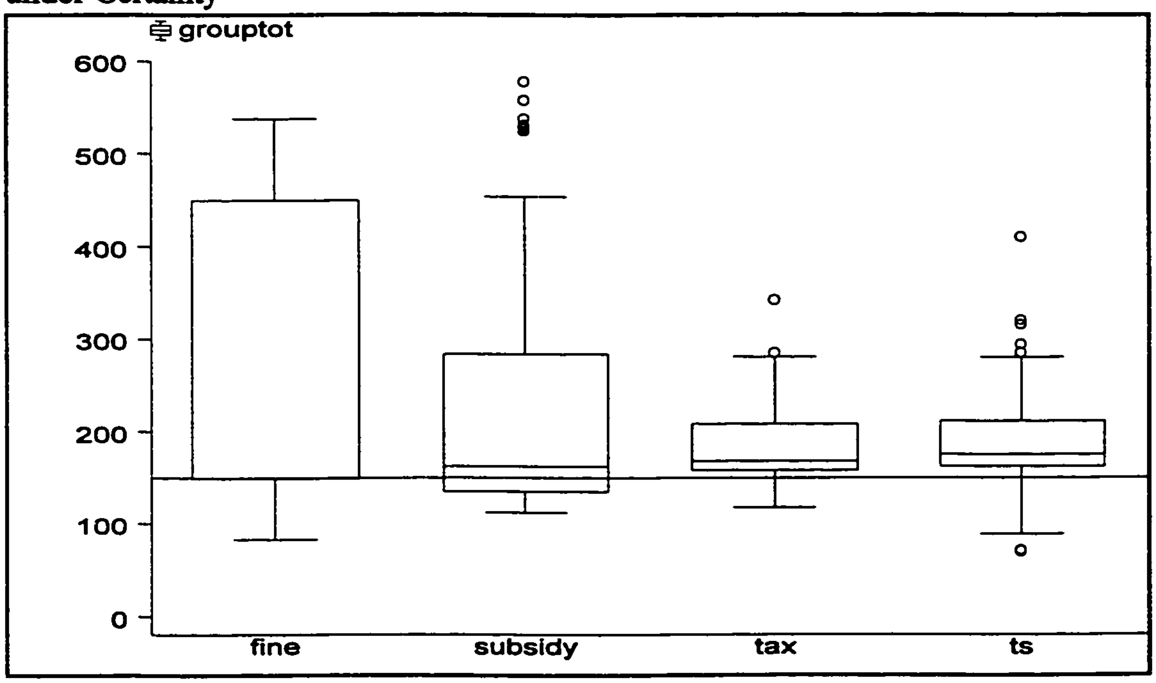


Figure 2.7.16: Box-and-Whisker Plot, Group Totals for Experienced Subjects under Uncertainty

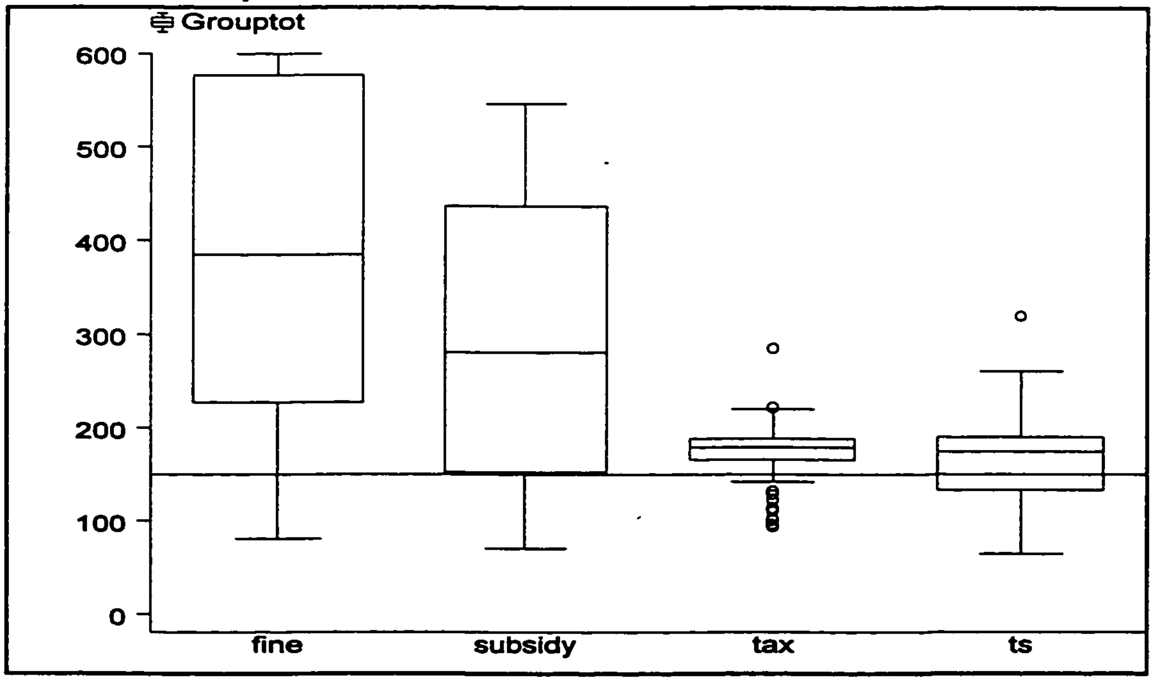


Figure 2.7.17: Distributions of Individual Decisions for Inexperienced Subjects under Certainty

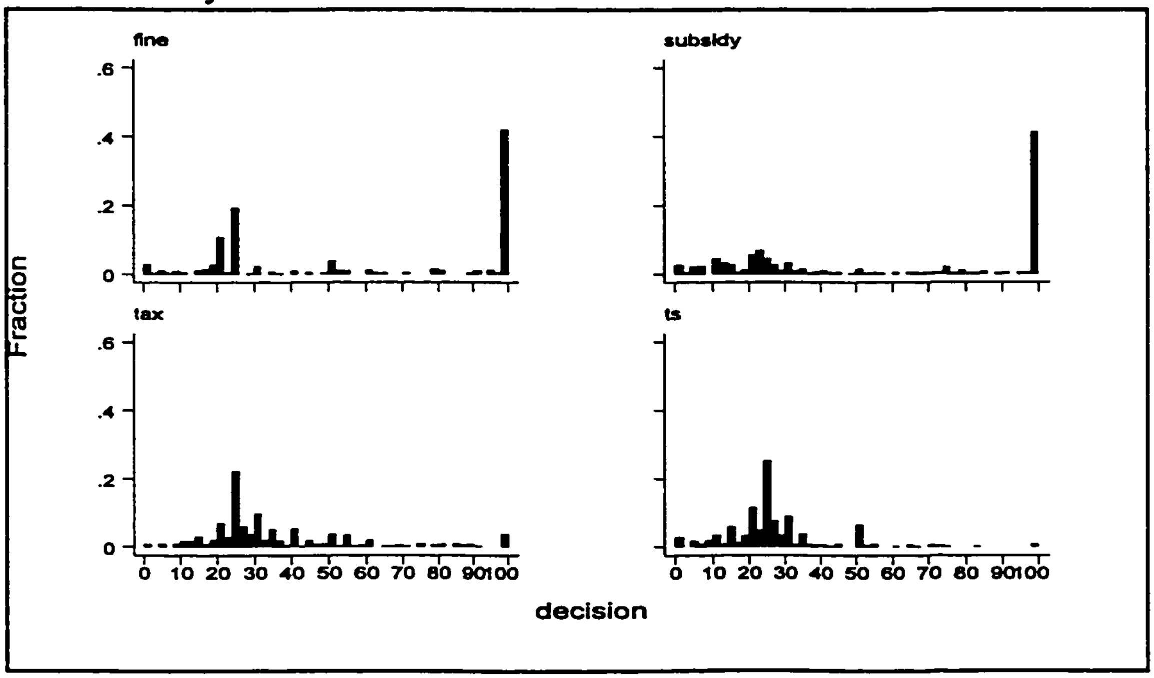


Figure 2.7.18: Distributions of Individual Decisions for Inexperienced Subjects under Uncertainty

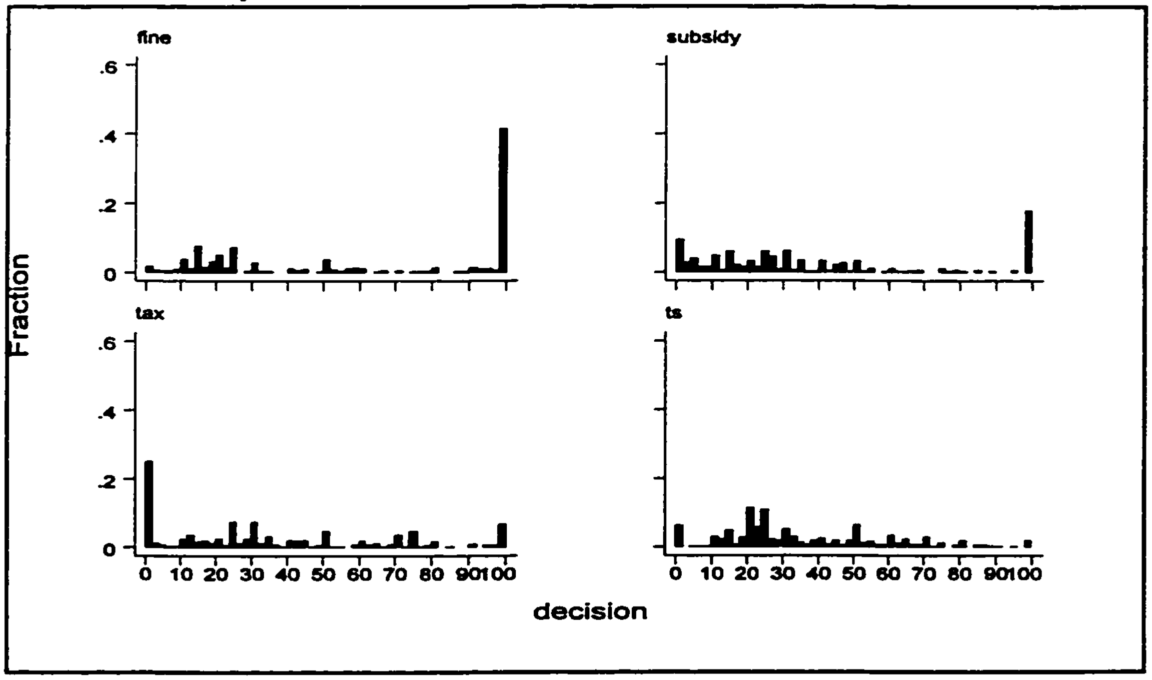


Figure 2.7.19: Distributions of Individual Decisions for Experienced Subjects under Certainty

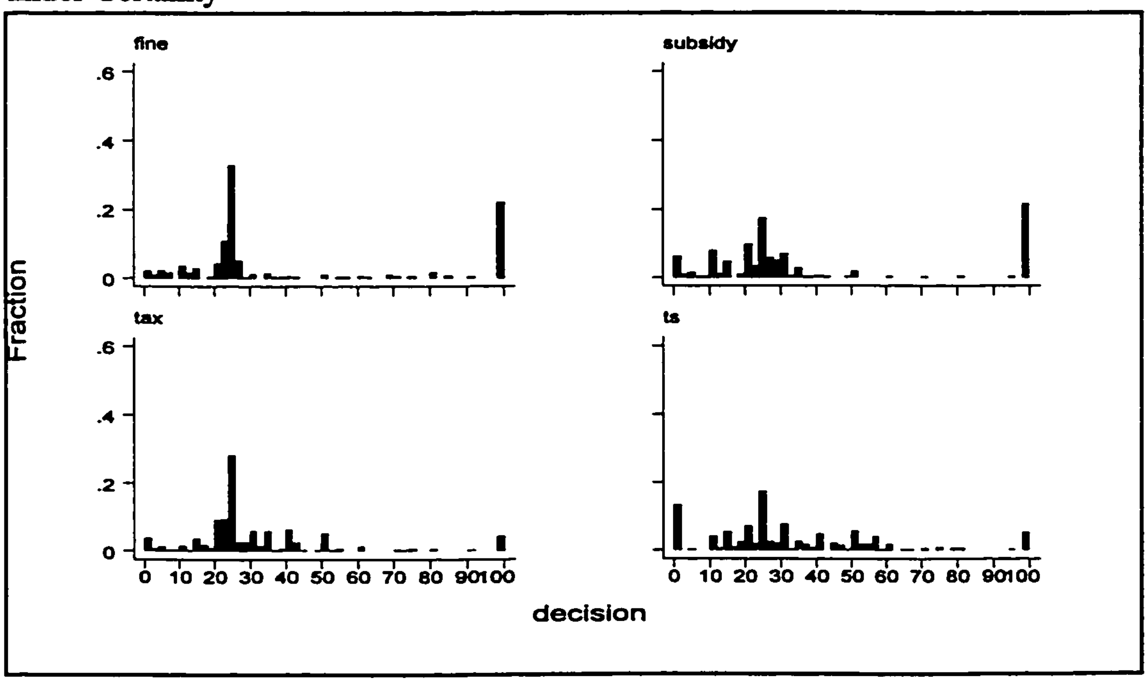
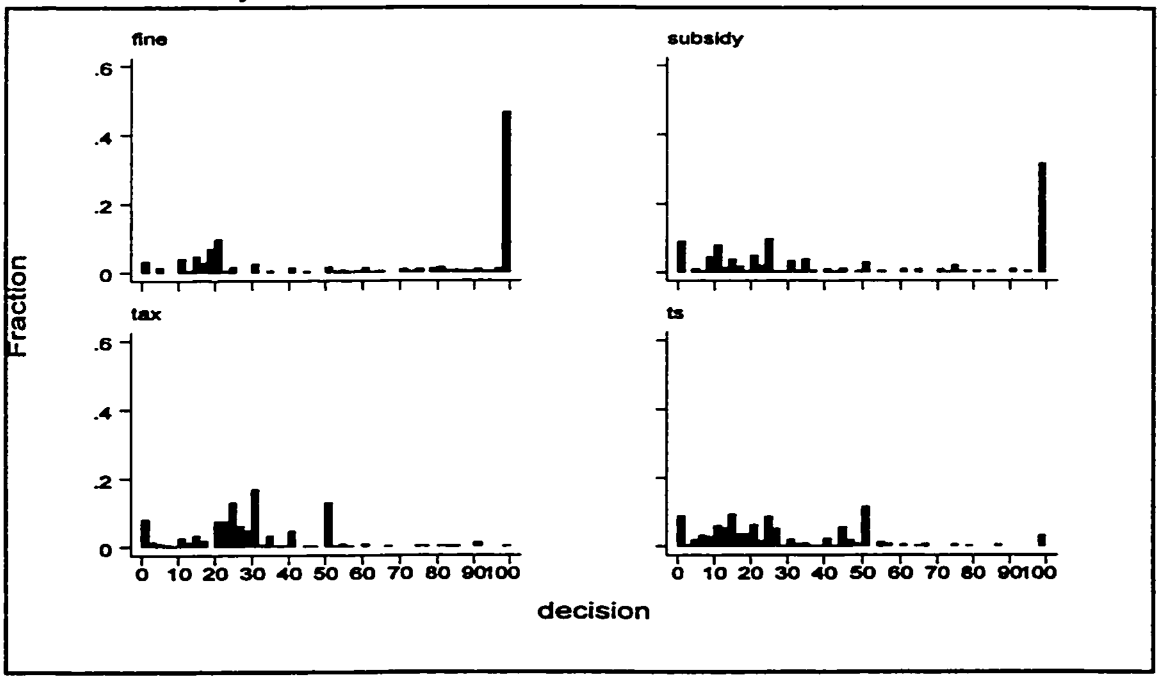


Figure 2.7.20: Distributions of Individual Decisions for Experienced Subjects under Uncertainty



Chapter 3

Exogenous Targeting Instruments with Heterogeneous Agents

3.1 Introduction

In Chapters 1 and 2 the problem of moral hazard in groups was discussed in detail. This common social dilemma encompasses situations such as the worker effort problem, common pool resources, and non-point source pollution. Clearly in all of these cases, agents are likely to be heterogeneous. In the previous chapter, it was shown that instruments suggested by Segerson (1988) and McAfee and McMillian (1991) are able to induce groups with homogeneous payoff functions to choose the target outcome. This chapter addresses the ability of these instruments to induce groups of individuals with heterogeneous payoff functions to choose a target outcome. The environment with homogeneous payoff functions is particularly simple. The target can be thought of as a quota on the level of emission and then the socially optimal outcome is for each subject to choose an equal share of this quota. Thus, subjects who use a simple heuristic, namely that everyone chooses an equal share of the quota, cannot be distinguished from those who are induced to the optimal decision by the incentives provided by the contracts. Heterogeneity in the individual payoff functions separates the prediction of simple heuristic based on equity from the optimal strategy. Hackett, Schlager, and Walker (1994) discuss these simple heuristics as "sharing rules" and suggest that subjects may choose "proportional rules", "proportionate reduction", "equal appropriation" or "equal absolute reduction". This added complexity provides some intuition for why many authors observe lower group contributions in environments where agents have heterogeneous payoff functions as opposed to environments where payoff functions are homogeneous. Ledyard (1995) provides an excellent survey of this literature. The papers which are most similar to the experiment presented here are Bagnoli and McKee (1991), Rapoport and Suliman (1993), Hackett, Schlager, and Walker (1994), and, Chan et al. (1996, 1999).

This paper reports a group moral hazard experiment in which agents are heterogeneous and fully informed of the payoff schedules of all of the members in their group. Two different instruments are tested. The first induces the optimal outcome as one of multiple equilibria, as the Holmstrom (1982) forcing contract, and the second instrument induces the optimal outcome as the unique Nash equilibrium. The experiment is based on the non-point source pollution problem where each firm's choice of emission level is unobservable.

Two exogenous targeting instruments are tested. The first is the Tax-Subsidy contract suggested by Segerson (1988) which induces agents to select values closest to the target level in the homogeneous study. 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 Chapter 2, 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 tested for comparison with previous experiments on threshold public goods and common pool resources such as the Bagnoli and McKee (1991) and Rapoport and Sulieman (1993) studies. 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. For consistency with the homogeneous agent study, groups participate 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.

Heterogeneity is introduced in the experiment by assuming that subjects represent different sized polluters. Half of the subjects are analogous to small capacity polluters whose uncontrolled emission level is below that of the subjects from the homogeneous study and the other half are analogous to large capacity polluters whose uncontrolled emission level is above that of the subjects from the homogeneous study.

This study shows that exogenous targeting instruments which 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 from the homogeneous study. Further, the effects of switching between the contracts are significant. As in the homogeneous study, (Chapter 2) 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. As a result, 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. This is similar to the results observed by Chan et al. (1996) who find that subjects with higher endowments, analogous to the large capacity subjects, tend to under-contribute while subjects with lower endowments, analogous to the small capacity subjects, tend to over-contribute.

3.2 Experimental Design

The experiment examines the moral hazard in groups problem in the context of non-point source pollution problem (Segerson 1988, Xepapadeas 1992). Heterogeneity is introduced to model the situation where firms have different uncontrolled emission levels. In other respects the experiment is identical to Chapter 2.[1] 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

[1] Four contracts were tested in Chapter 2 whereas only two are tested here.

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. A copy of the instructions is included in Appendix B section B.1.

The moral hazard in this environment is that individuals can raise their decision numbers without being observed. The higher the individual's decision number, the higher the private payoff but the lower the payoff to the group. The individual's private payoff rises by more than the individual's share of the group payoff falls. This is analogous to the wide class of common social dilemmas described earlier. 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 minus the costs. The joint benefit function is

$$SP = \sum_{n=1}^{6} B_n(x_n) - D(X) \qquad (3.2.1)$$

where n indexes subjects n=1,..,6 and x_n is the decision number chosen by subject n, which represents a firm's emission level, and X is the observed total of the decision numbers, representing aggregate emissions. Aggregate emissions which are directly related to ambient level of pollution for a non-cumulative (or "flow") pollutant. I will maintain the assumption from the homogeneous study that the costs are given by 0.3 times the sum of the individual decisions:

$$D(X) = 0.3\sum_{n=1}^{6} x_n. \tag{3.2.2}$$

Heterogeneity is introduced through the individuals' benefit functions. Individuals represent either small capacity or large capacity firms. Subjects of the small type had a maximum decision number of 75 (representing an unconstrained emission capacity of 75 units) and those of the large type had a maximum decision number of 125 (representing an unconstrained emission capacity of 125 units). 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 decision number (x_n) and her maximum decision number (x_n^{max}):

$$B_n(x_n) = 25 - 0.002(x_n^{max} - x_n)^2 \tag{3.2.3}$$

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

$$SP = \sum_{n=1}^{6} (25 - 0.002(x_n^{\max} - x_n)^2) - 0.3\sum_{n=1}^{6} x_n, \tag{3.2.4}$$

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 decision number for each individual is found by solving:

$$\partial SP/\partial x_n = 0.004(x_n^{\max} - x_n) - 0.3 = 0 \rightarrow x_n^* = x_n^{\max} - 75. \tag{3.2.5}$$

Therefore the socially optimal decision number for small types ($x_n^{max} = 75$) is 0, and the socially optimal decision number for the large types ($x_n^{max} = 125$) is 50. Thus, the socially optimal group total is equal to 150 units (as it was in the homogeneous agent case).

3.3 Contracts

The non-point 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 to mitigate this problem is evaluated in the experiment reported in this chapter. These are the Tax-Subsidy and Group Fine contracts. These contracts are of the same form as suggested by Segerson (1988) for the non-point source pollution problem

$$T_n(X) = \begin{cases} t_n(X-X^*)+\tau_n & \text{if } X > X^* \\ s_n(X-X^*)-\beta_n & \text{if } X \leq X^* \end{cases} \tag{3.3.1}$$

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 enforce. For the purposes of the experiment X^* is the socially optimal aggregate decision number from the social planner's problem given by equation (3.2.4).

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 the same as were used for the homogeneous agent study (Chapter 1). The Tax-Subsidy contract results in the socially optimal decision number being a dominant strategy, while the Group Fine contract results in multiple Nash equilibria. Xepapadeas (1992) shows that the Tax-Subsidy contract is also an efficient solution to the non-point source pollution problem in an infinite-horizon dynamic model.[2] The Group Fine contract is similar to the threshold public good or threshold common property resource environments tested by Rapoport and Sulieman (1993) and Sulieman and Rapoport (1992).

3.4 Payoff Maximization

An individual's payoff function is the benefit function (3.2.3) minus the value of the contract (3.3.1), $\pi_n = B(x_n) - T(X)$. Thus, the expected payoff function for the Tax-Subsidy contract is

$$\pi_n = 25.00 - 0.002(x_n^{max} - x_n)^2 - 0.3(X - 150). \tag{3.4.1}$$

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.[3] Since this is a dominant strategy, it is

[2] Xepapadeas (1992) 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.

[3] $\partial\pi_n^e/\partial x_n = 0.004(x_n^{max} - x_n) - 0.3$ which is identical to the first order condition of the social planner's problem (3.2.5). More detail is provided in the mathematical appendix section

also the Nash equilibrium for the repeated game.

An individual's expected payoff function under the Group Fine contract depends on the probability that the sum of the decision numbers is less than the target level $Prob(X < 150)$ or $Prob(X_{-n} = \sum_{j \neq n} x_j \leq 150 - x_n)$ where X_{-n} is the sum of all of the other subjects' decision numbers 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

$$\pi_n = 25 - 0.002(x_n^{max} - x_n)^2 - 24[1 - Prob(X_{-n} \leq 150 - x_n)]. \qquad (3.4.2)$$

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 Nash equilibrium. These equilibria can be described as socially optimal when the group total is equal to 150 and individually optimal where each subject chooses the maximum decision number. See Appendix C section C.3.1 for more details. That there are multiple equilibria in a one-shot version of the game suggests that there may be repeated game effects in the experiment. The Group Fine contract, however, is discussed for comparison with the previous experiments such as Rapoport's and Sulieman's (1993) threshold public good experiment and the analysis of the repeated game effects are beyond the scope of this paper.

C.3.1.

Subjects may use simple heuristics to determine how to choose their decision number, as suggested by Rapoport and Sulieman (1993) and Hackett, Schlager and Walker (1994) . Such heuristics might be based on notions of equity. Subjects could choose to select decision numbers which are equal, an equal proportion of their maximum decision number, an equal reduction from their maximum decision number 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 decision numbers, the six subjects in this study, with a target of 150, would each choose $e_n = 25$. If the subjects reach the target of 150 by either reducing their maximum potential number by the same proportion or by selecting a number which is the same proportion of their endowments, large capacity and small capacity subjects will choose 31 and 19 respectively.[4] 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 3.4.1.

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

Table 3.4.1
Theoretical Predictions

Contract	Subject Capacity	Nash Equilibrium		Simple Heuristics		
		Optimal	Sub-Optimal	Abs Dec	Prop Dec	Abs Red.
Tax-Subsidy	Large	50		25	31	50
	Medium	25		25	25	25
	Small	0		25	19	0
Group Fine	Large	Multiple	125	25	31	50
	Medium	Multiple	100	25	25	25
	Small	Multiple	75	25	19	0

3.5 Results

Thirty-six subjects were recruited from the student population at McMaster University during the winter term of 1998. 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. Bankruptcies[5] 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.

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[5]It was possible for subjects to earn negative payoffs in each period. Each subject was given an initial endowment of five Canadian dollars 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' decision numbers.

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 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 decision-number totals and mean decision-numbers 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. Table 3.5.1 presents the mean group decision numbers for all of the treatment cells and the corresponding efficiencies[6] are found in Table 3.7.1. Results are presented first by twenty-five period phase and then the individual decisions are discussed. The first two results concern inexperienced subjects, or those from the first phase. The third result concerns experienced subjects, or those from the second phase. Result four compares the results between the two phases and result five compares the outcome between the different possible capacities. The first three results are based on the aggregate data while the final two results use the individual level data.

[6]For a discussion of efficiency see Chapter 2 section 2.3.

Table 3.5.1
Mean Group Decision Numbers for Homogeneous and Heterogeneous Treatments

Contract	No Experience			Experience			Overall
	Hom	Het	Overall	Hom	Het	Overall	
Tax-Subsidy	158^{B} (7.70) [3]	170^{B} (6.62) [3]	164^{B} (5.28) [6]	189^{B} (4.00) [3]	185^{B} (7.51) [3]	187^{B} (3.91) [6]	176^{B} (4.62) [12]
Group Fine	358^{C} (105.73) [3]	509^{A} (14.47) [3]	434^{C} (58.52) [6]	250^{B} (102.63) [3]	289^{C} (85.53) [3]	270^{C} (60.37) [6]	352^{C} (47.09) [12]
Overall	258^{C} (65.11) [6]	340^{C} (76.13) [6]	299^{C} (49.32) [12]	220^{B} (47.94) [6]	237^{B} (44.92) [6]	228^{C} (31.43) [12]	263^{C} (29.53) [24]

Notes: The number in parenthesis are standard errors from and the numbers in square brackets are numbers of observations. The superscript A, B and C indicate the results of the test of the appropriate restrictions the full sample regression (Table 3.5.8), A represents significantly different from 150 at the 5% level, B represents significantly different from 600 at the 5% level, and C significantly different from 150 & 600 at the 5% level.

Result 1: **For inexperienced subjects the Tax-Subsidy contract is able to induce heterogeneous groups to choose the socially optimal outcome while the Group Fine contract is not.**

Table 3.5.2 clearly shows that the Tax-Subsidy contract is better able to induce the group to choose the target outcome than the Group Fine contract for heterogeneous groups. Notice that the group totals (Table 3.5.2 and Figure 3.8.1 Panel A) are closer to the target level of 150 and that the efficiencies are much higher (Table 3.7.1 and Figure 3.8.1 Panel B) for the Tax-Subsidy instrument than for the Group Fine with heterogeneous groups.

Table 3.5.2
Mean Group Totals and Efficiencies for Inexperienced Subjects and Heterogeneous Payoff Functions

Contract	Tax-Subsidy	Group Fine
Mean Group Total	170 (6.62) [3]	509 (14.47) [3]
Efficiency	85.1% (4.88) [3]	22.2% (3.63) [3]

A simple Anova of a dummy variable for sessions which involved the Group Fine instrument on the group total shows that this difference is significant (Table 3.5.3), and the subsequent regression (Table 3.5.4) shows that the mean group total for the Tax-Subsidy instrument is not significantly different from the target (150) while the mean group total for the Group Fine instrument is significantly higher than the target using a test of the difference of the regression coefficients (in Table 3.5.4) from 150.

Table 3.5.3
Anova on Group Total, by Session with Heterogeneous, Inexperienced Subjects and Heterogeneous Payoff Functions

Number of Observations: 6
Root MSE: 19.49

R-squared: 0.9913
Adj R-squared: 0.9891

Source	Partial SS	df	MS	F	Prob > F
Model	172381.5	1	172381.5	453.83	0.000
Group Fine	172381.5	1	172381.5	453.83	0.000
Residual	1519.36	4	379.84		
Total	173900.86	5	34780.17		

Table 3.5.4
Regression on Group Total by Session with Inexperienced Subjects and Heterogeneous Payoff Functions

Variable	Coefficient	Standard Error	P-Value
Constant	170.47	11.25	0.000
Group Fine	339	21.303	0.000

Group $Total_s = \beta_1 + \beta_2 group\ fine_s + \varepsilon_s$, where s indexes sessions.

Result 2: **Heterogeneity degrades the performance of both instruments among inexperienced subjects but the difference is not significant.**

Tables 3.5.5 and 3.5.6 show that the group totals are slightly higher for both Tax-Subsidy and Group Fine and the efficiencies are lower for heterogeneous as compared to homogeneous groups.

Table 3.5.5
Mean Group Decision Numbers for Homogeneous and Heterogeneous Treatments, Inexperienced Subjects

Contract	No Experience	
	Homogeneous	Heterogeneous
Tax-Subsidy	158 (7.70) [3]	170 (6.62) [3]
Group Fine	358 (105.73) [3]	509 (14.47) [3]

Notes: The numbers in parenthesis are standard deviations over the three sessions and the numbers in square brackets are numbers of observations.

This suggests that the heterogeneous environment is more complicated and that the

Tax-Subsidy instrument is slightly less able to induce the group to the socially optimal outcome. This can also be seen in Figures 3.8.1 and 3.8.2. In Figure 3.8.2 notice that, although the group totals for the Tax-Subsidy instrument are very similar between the homogeneous subjects (Panel A) and the heterogeneous subjects (Panel B), there is a noticeable difference between the Group Fine instrument with homogeneous and heterogeneous subjects. Figure 3.8.3 shows the between session variation for the Tax-Subsidy (Panel A) and Group Fine (Panel B) instruments with inexperienced subjects and heterogeneous payoff functions. Figures 2.7.5 and 2.7.6 in Chapter 2 show the same comparisons for the homogeneous groups.

Table 3.5.6
Efficiencies for Homogeneous and Heterogeneous Treatments, Inexperienced Subjects

Contract	No Experience	
	Homogeneous	Heterogeneous
Tax-Subsidy	96.3% (1.09) [3]	85.1% (4.88) [3]
Group Fine	53.5% (22.46) [3]	22.2% (3.63) [3]

Notes: The numbers in parenthesis are standard deviations over the three sessions and the numbers in square brackets are numbers of observations.

Analysis of variance (Table 3.5.7) shows that heterogeneity has no significant effect on the mean group totals.

Table 3.5.7
Anova on Group Total, by Session with Inexperienced Subjects

Number of Observations: 12
Root MSE: 92.84
R-squared: 0.7853
Adj R-squared: 0.7048

Source	Partial SS	df	MS	F	Prob > F
Model	252165.34	3	84055.11	9.75	0.0048
Group Fine	217535.16	1	317535.16	25.24	0.001
Homogeneity	20047.55	1	20047.55	2.33	0.166
Interaction	14582.63	1	14582.63	1.69	0.2295
Residual	68946.75	8	8618.34		
Total	321112.09	11	29192.01		

The standard errors from the corresponding regression (Table 3.5.8) suggest that only the group totals for the Group Fine instrument with heterogeneous payoff functions are significantly different from the target level of 150.

Table 3.5.8
Regression on Group Total by Session with Inexperienced Subjects

Variable	Coefficient	Standard Error	P-Value
Constant	158.44	53.6	0.018
Group Fine	199.56	75.8	0.030
Homogeneity	12.03	75.8	0.878
GF*Homogeneity	139.44	107.2	0.230

Group Total$_s$ = β_1 + $\beta_2$group fine$_s$ + β_3Homogeneity$_s$ + β_4(group fine*Hom)$_s$ + ε_s, where s indexes sessions.

Result 3: Among experienced subjects The Tax-Subsidy instrument is able to induce the group to the target outcome but the Group Fine instrument is not. Further, heterogeneity has no significant effect.

Tables 3.5.1 and 3.7.1 show that the group totals are closer to the target level and the efficiencies are higher for the Tax-Subsidy than for the Group Fine instrument. Figure 3.8.4 shows the mean group totals by instrument and period for homogeneous (Panel A) and heterogeneous (Panel B) experienced subjects. Figure 3.8.5 shows the across session variation. Notice that for both instruments the group totals are closer to the target of 150 than they were for inexperienced subjects. Also notice that the results for both instruments are very similar for the Homogeneous and Heterogeneous groups.

Anova analysis for all of the treatment variables on group total (Table 3.7.2) suggests that instrument and instrument interacted with experience are the only treatment variables which have significant effects (at both the 5 and 10% levels). The corresponding regression (Table 3.5.9) suggests that the group totals are not significantly different from the target of 150 for the Tax-Subsidy contract for either inexperienced or experienced subjects with homogeneous or heterogeneous payoff functions. However, the group totals are significantly different from 150 for the Group Fine instrument for all but experienced subjects with homogeneous payoff functions (see Table 3.5.1).

Table 3.5.9
Regression on Group Total by Session, Full Sample

Variable	Coefficient	Standard Error	P-Value
Constant	188.97	60.63	0.007
Group Fine	61.49	85.75	0.484
Homogeneity	-4.01	85.75	0.963
Experience	-30.53	85.75	0.726
Group Fine* Homogeneity	42.77	121.27	0.729
Group Fine*Experience	138.07	121.27	0.272
Homogeneity* Experience	16.04	121.27	0.896
Group Fine* Homogeneity* Experience	96.67	171.5	0.581

Group $Total_s = \beta_1 + \beta_2 group\ fine_s + \beta_3 Homogeneity_s + \beta_4(group\ fine*Hom)_s + \beta_5(group\ fine*order)_s + \beta_6(Hom*order)_s + \beta_6(group\ fine*Hom*order)_s + \varepsilon_s$, where s indexes sessions.

Result 4: There are significant spillover effects from switching between contracts.

That the Group Fine and experience interaction term in the full sample Anova (Table 3.7.2) is significant suggests that subjects' experience with one instrument affected their decisions under the other. This can be clearly seen when the aggregate data are plotted Figure 3.8.6 for both the mean group totals (Panel A) and the efficiencies (Panel B). This spillover effect resulted in more bankruptcies when subjects were experienced (Table 3.5.10).

Table 3.5.10
Bankruptcies by Treatment

	No Experience		Experience	
Contract	Homogeneity	Heterogeneity	Homogeneity	Heterogeneity
Tax-Subsidy	1 [5]	0 [4]	1 [5]	2 [6]
Group Fine	0 [3]	0 [5]	2 [6]	0 [4]

Note: The numbers in square brackets are number of sessions.

This effect can also be observed in the distributions of individual decisions, Figure 3.8.7 for the large capacity subjects and Figure 3.8.8 for the small capacity subjects. Under the Group Fine contract there are many more observations below 50 for large type subjects and below 30 for small type subjects with experience than for subjects without experience (Figures 3.8.7 and 3.8.8). Similarly, for large capacity subjects under the Tax-Subsidy contract there are many more observations above 100 for subjects with experience but the effect is opposite for the small capacity subjects with many more observations at zero for those with experience (Figures 3.8.7 and 3.8.8). This suggests that the outcome subjects coordinate on under the first contract "spills over" into the second contract. This results in the increased likelihood of bankruptcy under the Tax-Subsidy contract and the group totals being lower under the Group Fine contract with experienced subjects.

Result 5: Small capacity subjects earn significantly more than large capacity subjects under the Tax-Subsidy contract

This result is shown in Table 3.5.11. Small capacity subjects earn on average 6.63 Canadian dollars (C$) more than large capacity subjects for inexperienced groups under the Tax-Subsidy contract, C$ 6.14 more for experienced groups under the Tax-Subsidy contract, C$ 0.71 more for inexperienced groups under the Group Fine contract and C$ 4.12 more for experienced groups under the Group Fine contract. Table 3.7.3 presents the Anova for payoff on all of the 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.

Table 3.5.11
Mean Payoffs for Heterogeneous Treatments

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

Using regression analysis (Table 3.5.12), the difference between the small capacity subjects' and the large capacity subjects' payoff is significantly different for all but the inexperienced subjects under the Group Fine.

Table 3.5.12

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	2.2	0.364
Group Fine*Experience	-5.78	2.2	0.011
Large Capacity* Experience	-0.49	2.2	0.821
Group Fine* Large Capacity* Experience	3.9	3.12	0.215

$\text{Payoff}_s = \beta_1 + \beta_2\text{group fine}_s + \beta_3\text{Homogeneity}_s + \beta_4(\text{group fine*Hom})_s + \beta_5(\text{group fine*order})_s + \beta_6(\text{Hom*order})_s + \beta_6(\text{group fine*Hom*order})_s + \varepsilon_s$, where s indexes individual.

Table 3.5.12 provides some explanation for this observation. Notice that small capacity subjects choose decision numbers significantly higher than the socially optimal level and large capacity subjects choose decision numbers significantly below this level. Since all of the subjects in the group receive the same group payoff, the small capacity subjects earn more than the large capacity subjects on average.

Table 3.5.13
Mean Individual Decision Numbers for Heterogeneous Treatments

Contract	No Experience			Experience		
	Large	Med.	Small	Large	Med.	Small
Tax-Subsidy	35 (3.75) [3]	26 (1.28) [3]	22^{C} (3.83) [3]	42 (11.65) [3]	31^{A} (0.67) [3]	20 (11.14) [3]
Group Fine	109 (4.51) [3]	60 (17.62) [3]	61^{D} (1.75) [3]	62 (18.47) [3]	42 (17.10) [3]	34 (10.68) [3]

Notes: The number in parenthesis are standard errors from the data and the numbers in square brackets are numbers of observations. The superscript capital letter represents that the mean is significantly different from the Nash outcome. A represents a significant difference from 25, B a significant difference from 125, C a significant difference from 0 and D a significant difference from 75

Nash equilibrium does a good job in predicting the aggregate decision numbers. Table 3.5.13 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 maximum decision number (or an equal reduction from their maximum decision number) small capacity subjects will choose 19 and large capacity subjects will choose 31, and if they decide that all subjects should choose the same decision number they will choose 25. However, there does not seem to be any significant coordination on any of these outcomes Figures 3.8.7 and 3.8.8.

It seems as if the large capacity subjects are reducing their decision numbers to offset or avoid the fines which must be paid due to the high decision numbers chosen by the small capacity subjects, even though this results in lower payoffs themselves and higher payments for those subjects who are choosing higher than Nash decision numbers. By reducing their decision numbers 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 decision number. The debriefing surveys which were conducted after each session, and which asked the subjects to describe how they chose their decision numbers, suggest that large capacity subjects were behaving in their own self-interest rather than altruistically.

3.6 Conclusions

Exogenous targeting instruments which theoretically induce the socially optimal outcome as a dominant strategy Nash equilibrium, are able to enforce a standard even when the environment is structured so that the Nash equilibrium differs from simple heuristic solutions. However, this study has only examined heterogeneity in individual endowment. Chan et al. (1999) shows that results may differ when agents differ in both endowment and preference. Their results suggest that the results observed in this paper (the large capacity subjects reducing the bulk of the emissions) could be reversed by giving the small capacity subjects stronger preferences for reduced emissions.

There are significant spillover effects in performance under one contract from experience with the other contract. Subjects coordinate on the non-compliance strategy under the Group Fine contract and then they continue to play this strategy under the Tax-Subsidy contract. This results in bankruptcies for the subjects who are in compliance with the target. However, greater levels of compliance with the target are observed under the Group Fine contract after subjects have had experience with the Tax-Subsidy contract, although, the Tax-Subsidy is still better able to induce groups to choose the target outcome.

Possibly more important is the observation that large capacity subjects are responsible for reducing significantly more of the externality than the small capacity subjects. This is similar to the result found by Chan et al. (1996). In a public good environment with heterogeneous subjects, rich subjects "tend to under-contribute and the poor tend to over-contribute." Chan et al. (1997) suggest that this observation is consistent with "equity theory" (Walster 1978). Chapter 4 provides further investigation to see whether this behaviour is consistent with this equity hypothesis, other hypotheses such as decision error and altruism or warm-glow as suggested by Palfrey and Prisbey (1997) and Anderson, Goerre and Holt (1998).

3.7 Supplemental Tables

Table 3.7.1
Efficiencies for Homogeneous and Heterogeneous Treatments (in percent)

Contract	No Experience			Experience			Overall
	Hom	Het	Overall	Hom	Het	Overall	
Tax-Subsidy	96.3	85.1	90.7	89.1	76.3	82.7	86.7
	(1.09)	(4.88)	(3.36)	(5.40)	(6.89)	(4.85)	(3.06)
	[3]	[3]	[6]	[3]	[3]	[6]	[12]
Group Fine	53.5	22.2	37.8	74.8	63.9	69.4	53.6
	(22.46)	(3.63)	(12.34)	(21.67)	(17.78)	(12.77)	(9.71)
	[3]	[3]	[6]	[3]	[3]	[6]	[12]
Overall	74.9	53.7	64.3	82.0	70.1	76.0	70.2
	(13.89)	(14.31)	(10.04)	(10.48)	(8.96)	(6.81)	(6.06)
	[6]	[6]	[12]	[6]	[6]	[12]	[24]

Notes: The numbers in parenthesis are standard errors from the data the and the numbers in square brackets are numbers of observations.

Table 3.7.2

Anova on Group Total, by Session, Full Sample

Number of Observations: 24 R-squared: 0.6335

Root MSE: 105.02 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		

Table 3.7.3

Anova on Payoff, Full Sample by Individual

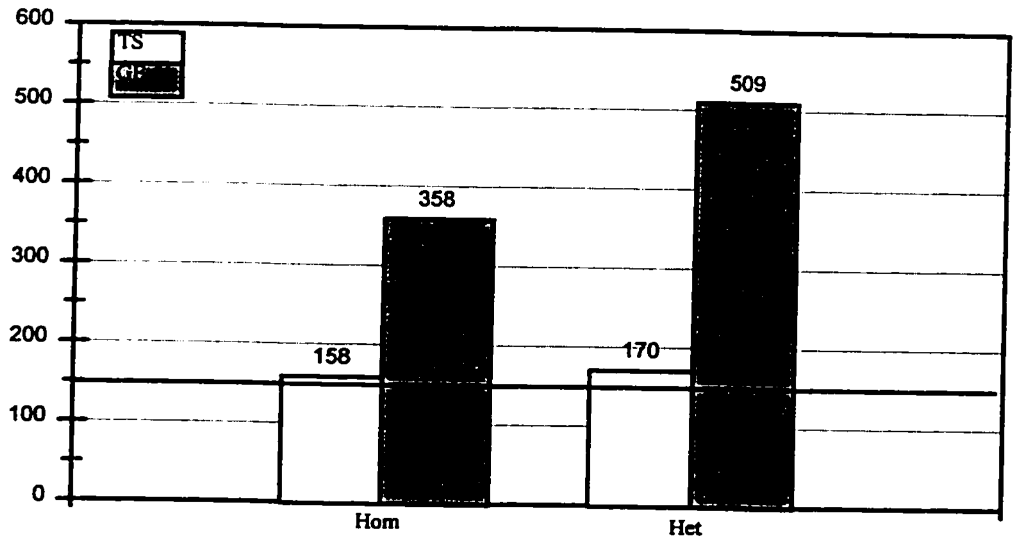
Number of observations: 72 R-squared: 0.5010

Root MSE: 3.31 Adj R-squared: 0.4464

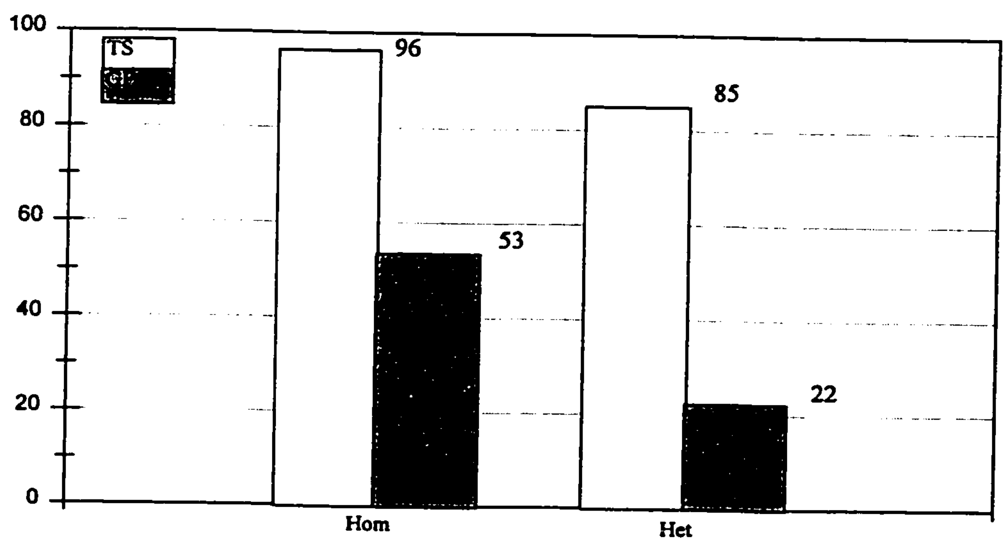
Source	Partial SS	df	MS	F	Prob > F
Model	702.06	3	100.29	9.18	0
Group Fine	170.06	1	170.06	15.56	0.0002
Large Capacity	348.17	1	348.17	31.87	0
Experience	20.4	1	20.4	1.87	0.1766
Group Fine * Large Cap.	70.69	1	70.69	6.47	0.0134
Group Fine * Experience	66	1	66	6.04	0.0167
Large Cap.* Experience	9.61	1	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		

3.8 Supplemental Figures

Figure 3.8.1: Aggregate Data, Homogeneity versus Heterogeneity

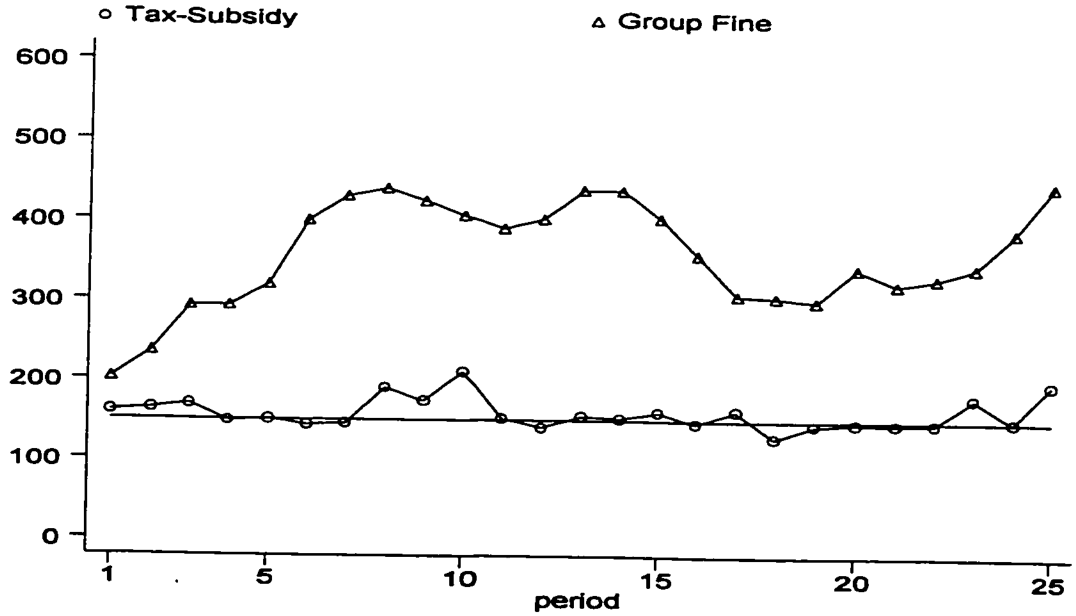


Panel A: Mean Group Total

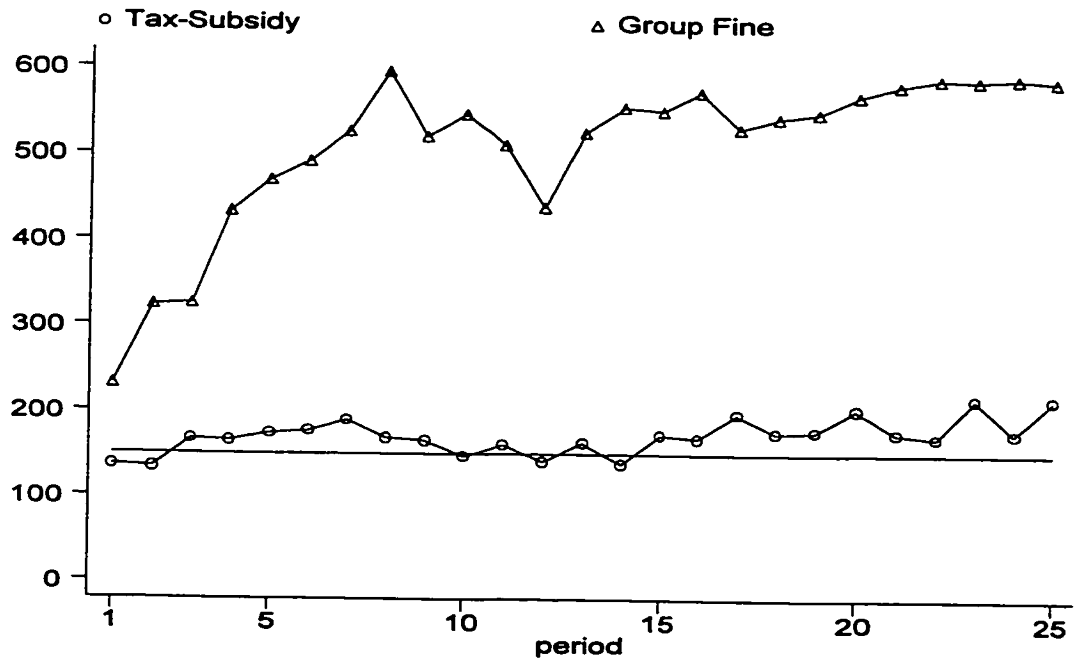


Panel B: Efficiency

Figure 3.8.2: Mean Group Totals by Treatment Cell

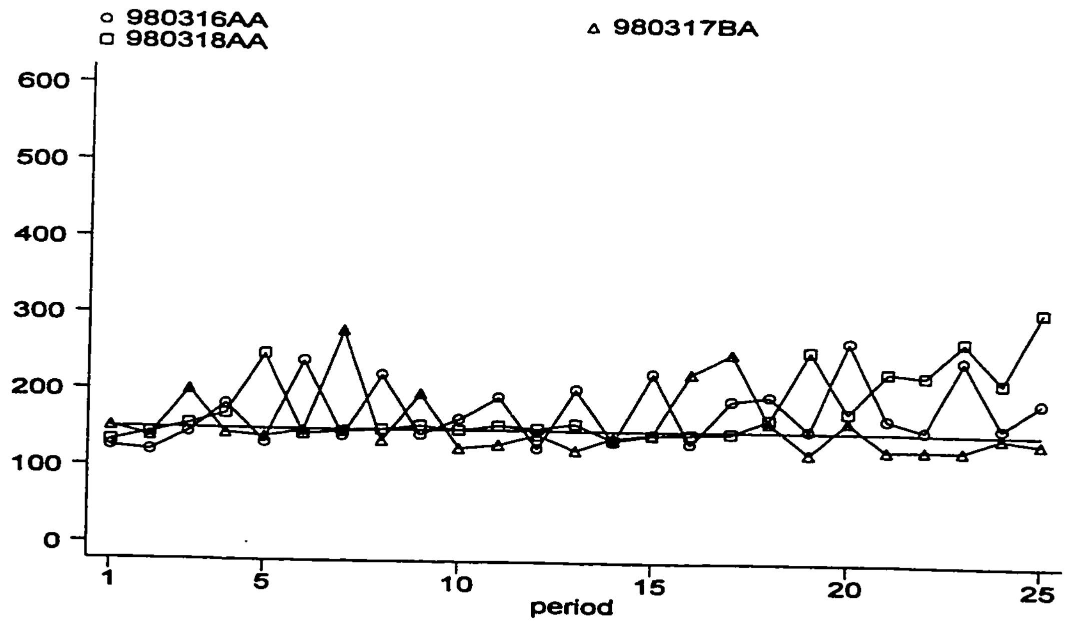


Panel A: Homogeneous, Inexperienced Subjects

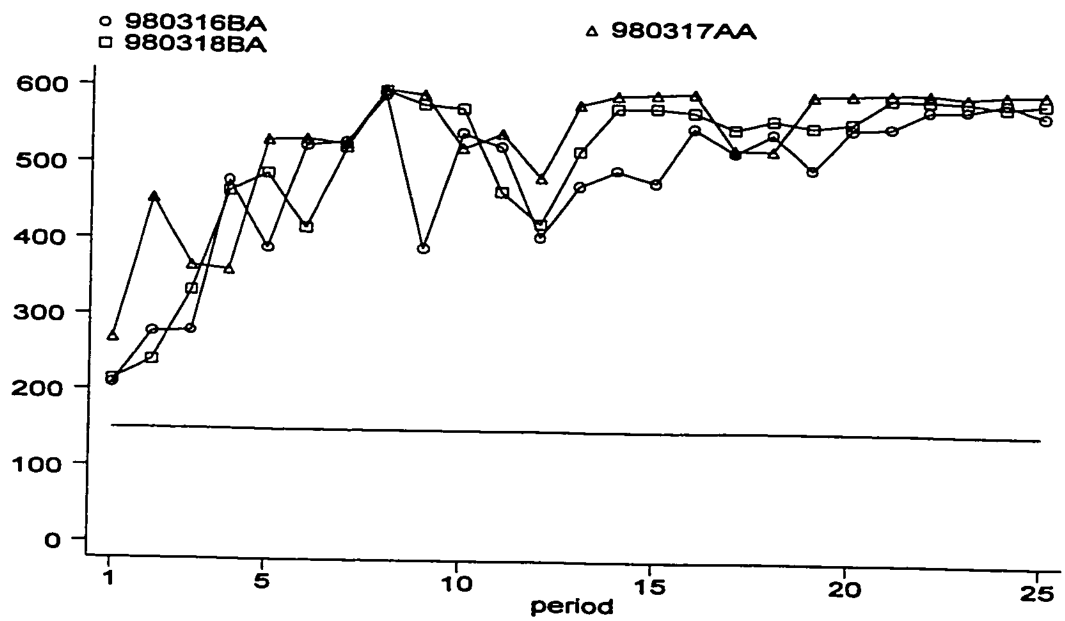


Panel B: Heterogeneous, Inexperienced Subjects

Figure 3.8.3: Group Totals by Period and Session, Heterogeneous, Inexperienced Subjects

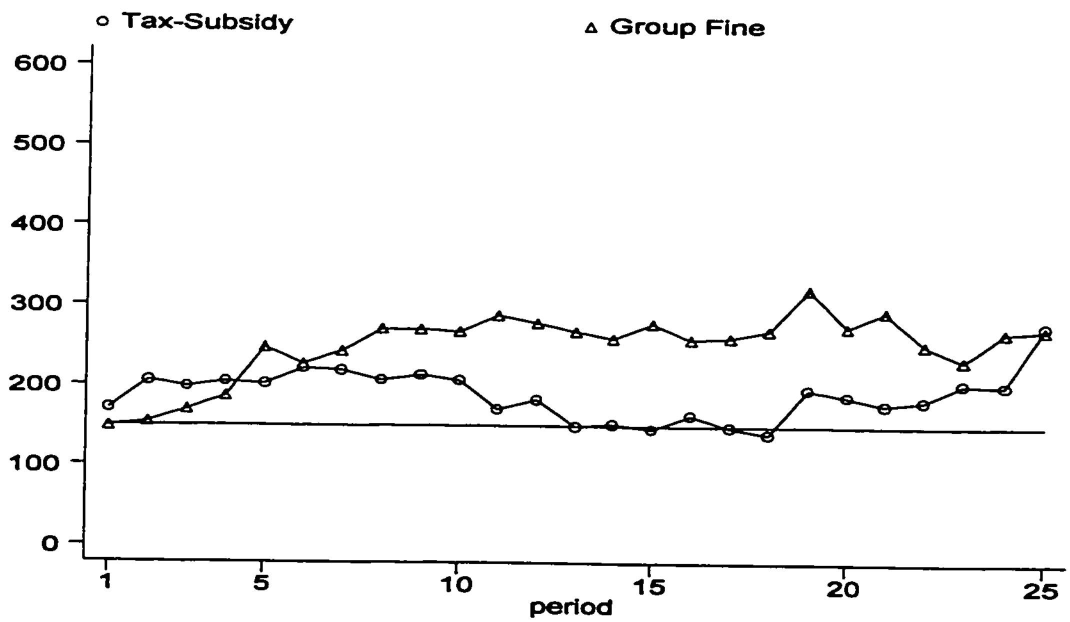


Panel A: Tax-Subsidy Instrument

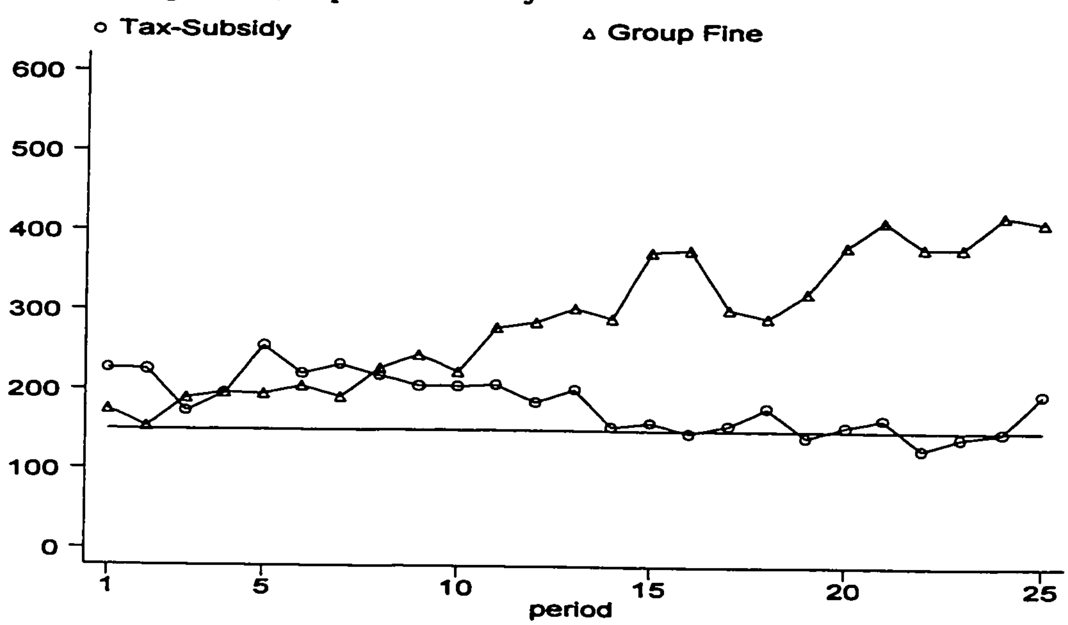


Panel B: Group Fine Instrument

Figure 3.8.4: Mean Group totals by Treatment Cell

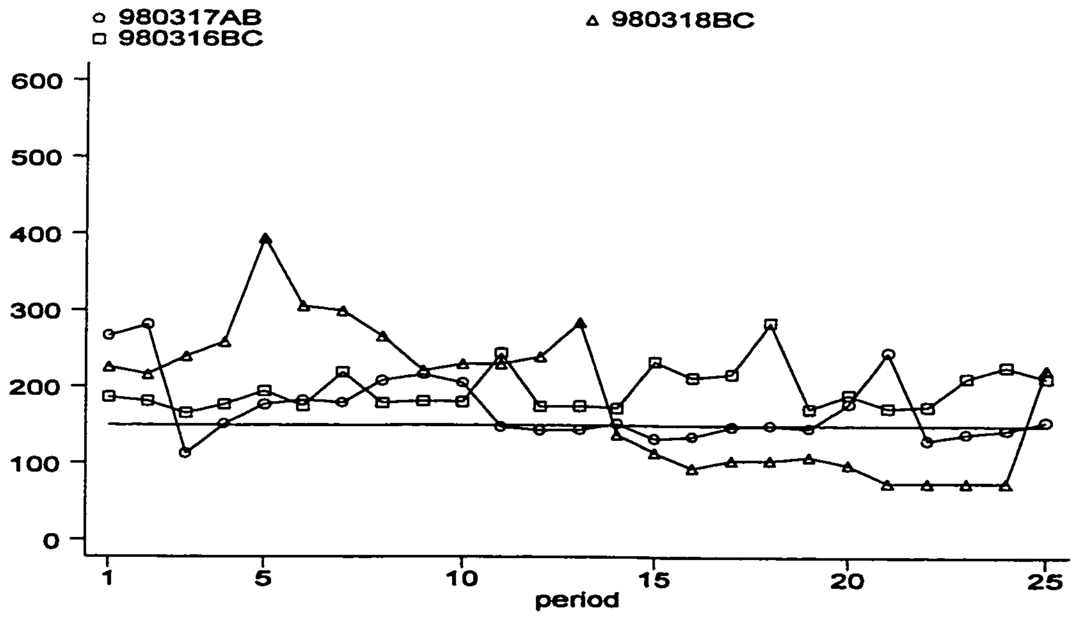


Panel A: Homogeneous, Experienced Subjects

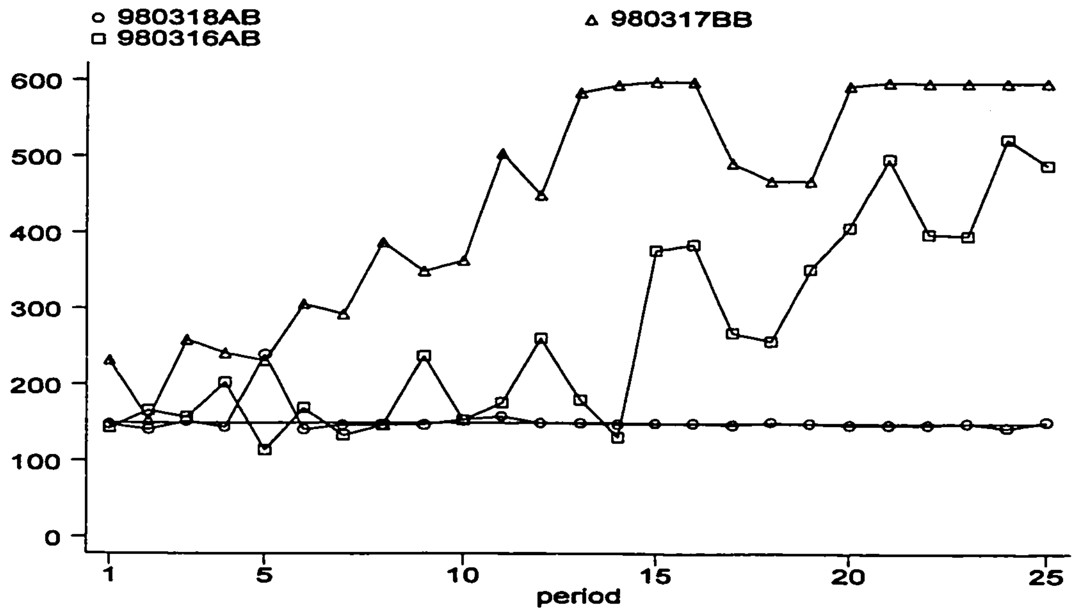


Panel B: Heterogeneous, Experienced Subjects

Figure 3.8.5: Group Totals by Period and Session, Heterogeneous, Experienced Subjects

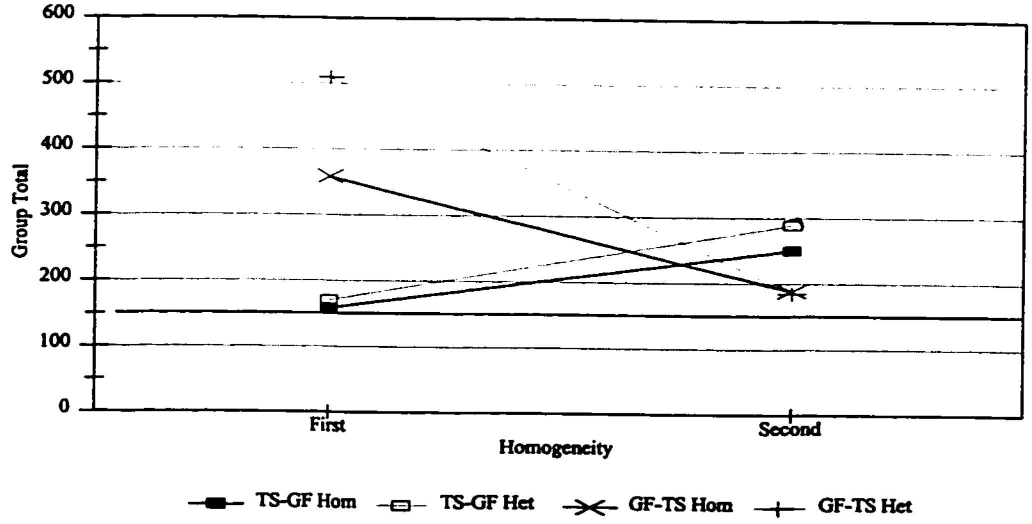


Panel A: Tax-Subsidy Instrument

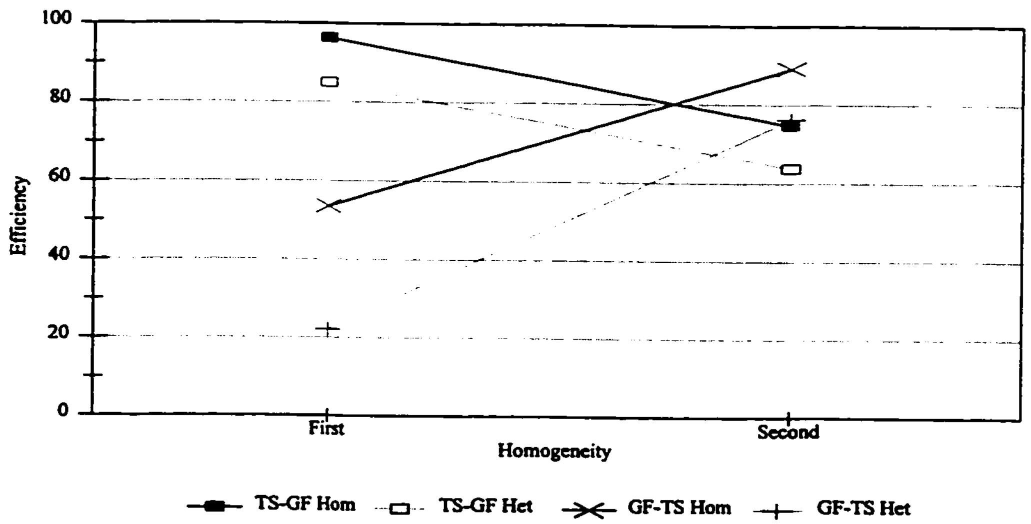


Panel B: Group Fine Instrument

Figure 3.8.6: Aggregate Data, Order Effects, Homogeneity versus Heterogeneity



Panel A: Mean Group Total



Panel B: Efficiency

Figure 3.8.7: Distributions of Individual Decisions, Large Type Subjects, Periods 11-20

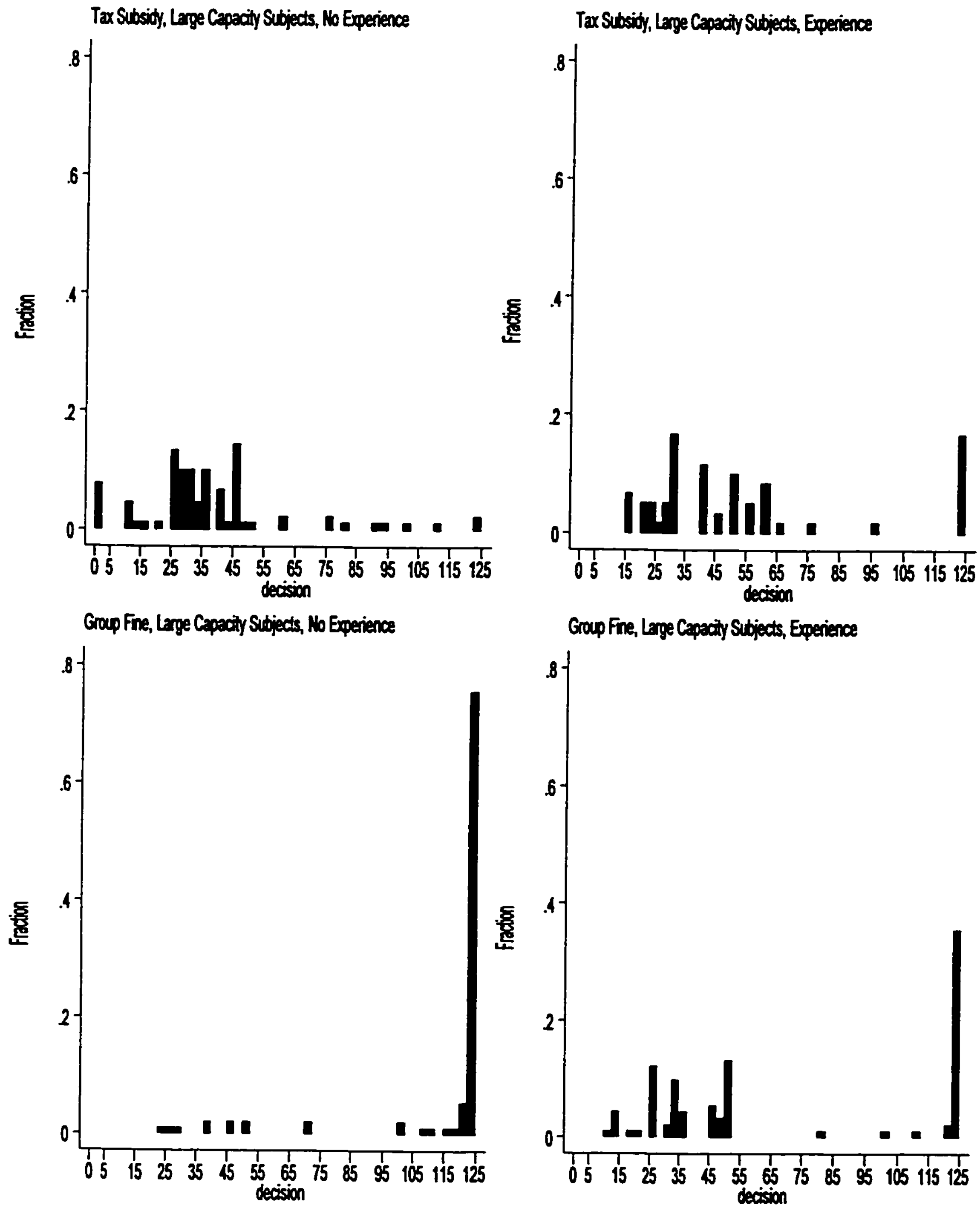
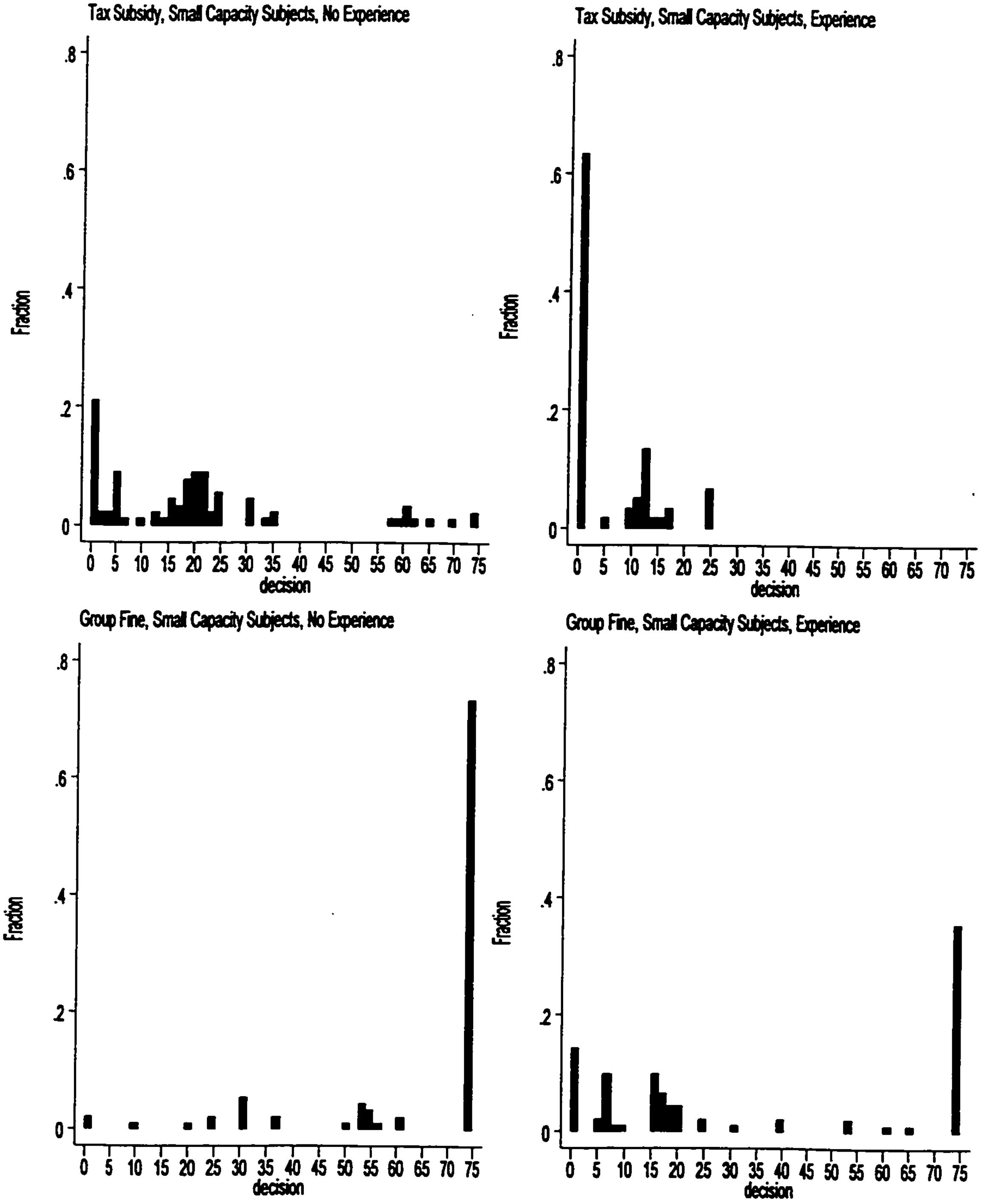


Figure 3.8.8: Distributions of Individual Decisions, Small Type Subjects, Periods 11-20



Chapter 4

Individual Decision Making

4.1 Introduction

Exogenous targeting instruments are able to mitigate the problem of moral hazard in groups in a controlled laboratory environment (Chapters 2 and 3). However, these instruments are not able to induce individual agents to choose the socially optimal outcome even when it is a dominant strategy to do so. Ledyard (1995) discusses a similar anomaly observed in public good games.[1] In the public good environment, with linear payoff functions, the payoff maximizing dominant strategy is either contributing everything or not contributing anything, but partial contributions are consistently observed. Ledyard suggests that subjects can be classified into those whose decisions can be explained by either payoff or alternate preference maximization and decision error and those whose decisions cannot be explained at all. This chapter investigates the ability of these explanations to characterize the deviations from dominant strategy Nash equilibria observed in the Moral Hazard in Groups experiment discussed in the previous chapters.

Preference explanations for partial contribution refers to deliberate choices of individuals which are not consistent with payoff maximization. The primary

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[1]Ledyard (1995) points out the similarity between the public good environments and other environments such as the moral hazard in groups environment presented here (pg. 118-119).

preference explanations for partial contributions in public good games are altruism and warm-glow (Palfrey and Prisbrey 1997, Anderson et al. 1998). Palfrey and Prisbrey define altruism as a preference for increasing the group payoff and warm-glow as a preference for the contributing to the public good. A third preference-based explanation for partial contributions is suggested by authors such as Hackett, Schlager, and Walker (1994) and Chan et al. (1997) who suggest that preferences for equity might also play a role when subjects have heterogeneous payoff functions or endowments.

Decision error refers to stochastic errors in individuals' decisions. Many authors have also been interested in estimating the importance of decision-making errors. Authors such as Anderson, Goeree, and Holt (1998) and Offerman et al. (1998) apply the quantal response model proposed by McKelvey and Palfrey (1995) to the public good environment. This model defines an equilibrium on the assumption that individuals make errors and that they assume that others make errors as well. Palfrey and Prisbrey account for these errors by estimating a probit model in their experiment where individuals make binary choices. Similarly, Chan et al. (1994) use a Tobit model to account for the errors observed in their public goods experiments. In this paper both the quantal response model used by Anderson et al. (1998) and the Tobit model used by Chan et al. (1994) are used to account for decision error. It is shown that the only difference between these models is that the Tobit model allows for the data to be censored while the quantal response model assumes that the data are drawn from a truncated distribution. Theoretically, the experimental environment is more consistent with a censored model as it allows for the possibility that subjects might like to choose numbers which are outside of the decision space which the truncated model does not.

In the standard public good environment it is difficult to identify whether the partial contributions are due to incompletely controlled preferences or decision error. When the dominant-strategy Nash equilibrium is on a boundary (as it is in the standard linear public good environment) both preference and decision error hypotheses predict the same behaviour. To discriminate between these two explanations, the parameters of the experiment must be varied (Palfrey and Prisbrey 1997). Palfrey and Prisbrey use the simple linear public good environment and vary the parameters faced by each subject in each period. Anderson et al. use the variation of parameters across different experiments to identify the effects of the different hypotheses. Both papers find that both preference explanations (altruism or warm-glow) and decision error are important in how subjects make their decisions.

Other authors have complicated the simple public good environment by introducing payoff functions which are either quadratic or have some other functional form, so that partial contribution is the payoff maximizing dominant strategy (Keser 1996, Sefton and Steinberg 1996, and Chan et al. 1996). This allows different effects of errors and preferences to be identified because errors should result in a distribution of decisions which is symmetric about the payoff maximizing dominant strategy Nash equilibrium while preferences should result in the distribution subjects' contributions being skewed away from the payoff maximizing decision. Keser's (1996) paper provides evidence for the quantal response model as implemented by Anderson et al. (1998). Sefton and Steinberg (1996) compare an environment with a dominant strategy Nash equilibrium with an environment which has multiple Nash equilibria. Both of these studies suggest that both altruism and decision error are important in how subjects make their decisions.

Chan et al. (1997) not only employ a nonlinear public good environment but also vary the payoff parameters between the subjects within a session to identify the different explanations for non-payoff maximizing behaviour. They show that the results from their public good experiments are consistent with the predictions of a model of equity from the psychology literature suggested by Walster et al. (1978). Chan et al. observe that poor individuals tend to over-contribute to the public good, while rich individuals tend to under-contribute. They hypothesize that poor individuals tend to over-contribute because they feel guilty that their contributions are lower than the rich subjects, while rich subjects tend to under-contribute because they feel spiteful that their contributions are higher than the poor individuals.

This paper uses variation between subjects' payoff functions , as in Chan et al. (1997), to investigate the ability of the warm-glow or altruism model and the equity model to explain why individual decisions differ from the dominant strategy Nash equilibria in an experimental investigation of exogenous targeting instruments.

Further, these preference-based explanations of individual decision making are augmented with decision error models used by Anderson et al. (1998) and Chan et al. (1994). This paper also presents the results from a convergence model suggested by Noussair et al. (1995). This convergence model hypothesizes that individual decisions adjust from an initial value towards some final value. This allows us to determine if individual decisions are converging towards the dominant strategy through time.

Section two of this paper presents the model which underlies the experiment and the predictions if subjects are payoff maximizers, altruists, or have preferences for equity (Walster et al. 1978). Also, in section two the logit quantal response and Tobit models are presented. Section three summarizes the predictions of these models of preferences and decision error. Section four discusses the consistency of the individual level data from the experiments with the predictions of the preference models and the preference models augmented by the decision error models. Finally, section five summarizes and concludes the chapter.

4.2 The Moral Hazard in Groups Experiment

Both the model and experimental design are discussed in Chapters 2 and 3. For the purposes of this chapter, I will only discuss the treatment which induces the socially optimal outcome as a dominant strategy Nash equilibrium. Each experimental session involved one group of six subjects indexed n=1...6. Each subject made twenty-five decisions for each of two treatments in each session.

Subjects had full information. They knew that there were six people in their group. They also knew the payoff information of all of the subjects in their group and that they would be participating in two twenty-five period decision rounds. This chapter uses data from the Tax-Subsidy periods which came first (i.e., the effects of experience with a different treatment on an individual's decisions are not addressed). The subjects were told that their total payoff was the sum of a private payoff and a group payoff. Subjects were randomly assigned a capacity which determined their private payoff for each possible decision number.[2] For the homogeneous treatments all subjects are of the same capacity, whereas for the heterogeneous treatments there are two capacities.

The subject's capacity determined the range of decision numbers they could choose. The subjects in the homogeneous treatments choose decision numbers between 0 and 100, while the subjects in the heterogeneous treatments choose decision numbers between either 0 and 75 or 0 and 125. The subjects in the homogeneous treatments are referred to as medium capacity subjects, and the subjects in the heterogeneous study are referred to as small capacity if their decision number was between 0 and 75 or large capacity subjects if their choice was between 0 and 125. All subjects were provided with a table indicating their private payoff for each possible decision number. Subjects in the heterogeneous treatments were also

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[2]When subjects arrived for the experiment they chose a numbered card from a pile. The number determined their capacity.

provided with a table indicating the private payoff to a subject of the other capacity for each of their possible decision numbers. The private payoffs were calculated from a payoff function which is quadratic in the difference between the decision number (x_n) and the maximum decision number (x_n^{max}):

$$B_n(x_n) = 25 - 0.002(x_n^{max} - x_n)^2 \tag{4.2.1}$$

Notice that this function is maximized when $x_n = x_n^{max}$. Therefore, it is in the subject's individual best interest to choose the maximum decision number in an unregulated environment. In the homogeneous treatments subjects were informed that they all had the same payoff functions, while in the heterogeneous treatments subjects were told that three of the people in their group choose decision numbers between 0 and 75 and three choose decision numbers between 0 and 125.

Subjects were informed that the group payoff, which depended on the sum of their own decision numbers and the decision numbers of everyone else in their group, was the same for everyone in their group. The sum of the decision numbers chosen by everyone in a group was referred to as the group total. The subjects were also informed that the maximum possible group total was 600.[3] The group payoff was described to the subjects as a positive value equal to 30 percent of the difference between 150 and the group total if the group total was less than or equal to 150 and a negative value equal to 30 percent of the difference between 150 and the group total

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[3] The maximum possible decision number is 600, 6×100 in the homogeneous treatments and $3\times75 + 3\times125$ in the heterogeneous treatments.

if the group total was greater than 150. The group payoff was also presented formally as

$$\text{Group Payoff} = \begin{cases} 0.3(\ 150 - \text{Group Total}\ ) & \text{If GT} > 150 \\ 0.3(\ 150 - \text{Group Total}\ ) & \text{if GT} \leq 150.^{4} \end{cases} \qquad (4.2.2)$$

It was pointed out that the higher the group total, the lower the group payoff. This treatment is referred to as the Tax-Subsidy instrument in Chapters 2 and 3.

An individual's total payoff function is given by the sum of the private payoff function ($B_n(x_n)$) and the group payoff function:

$$\pi_n = 25 - 0.002(x_n^{max} - x_n)^2 + 0.3(150 - \textstyle\sum_{n=1}^{6} x_n) \qquad (4.2.3)$$

The following sections describe the Nash equilibrium predictions when subjects are maximizing only their monetary payoff, if they have preferences for altruism and warm-glow, if they have preferences for equity (Chan et al. 1997), or if they have preferences for altruism, warm-glow and equity. The final section describes the logit quantal response model (McKelvey and Palfrey 1995) applied to the aforementioned preference hypotheses which assume subjects maximize their monetary payoff, maximize utility augmented by altruism and warm-glow or utility augmented by a notion of equity.

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[4]This instrument was presented in this way for consistency with the other instruments. Also note that GT represents the group total.

4.2.1 Payoff Maximization

The Nash equilibrium for the stage game is trivial to calculate. A subject's best response is to choose a decision number which maximizes the payoff function (4.2.3). Note that this function is separable in the individual's decision (x_n) and the decisions of the other subjects. The first order condition for this maximization is

$$\frac{\partial \pi_n}{\partial x_n} = -0.004(x_n^{max} - x_n^{*}) - 0.3 = 0 \qquad (4.2.1.1)$$

which results in a dominant strategy for each subject given by $x_n^{*} = x_n^{max} - 75$. Thus, the Nash equilibrium decision numbers are 0, 25 and 50 for small, medium and large capacity subjects, respectively. For both the homogeneous and heterogeneous treatments, if all subjects choose the Nash equilibrium decision number, the group total will be equal to the target level of 150. Since this is the unique Nash equilibrium in the stage game it is also the unique subgame perfect equilibrium in the finitely repeated game (Osborne and Rubinstein 1994, pp. 157-158).

4.2.2 Altruism and Warm-Glow

People could contribute to a public good (when it is not in their financial interest) because they receive a non-monetary reward simply from contributing or from making others better off. The former is referred to as "warm-glow", the latter is referred to as altruism (Palfrey and Prisbrey 1997). If warm-glow is important, then the contribution is independent of the number of people it will benefit while if altruism is important then increasing the number of people who enjoy the public good should lead to higher contributions. In the present environment reducing one's decision number from the maximum makes the other people in the group better off in the same way as contributing to a public good. As a result, following Palfrey and Prisbrey (1997), altruism and warm-glow can be modelled by assuming that individuals maximize utility, which depends on their own payoff, the payoffs to other individuals (altruism), and from reducing their decision number from the maximum (warm-glow). Therefore,

$$U_n = \pi_n + g_n(x_n^{\max} - x_n) + \alpha_n \sum_{j \neq n}^{6} \pi_j \qquad \text{or}$$

$$U_n = 25 - 0.002(x_n^{\max} - x_n)^2 - 0.3(X^e - 150) + g_n(x_n^{\max} - x_n)$$
$$+ \alpha_n \sum_{j \neq n}^{6} (25 - 0.002(x_j^{\max} - x_j)^2 - 0.3(X^e - 150)) \qquad (4.2.2.1)$$

where α_n is an altruism parameter and g_n represents warm-glow, and X^e is subject n's expectation of the group total.[5] The altruism hypothesis implies that $\alpha_n > 0$ and the warm-glow hypothesis implies that $g_n > 0$. Maximizing this function with respect to x_n results in the first order condition

$$\frac{\partial U_n}{\partial x_n} = 0.004(x_n^{\max} - x_n) - 0.3 - g_n - 0.3(5)\alpha_n = 0 \qquad (4.2.2.2)$$

which implies that the dominant strategy Nash decision number is given by

$$x_n^* = x_n^{\max} - \frac{0.3(1 + 5\alpha_n) + g_n}{0.004} \qquad (4.2.2.3)$$

and consequently $g_n + 1.5\alpha_n = 0.004(x_n^{\max} - x_n) - 0.3$ if player n chooses her dominant strategy. Notice that altruism and warm-glow cannot be identified

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[5] The altruism and warm-glow parameters do not need to enter the utility function linearly but are modelled in this way for simplicity.

separately as only the parameter x_n^{max} is varied. However, they can be identified jointly. If there is no altruism or warm-glow effect ($\alpha_n = g_n = 0$) the Nash equilibrium predicted by this model is the same as the payoff maximization outcome. Note that $\partial x^*/\partial\alpha_n<0$ and

$\partial x^*/\partial g_n<0$ so that the predicted decision number falls as either altruism or warm-glow increases. Thus the warm-glow and altruism models yield the same qualitative predictions. I will refer to this model which encompasses both altruism and warm-glow as the altruism model. Palfrey and Prisbrey (1997) and Anderson et al. (1998) are able to identify altruism and the warm-glow separately, but find conflicting results. However, Anderson et al. assert that in both cases the effects of altruism or warm-glow are small and that the differences between the studies are minor (p. 310). As a result I will assume that the warm-glow parameter is equal to zero and estimate the altruism parameter as

$$\alpha_n = 1-0.004(x_n^{max}-x_n)/0.3\,. \tag{4.2.2.4}$$

Notice that the joint hypothesis that subjects play their dominant strategy on average and that warm-glow or altruism exists can be rejected if on average subjects of one capacity choose numbers which exceed the payoff maximizing ($\alpha_n = g_n = 0$) Nash prediction and those of the other capacity choose numbers below the payoff maximizing Nash prediction. Moreover, the hypotheses of warm-glow or altruism can be rejected if subjects on average choose decisions which are significantly above their payoff maximizing dominant strategy, as both warm-glow and altruism suggest that subjects will reduce their decision number below the optimal.

4.2.3 Simple Heuristics based on Equity

There are many different ideas of equity which subjects might use to choose their decision numbers in this moral hazard in groups environment if they are concerned with the group total being equal to the target of 150. They might feel that they should all choose the same decision number, or the same proportion of their maximum decision number, or reduce their decision number from the maximum by the same amount, or reduce their maximum decision number by the same proportion. For the homogeneous treatments, all of these equitable solutions result in the subjects choosing the decision number of the payoff maximization model. This is the Nash equilibrium prediction. For the heterogeneous treatments, the Nash equilibrium prediction of the payoff maximization model is an equal reduction from the maximum decision number. If subjects choose the same decision number, they would all choose 25. If they reduce their decision number by the same proportion or choose the same proportion of their decision number, the small capacity subjects would choose 19 and the large capacity subjects would choose 31. I refer to all subjects choosing 25 as the simple heuristic solution as it can be arrived at by dividing the target (150) by the number of people in the group.

Chan et al. (1997), appealing to a book by Walster et al. (1978), formalize the idea that subjects might use simple heuristics based on equity theory to make their decisions. They hypothesize that subjects who contribute more than the average contribution feel spite towards those who contribute less, and those who contribute less than the average amount feel guilt. They model this phenomenon by including a term which depends on the difference between the subject's proportional contribution and the proportional contribution of the group ($d_n = \frac{x_n}{x_n^{\max}} - \frac{\sum_n^6 x_n}{\sum_n^6 x_n^{\max}}$). This term could also be modelled as depending on the difference between the subjects actual appropriation and the average appropriation ($d_n = x_n - \frac{\sum_n^6 x_n}{N}$). Thus, the utility function for a subject whose preference included equity considerations could be modelled as $U_n = \pi_n - e_n|d_n|$, where e_n is the equity parameter and $|d_n|$ is the absolute value of the difference between the subject contributions and the average contribution. The dominant strategy decision in this case is

$$x_n^E = x_n^* - \left(\frac{e_n}{0.004}\right)\left(\frac{N-1}{N}\right) \times sgn(d_i) \tag{4.2.3.1}$$

where $sgn(d_i)$ refers to the sign of d_i and accounts for the absolute value. Clearly, for as e_n approaches zero x_n^E approaches x_n^*. Thus, small capacity subjects contribute close to zero and large capacity subjects contribute close to 50. Further, it must be the case that the average contribution is greater than the contribution of a small capacity subject and less than the contribution of a large capacity subject on average. This implies that $d_k<0$ for small capacity subjects and $d_j>0$ for large capacity subjects. Consequently, this model predicts that $x_n^E > x_n^*$ for small capacity subjects and $x_n^E < x_n^*$ for large capacity subjects. This result suggests that the large capacity subjects will choose numbers that are lower than the Nash equilibrium prediction of the payoff maximization model and the small capacity subjects will choose numbers that are higher than the Nash equilibrium prediction of the payoff maximization model. These outcomes are dominant strategy outcomes.[6] Notice that this argument is independent of whether the proportional or average definition of d_n is used. As a result, the average definition of d_n will be used in the following sections.

4.2.4 An Overall Model of Preferences

Clearly subjects might have preferences for altruism, warm-glow, and equity. A utility function which encompasses all of these concerns could be written as follows assuming that these different preferences enter linearly:

$$U_n = \pi_n + g_n(x_n^{\max} - x_n) + \alpha_n \sum_{j \neq n}^{N} \pi_j - e_n \left| x_n - \frac{\sum_i^N x_i}{N} \right|. \qquad (4.2.4.1)$$

Under the assumption that subjects choose x_n to maximize U_n, the utility maximizing decision is given by $\frac{\partial U_n}{\partial x_n} = 0$, which implies the preference maximizing decision number is given by

$$x_j^p = x_j^{\max} - \frac{0.3(1 + \alpha_j(N-1)) + g_j + e_j(\frac{N-1}{N})}{0.004} \qquad (4.2.4.2)$$

where subject j's decision is greater than the average or

$$x_k^p = x_k^{\max} - \frac{0.3(1 + \alpha_k(N-1)) + g_k - e_k(\frac{N-1}{N})}{0.004} \qquad (4.2.4.3)$$

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[6]See the Mathematical Appendix section C.3.1 for details.

if subject k's decision is less than average. Notice that if subjects n's decision is equal to the average decision $d_n = 0$ and

$$x_n^p = x_n^{\max} - \frac{0.3(1 + \alpha_n(N-1)) + g_n}{0.004}. \qquad (4.2.4.4)$$

The preference for equity has the same effect on the preference maximizing decision as altruism and warm-glow when the subject's decision is greater than average, the opposite effect when the subject's decision is less than average, and no effect if the subject's decision is equal to the average decision. Notice that this is still a dominant strategy and although we cannot identify altruism or warm-glow, we can identify an average equity parameter (e) since it has different effects for large and small capacity subjects. The appendix section C.4 shows that

$$e = -1/2(\frac{N}{N-1})(0.004)[(x_j^p - x_k^p) - (x_j^{\max} - x_k^{\max})] \qquad (4.2.4.5)$$

where j and k represent a large capacity subject and a small capacity subject, respectively. Thus, the equity parameter can be estimated from the difference between the observed appropriation and the difference in capacity. Table 4.2.4.1 summarizes the predictions of payoff maximization, altruism and equity.

Table 4.2.4.1
Predictions of Payoff Maximization, Altruism and Equity

Treatment	Payoff Maximization	Altruism	Equity
Large Capacity	50	<50	<50
Medium Capacity	25	<25	25
Small Capacity	0	0	>0

4.2.5 Logit Quantal Response Equilibrium

Anderson, Goeree, and Holt (1998) apply the McKelvey and Palfrey (1995) quantal response equilibrium to threshold public good games. This theory is based on the assumption that subjects make mistakes or are uncertain with respect to their utility. Further, subjects are assumed to make their decisions under the belief that others also make mistakes or are uncertain about their utility from a given strategy. The probability of a strategy being chosen is modelled as depending on the expected payoff of the strategy. Strategies with higher expected payoffs are played with higher frequencies than strategies with lower expected payoffs. The distribution of individual decisions is modelled as the truncated logistic distribution

$$f_n(x_n) = K \exp(\pi_n^e(x_n)/\mu) \qquad (4.2.5.1)$$

where K is a constant chosen such that the density integrates to one and μ parameterizes the importance of individual errors. As the decision error parameter (μ) approaches zero, the quantal response equilibrium approaches the Nash equilibrium prediction of the payoff maximizing model and as μ approaches infinity, the quantal response model predicts random play. The expected payoff function is given by (4.2.3). Notice that this function is quadratic in the individual decision x_n, of the form $\pi_n = A + Bx_n + Cx_n^2$, where $A = 70 - 0.002(x_n^{max})^2 - 0.3\sum_{i\neq n} x_i$, $B = (0.004x_n^{max} - 0.3)$ and $C = 0.002$. It can be shown by completing the square that $\pi_n = D - 0.002(x_n - x_n^*)^2$, where $D = (A/C)-(B/2C)^2$ is a constant with respect to x_n, and x_n^*

is the payoff maximizing decision number from (4.2.1.1) or the preference maximizing decision number (4.2.4.2 through 4.2.4.4). Notice that since the expected payoff function is separable in the subject's decision and the decisions of the other subjects, the density is also separable in this way.

Under this model the distribution of individual decisions under the Tax-Subsidy instrument is given by

$$f_n(x_n) = K' \exp(-0.002(x_n - x^*)^2/\mu), \tag{4.2.5.2}$$

where x^*, the utility maximizing decision, is the peak of the distribution and K' is a constant which depends on the decisions of other subjects. Anderson et al. (1998) show that for expected payoff functions of this form, there is a unique quantal response equilibrium and that the expected contribution under this equilibrium is "sandwiched" between the equilibrium outcome without decision error and half of the endowment. This is a direct result of the assumption that more costly errors are less likely to be observed. As shown in Figure 4.7.1, the peak of the distribution is at the preference maximizing decision for medium capacity subjects. The distribution then falls to both sides of this peak. Figure 4.7.1 also shows the importance of the decision error parameter (μ). Notice that when μ=1 there is a very definite peak and as μ approaches infinity the distribution approaches a uniform distribution. As a result, this model's prediction depends on the decision error parameter as well as the subject's capacity, and the subject's preferences for altruism and equity.

Table 4.2.5.1
Predictions Models with Decision Error

Treatment	Payoff Maximization	Altruism	Equity
Large Capacity	50 - 62.5	0 - 62.5	25 - 62.5
Medium Capacity	25 - 50	0 - 50	25 - 50
Small Capacity	0 - 32.5	0 - 32.5	0 - 25

Table 4.2.5.1 summarizes the predictions of the quantal response decision error model for the three different preference hypotheses. For the medium capacity subjects, half of the endowment is 50. The payoff maximizing and equity preference maximizing decisions are 25 and the altruism preference maximizing decision is less than 25. Therefore, the decision error model predicts that the mean individual decision will lie between 25 and 50 if subjects maximize their payoff or if their preferences depend on equity, and between 0 and 50 if their preferences depend on altruism. For the large capacity subjects, half of the endowment is 62.5. The payoff maximization decision is 50, the altruism preference maximizing decision lies between 0 and 50, and equity preference maximizing decision lies between 25 and 50. Therefore, the decision error model predicts that the mean individual decision will lie between 50 and 62.5 if subjects maximized their payoff, and between 0 and 62.5 if subjects' utility functions depend on altruism and 25 and 62.5 if subjects'

utility functions depend on equity. For the small capacity subjects, half of the endowment is 37.5. The payoff maximization and altruism preference maximizing decisions are 0, and the equity preference maximizing decision is between 0 and 25. Therefore, the decision error model predicts that the mean individual decision will lie between 0 and 37.5 for all of the utility functions considered here.

Anderson et al.'s assumption that the distribution of individual decisions is truncated is not innocuous. Greene (1993) describes truncated data as data which is "drawn from a subset of a larger population of interest" (p. 682) as opposed to censored data where the actual observation may differ from the true observation. In terms of the experimental data presented here, truncation would best describe the data if the subjects were selected from a group of people who would never want to choose below zero or above their maximum (x_n^{max}). Alternatively, the data is best described by censoring if subjects who might like to choose numbers below zero or above their maximum (x_n^{max}) choose zero or their maximum (x_n^{max}) instead. This is at least partially an empirical question, and as a result, both a truncated and a censored distribution are fit to the data.

The censored distribution differs from the truncated distribution in that instead of normalizing all of the frequencies in the decision space, the density is estimated separately for observations at the lower bound, observations in the middle of the density, and observations at the upper bound. The distribution of decisions in this case is given by

$$g_n(x_n) = \begin{cases} \Phi(-x^*/\sqrt{\mu/2k}) & \text{if} \quad x_n = 0 \\ (\exp[-k(x_n - x^*)^2/\mu])/(\sqrt{2\pi}\sqrt{\mu/2k}) & \text{if} \quad 0 < x_n < x_n^{\max} \\ 1 - \Phi(x^{\max} - x^*/\sqrt{\mu/2k}) & \text{if} \quad x_n = x_n^{\max} \end{cases} \quad (4.5.2.3)$$

where Φ is the cumulative standard normal distribution. More information on the censored distribution is provided in Appendix C, section C.5.

4.3 Theoretical Predictions

The data for the mean decisions of small capacity subjects allows us to distinguish between the equity model and the payoff maximization and altruism models in the absence of decision error. For small capacity subjects, the equity model predicts that the equilibrium decision number will be above zero while the payoff maximization and altruism models predict that the equilibrium decision number will be zero. The data from the large capacity subjects are able to distinguish between the payoff maximization and the altruism and equity models. For the large capacity subjects payoff maximization predicts the equilibrium decision will be 50, and the altruism and equity models predict that it will be below 50. Because the subjects were assigned to capacity randomly, and there is no reason to believe that preferences will vary by capacity, these data can distinguish between the alternate preference hypotheses.

Allowing for decision error, these distinctions are eliminated for the mean of the decision numbers. However, the preference maximizing decision number from the quantal response model can be estimated. Thus, the different preference models can be distinguished by this estimation of the preference maximizing decision number in the same way that the mean of the subjects' decisions by capacity is able to distinguish between these hypotheses. If the preference maximizing decision number suggests that the sign of the altruism parameter varies by capacity, it contradicts the hypothesis that these preferences are important in how subjects make their decisions on average.

4.4 Results

This section discusses the results from the experiments, the estimation of the quantal response model with both truncated and censored distributions, and the estimation of the convergence model.

Individual decisions are not independent, either between individuals in the same session or for the same individual. Despite this, all of the estimation conducted in this section relies on the assumption that individual decisions are independent both between individuals and for the same individual. As a result, ordinary least squares results are consistent but inefficient, while the quantal response and tobit models are inconsistent and inefficient as they rely more strongly on the independence assumption. In both cases the models are estimated by maximizing the probability of observing the individual decisions. White's (1980) robust estimator has been used to account for the non-independence within sessions. This estimator uses the variance between the independent observations (in this case sessions) to calculate the standard errors (StataCorp 1999a).

Result 1: Point estimates of the key parameters are most consistent with the equity model.

Table 4.3.1 presents the observed mean, standard errors and number of observations by each capacity and the hypothesis with which the observed mean is most consistent. Notice for the medium capacity subjects, the mean is not statistically different from the payoff maximizing prediction and as such is unable to distinguish between these different hypotheses. For the large capacity subjects, the mean is significantly different from payoff maximizing prediction but is unable to distinguish between subjects having preferences for altruism or equity. However, the observed mean for the small capacity subjects is most consistent with the equity hypothesis. The altruism parameter can be calculated from the mean decision numbers using equation (4.2.2.4). The implied altruism parameter is 0.039 for large capacity subjects, -0.00376 for medium capacity subjects, and -0.0574 for small capacity subjects. This suggests that the large capacity subjects exhibit a significant degree of altruism, the medium capacity subject do not exhibit a significant degree of altruism and small capacity subjects exhibit a significant degree of negative altruism. As subjects were assigned to roles randomly, this observation is not consistent with the altruism hypothesis. Equation (4.2.4.5) gives an expression for the equity parameter which can be calculated from the mean decision number for the large capacity subjects (x_j^p = 35.29) and the mean decision number for the small capacity subjects (x_k^p = 21.53). These means suggest that the average equity parameter (e) is equal to -0.002(6/5)[(35.29-21.53) - (125-75)] = 0.0869 (from 4.2.4.5). That the equity hypothesis is consistent with the results from the large, medium and small capacity subjects while the other hypotheses are not suggests that the equity hypothesis is more consistent with the data than payoff maximization or altruism.

Table 4.3.1
Mean Decision Numbers by Capacity

Treatment	Observed Mean	Most Consistent Hypothesis (ignoring decision error)
Large Capacity	35.29 (1.57) 225	Altruism or Equity
Medium Capacity	26.41 (0.674) 450	Payoff Maximization or Equity
Small Capacity	21.53 (1.41) 225	Equity

* the numbers in parenthesis are standard errors and the last number in column two is the number of observations.

Result 2: **Estimation of the decision error models for the three different subject capacities suggests that the data are more consistent with a censored model than a truncated model.**

The parameters of the decision error model (the preference maximizing decision (x^*), and error parameter (μ)) can be estimated by maximum likelihood for both the truncated and censored distributions.[7] Table 4.3.2 shows the estimated parameters, mean of the estimated distribution, and the mean log-likelihood for each subject type and for the truncated and censored models.

Table 4.3.2
Predictions from Estimations with Decision Error Model

Treatment	Estimated μ	Estimated x^*	Mean Fitted Distribution	Mean Log-likelihood
Large Capacity, Observed Mean: 35.293				
Truncated	4.3010 (0.8884)	20.9528 (5.5683)	35.30	-3.53967 (225 obs)
Censored	2.3468 (0.1795)	35.1784 (1.4508)	35.97	-4.50947 (225 obs)
Medium Capacity, Observed Mean: 26.407				
Truncated	1.0688 (0.1029)	24.0232 (1.0167)	26.41	-4.03231 (450 obs)
Censored	0.8679 (0.0547)	26.2678 (0.6990)	26.49	-4.02168 (450 obs)
Small Capacity, Observed Mean: 21.529				
Truncated	4.1492 (0.5104)	0 (0)	24.54	-4.11492 (225 obs)
Censored	2.4907 (0.2725)	18.9855 (1.7105)	22.04	-3.94358 (225 obs)

* the numbers in parenthesis are standard errors.

For the large capacity subjects, the truncated model has a large error parameter

[7]See the mathematical appendix section C.5 for the derivation of the log likelihood functions. The estimations were conducted using all of the data (450 observations for the medium, and 250 for the large and small capacity subjects), using the maximum likelihood package in the Gauss computer language (see Appendix D, section D.1 for code & data).

(μ=4.3) and the estimated peak ($x^* = 20.95$) is very low, indicating a strong degree of altruism. This low value of the peak is inconsistent with the equity model as the equity model predicts the mean decision number will be above 25. The censored distribution has a much lower error parameter (μ=2.35) and the estimated peak ($x^* = 35.18$) is closer to the mean decision number (35.29). The means of both of these estimated distributions are not significantly different from the observed mean.

Figures 4.7.2 through 4.7.4 depict the actual data and the estimated distributions for the three subject capacities. Figure 4.7.2 shows the distributions for large capacity subjects. The density rises from 0.18 percent of observations at zero, 0.044 percent at 1 or 2, 0.058 percent between 3 and 15, 0.12 between 23 and 25, to a peek of 0.15 percent of observations between 28 and 30. It then falls off with 0.89 percent between 33 and 35, 0.67 between 38 and 40 and 0.089 at 46 and 47. For the small capacity subjects depicted in Figure 4.7.3 the highest peak is at zero, the distribution seems to fall off from there ie, 0.084 percent of observations are at 5 or 6, there is another peak of 0.10 at decisions between 19 and 21, and then the distribution falls off again with 0.089 percent at 24 or 25. Finally, in Figure 4.7.4, for the medium capacity subjects, notice that the highest peak is 0.25 percent of the distribution at 25 or 26, and it falls of on either side with approximately 0.1 percent at both 19 and 20 and 29 and 30.

For the small capacity subjects (Figure 4.7.3), the truncated model is only able to converge if the estimated peak is constrained at zero, however both parameters are able to be estimated from the censored distribution. This suggests that the data are more consistent with the censoring hypothesis. Figure 4.7.4 shows that both the truncated and the censored models are able to fit the data from the medium capacity subjects very closely (the predicted mean is very close to the observed mean). The error parameter is slightly smaller for the censored distribution and the estimated peak is closer to the observed mean. Notice that the error parameter (μ) is much higher and that the peak is further from the observed mean for the truncated distributions than the censored distributions. This also suggests that the censored model better describes the data.

Result 3: **The censored model is most consistent with the equity hypothesis.**

Notice that under the censored model, the estimated peak (x^*) is 35.2, 26.3 and 19.0 for the large, medium and small capacity subjects respectively (Table 4.3.2). These estimated peaks are very similar to the observed means and as a result are more consistent with the equity hypothesis than the altruism hypothesis as they suggest negative altruism for the small and medium capacity subjects.

Result 4: **In early periods, individual decisions are closer to the simple heuristic prediction (25) than they are to the payoff maximizing decisions. However, decisions approach the Nash level as the session progresses.**

Table 4.3.3 and Figure 4.7.5 show the average individual decision number by capacity in five period intervals. Notice that in the first five periods the average individual decision number is very close to 25 for all three groups and that in higher periods the large capacity subjects' decision number increases towards the Nash prediction, the small capacity subjects decision numbers fall (slightly) while the medium capacity subjects' decision numbers are fairly consistent.

Table 4.3.3
Average Decision Numbers by Capacity and Period Groups

Capacity	Periods					
	1 -5	6 - 10	11 - 15	16 - 20	21 - 25	Overall
Large Capacity	26.9 (2.93)	32.9 (3.07)	32.5 (3.03)	42.3 (4.16)	41.8 (3.81)	35.3 (1.57)
Medium Capacity	26.4 (1.62)	28.7 (1.61)	25.3 (1.37)	24.3 (1.40)	27.3 (1.51)	26.4 (0.674)
Small Capacity	24.8 (3.20)	23.5 (3.35)	19.1 (2.82)	19 (2.88)	21.3 (3.46)	21.5 (1.41)

This suggests that subjects make their initial decision using a simple heuristic (the target divided by the number of people in the group), and then the incentives induce the large capacity subjects to increase their decision numbers and the small capacity subject to reduce their decision numbers.

The significance of this result can be tested by regression analysis. Table 4.3.4 reports the results from Tobit regressions of all of the individual decisions under the Tax-Subsidy instrument with no experience or uncertainty. The mathematical appendix section C.5 shows that the Tobit model is identical to the censored decision error distribution discussed above. The standard errors are calculated using White's estimator to allow for heteroscedasticity within sessions

(White 1980). In one specification, regressions were conducted separately by subject capacity using period dummies. An alternate specification uses a period (time trend) variable and the period variable crossed with the dummies for subject capacity. Both specifications suggest the same results and so the second specification is presented here.

Table 4.3.4
Tobit Regression - Individual Decisions on Capacity & Time

Number of Observations = 900 Log Likelihood = -3751.87

		Coefficient	Std. Error	z	P > |z|
Large	β_{11}	24.58	2.51	9.777	0.000
Small	β_{12}	23.85	2.86	8.341	0.000
Medium	β_{13}	26.52	2.42	10.96	0.000
L*Period	β_{21}	0.82	0.234	3.492	0.000
S*Period	β_{22}	-0.32	0.283	-1.135	0.256
M*Period	β_{23}	-0.025	0.123	-0.204	0.838

$x_n = \beta_{11}L + \beta_{12}S + \beta_{13}M + \beta_{21}Lt + \beta_{22}St + \beta_{23}Mt + \epsilon$, standard errors adjusted for clustering on session. Where L represents Large Capacity Subjects, S represents Small Capacity Subjects, M represents Medium Capacity Subjects, and t represents Period.

This regression suggests that the trend for the large capacity subjects observed in Figure 4.7.5 is statistically significant and that the first period decision numbers are not significantly different from 25 for any of the subject capacities. Table 4.3.5 reports the results from a Tobit estimation of a convergence model used by authors such as Noussair et al. (1995). This model estimates an initial individual decision number and the adjustment towards a different level

$$x_n = \beta_{11}L/t + \beta_{12}S/t + \beta_{13}M/t + \beta_{21}L(t-1)/t + \beta_{22}S(t-1)/t + \beta_{23}M(t-1)/t + \epsilon$$

where β_{1c} (c=1,2,3) represents the initial decision number by capacity and β_{2c} (c=1,2,3) represents the asymptote of the adjustment process.

Table 4.3.5
Tobit Regression of Convergence Model for Individual Decisions

Number of Observations = 900 Log Likelihood = -3755.53

		Coefficient	Std. Error	z	P > |z|
Large/t	β_{11}	15.22	2.87	5.298	0.000
Small/t	β_{12}	27.23	5.344	5.096	0.000
Medium/t	β_{13}	26.96	5.947	4.534	0.000
Large(t-1)/t	β_{21}	38.81	3.634	10.679	0.000
Small(t-1)/t	β_{22}	18.31	3.582	5.112	0.000
Medium(t-1)/t	β_{23}	26.05	0.232	112.495	0.000

$x_n = \beta_{11}L/t + \beta_{12}S/t + \beta_{13}M/t + \beta_{21}L(t-1)/t + \beta_{22}S(t-1)/t + \beta_{23}M(t-1)/t + \epsilon$, standard errors adjusted for clustering on session. Where L represents Large Capacity Subjects, S represents Small Capacity Subjects, M represents Medium Capacity Subjects, and t represents Period.

Table 4.3.5, suggests that the large capacity subjects initially choose even lower decision numbers (15.22) than the linear model predicts and that they adjust to a level significantly below the payoff maximizing Nash prediction (38.81). The small capacity subjects initially choose 27, which falls towards 18.31 through time and the initial decision number and the asymptotic value are not significantly different for the Medium capacity subjects (decision numbers start at 26.96 and fall to 26.05).

This analysis suggests that on average, subjects use a simple heuristic based on equity (the target divided by the number of people in the group) to choose their decision number initially. Notice that only the large capacity subjects adjust towards the payoff maximizing Nash equilibrium while the small and medium capacity subject make no significant adjustment. Neither of the regressions (Tables 4.3.4 or 4.3.5) are consistent with the altruism hypothesis as the Small and Medium capacity subjects exhibit negative altruism while the large capacity subjects exhibit a large degree of positive altruism. Figures 4.7.6, 4.7.7 and 4.7.8 show how well the linear as well as the convergence Tobit regressions (from Tables 4.3.4 and 4.3.5) are able to predict the actual average individual decisions for medium, large and small capacity subjects respectively. Notice that in most cases both models are similar to the path of the average decision numbers, however, there are some differences between sessions. This suggests that initially subjects use the simple equity heuristic and then adjust their decisions based on the incentives provided by the Tax-Subsidy instrument.

Result 5: Individual decisions vary by subject.

The preceding analysis is concerned primarily with individual decision making on average. As Ledyard (1995) suggests, decisions differ by individual. Figures 4.7.9, 4.7.10, and 4.7.11 show the distributions of individual decisions for the three subject capacities respectively. Figure 4.7.9 shows the distributions for large capacity subjects. Initially there is a peak between 25 and 50 and then this peak splits and part goes to 25 and the other part goes to 50. For the small capacity subjects depicted in Figure 4.7.10, there is initially a small peak about 25 but by the last 10 periods most of the observations are at zero. Finally, in Figure 4.7.11, for the medium capacity subjects, notice that the distributions are fairly stable with the peak always at 25. Tables 4.6.1, 4.6.2 and 4.6.3 present decisions by individual, categorically for large, small and medium capacity subjects respectively. The categories represent ranges of decision numbers from zero up to x_n^{max} depending on the subjects type. Categories which contain more than one third of subject's decisions are shaded.

Table 4.6.1 describes the individual decisions of the large capacity subjects. Notice that very few subjects (1 of 9) ever choose the payoff maximizing decision or above. This is inconsistent with the decision error hypothesis for payoff maximization. Two of the nine large capacity subjects choose most of their decision numbers below 25 (which is most consistent with altruism), one chooses 25 most often (20 out of 25 times), four of the nine choose decisions between 26 and 46 most often which is most consistent with the proportional equity hypothesis (large capacity subjects choose 31) and one chooses half of her decisions below and half above. These observations support altruism and equity with decision error over the payoff maximization model.

For the small capacity subjects (Table 4.6.2), we have one subject who always chooses the payoff maximizing Nash decision, and two others who typically choose less than five. There are three more subjects who choose most of their decisions below 25, but above 5, and two subjects whose decisions are distributed about 25 (which is most consistent with the equity hypothesis). One subject always chooses decision numbers above 50. These decisions are most consistent with the equity hypothesis

Finally, for the medium capacity subjects (Table 4.6.3) seven of eighteen subjects choose most of their decisions below 25, six of eighteen choose 25 most often, and seven choose greater than 25. This observation seems most consistent with payoff maximization or equity as those who choose decisions below 25 (most consistent with altruism) are completely offset by those who choose numbers above 25.

Thus, the individual decisions are most consistent with altruism and equity for the large capacity subjects, the equity hypothesis for small capacity subjects, and equity and payoff maximization for medium capacity subjects. Notice also that there is a great deal of heterogeneity between individuals but that most subjects decisions are consistent with one of the preference hypothesis.

4.5. Conclusions

This study exploits the fact that different hypotheses for how individuals make decisions can be identified by varying the payoff function parameters between subjects. The results suggest that the data is most consistent with the equity hypothesis (Walster et al. 1978, Chan et al. 1997). Moreover, the data are better described by a censored error distribution than the truncated distribution suggested by authors such as McKelvey and Palfrey (1995) and Anderson et al. (1998).

There is also strong evidence that dynamic adjustment is important. In early periods individual decisions are best described on average by the simple heuristic where everyone chooses an equal share of the target. As subjects gain more experience, their decisions tend toward an outcome which is more equitable in terms of payoff. However, individual decisions do not converge to the dominant strategy Nash equilibrium. As a result, large capacity subjects reduce their decision numbers, which are analogous to emissions in the nonpoint source pollution problem, by far more than the small capacity subjects. This results in the large capacity subjects earning significantly less than the small capacity subjects over the course of the experiment. This calls into question the feasibility of these instruments for field settings as some firms may be able to take advantage of others.

These results are similar to those found by authors such as Palfrey and Prisbrey (1997), Anderson et al. (1998) and Chan et al. (1997) who find that non-Nash behaviour is best explained by preference-based as well as decision-error models. There are several differences between this study and the other studies. Palfrey and Prisbey (1997) vary the parameters faced by individuals in different periods, which explains why a dynamic adjustment process is not important in their study. Further, these studies are all public good experiments and as such, the simple heuristic that seems to be focal in this environment is not available in these other environments. This study is most consistent with the Chan et al. (1997) study as both are concerned with heterogeneity in individual's payoff function. Chan et al. (1997)

also find that their data is best described by decision error and preferences for equity. This suggests that simple equity based heuristics are important in determining how individuals make decisions.

4.6 Supplemental Tables

Table 4.6.1
Distributions of Individual Decisions, Large Capacity Subjects

Session	Subject	0	1-5	6-10	11-20	21-24	25	26-30	31-45	46-49	50	51-55	56+	Avg Dec	Std Dev.
980316AA	1	4	11	0	8	0	0	0	2	0	0	0	0	8.56	10.832359
	2	0	0	0	0	1	0	7	14	0	2	1	0	36.44	7.8797208
	3	0	0	3	10	0	0	0	3	0	1	0	8	41.68	36.066744
	Total	4	11	3	18	1	0	7	19	0	3	1	8	28.89	
980317BA	1	0	0	0	1	4	20	0	0	0	0	0	0	24.60	1.0801234
	2	0	0	0	0	0	0	2	4	19	0	0	0	43.24	6.8937169
	3	0	1	1	8	1	1	4	3	0	2	0	4	37.48	30.701683
	Total	0	1	1	9	5	21	6	7	19	2	0	4	35.11	
980318AA	1	0	0	0	0	0	0	1	16	0	0	0	8	47.44	20.043869
	2	0	0	0	0	0	1	23	0	0	0	0	1	31.80	19.045997
	3	0	0	0	0	0	1	5	11	2	2	1	3	46.40	26.288464
	Total	0	0	0	0	0	2	29	27	2	2	1	12	41.88	
Total		4	12	4	27	6	23	42	53	21	7	2	24	35.29	

Table 4.6.2
Distributions of Individual Decisions, Small Capacity Subjects

Session	Subject	0	1-5	6-10	11-20	21-24	25	26-30	31-45	46-49	50	51-55	56+	Avg Dec	Std Dev
980316AA	4	0	1	1	8	7	2	4	2	0	0	0	0	21.48	7.5449763
	5	0	0	0	0	0	0	0	0	0	0	2	23	66.04	7.5855125
	6	25	0	0	0	0	0	0	0	0	0	0	0	0.00	0
	Total	25	1	1	8	7	2	4	2	0	0	2	23	29.17	
980317BA	4	15	1	1	4	0	4	0	0	0	0	0	0	7.64	10.688311
	5	0	2	1	6	3	3	5	2	0	0	0	3	26.28	17.570145
	6	0	0	1	17	3	4	0	0	0	0	0	0	18.36	4.4988888
	Total	15	3	3	27	6	11	5	2	0	0	0	3	17.43	
980318AA	4	0	20	5	0	0	0	0	0	0	0	0	0	4.32	1.5198684
	5	1	5	1	9	0	4	3	2	0	0	0	0	18.08	10.447966
	6	0	0	0	5	7	3	3	2	2	0	0	3	31.56	16.678529
	Total	1	25	6	14	7	7	6	4	2	0	0	3	17.99	
Total		41	29	10	49	20	20	15	8	2	0	2	29	21.53	

Table 4.6.3

Distributions of Individual Decisions, Medium Capacity Subjects

Session	Subject	0	1-5	6-10	11-20	21-24	25	26-30	31-45	46-49	50	51-55	56+	Avg Dec	Std. Dev
970211c	1	0	0	2	20	0	1	1	0	0	1	0	0	18.48	7.8162224
	2	0	0	1	6	8	4	4	2	0	0	0	0	23.36	6.395832
	3	0	0	0	11	3	1	2	3	0	1	0	4	31.32	17.985457
	4	0	4	9	6	0	1	4	0	0	0	0	1	17.08	19.399141
	5	4	0	4	0	4	0	0	1	0	6	1	5	36.56	28.905132
	6	0	0	0	2	3	20	0	0	0	0	0	0	24.24	1.6401219
	Total	4	4	16	45	18	27	11	6	0	8	1	10	25.17	
970213c	1	0	0	0	10	2	2	9	0	0	2	0	0	25.96	8.7914731
	2	1	0	2	5	3	7	6	1	0	0	0	0	23.28	8.5514131
	3	0	0	0	0	0	11	14	0	0	0	0	0	26.12	1.4236104
	4	1	1	4	11	3	3	1	0	0	1	0	0	16.96	10.122088
	5	0	0	0	0	0	2	22	0	0	0	0	1	30.44	14.379036
	6	0	0	0	3	5	5	3	9	0	0	0	0	27.68	6.0739883
	Total	2	1	6	29	13	30	55	10	0	3	0	1	25.07	
970218c	1	0	0	1	11	4	4	1	3	0	0	0	1	24.80	11.022704
	2	0	0	0	2	11	8	4	0	0	0	0	0	24.00	1.6832508
	3	4	0	0	1	0	6	6	5	0	1	2	0	27.40	15.38939
	4	1	1	0	6	3	14	0	0	0	0	0	0	20.92	6.9457421
	5	1	1	1	0	0	1	1	0	0	14	5	1	45.28	19.50752
	6	0	0	0	0	0	5	11	8	0	1	0	0	31.44	6.1174613
	Total	6	2	2	20	18	38	23	16	0	16	7	2	28.97	
Total		12	7	24	94	49	95	89	32	0	27	8	13	26.41	

4.7 Supplemental Figures

Figure 4.7.1: Predicted Distributions from the Truncated Logit Quantal Response Model for Medium Capacity Subjects

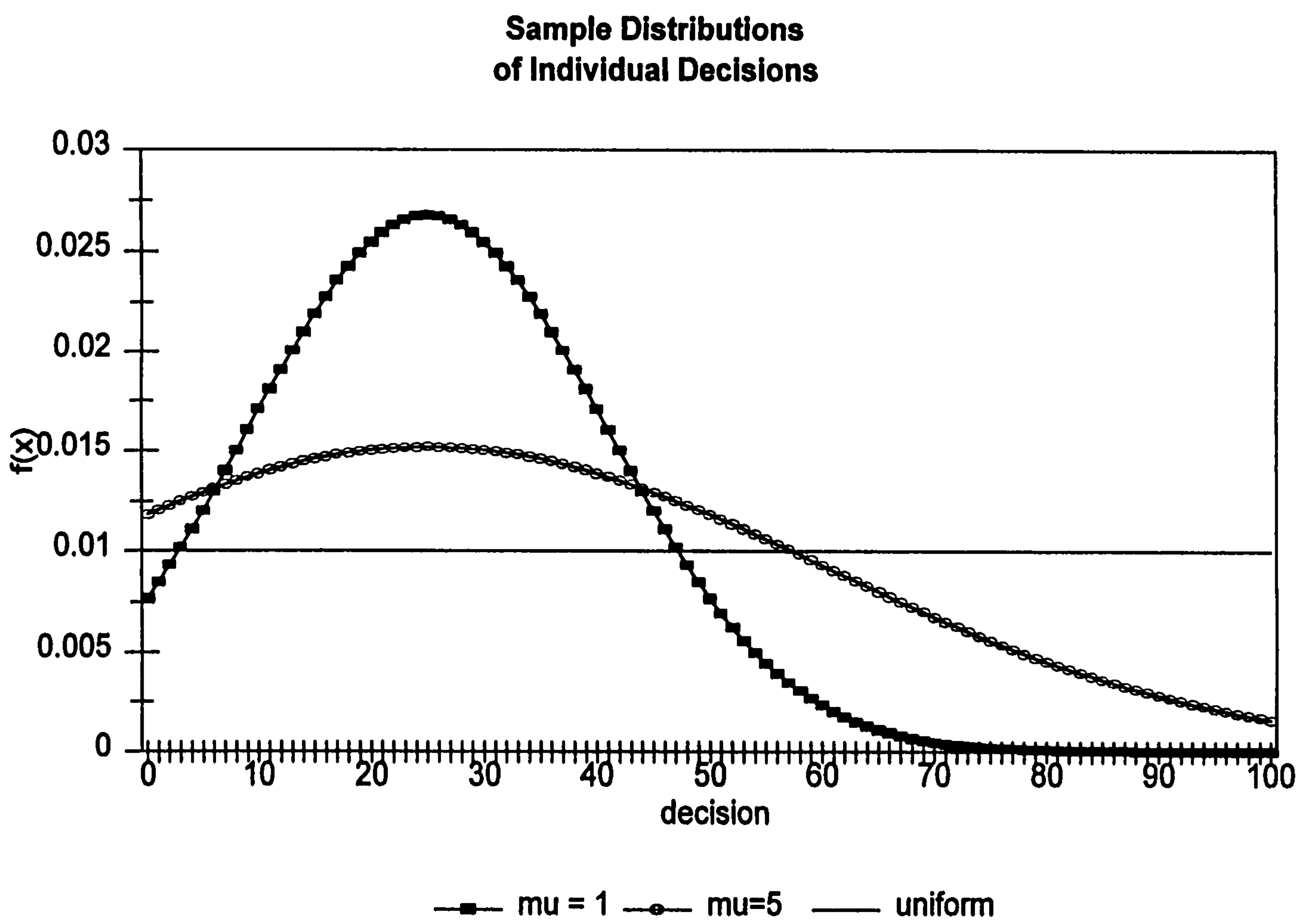


Figure 4.7.2: Actual and Fitted Distributions of Individual Decisions, Large Capacity Subjects

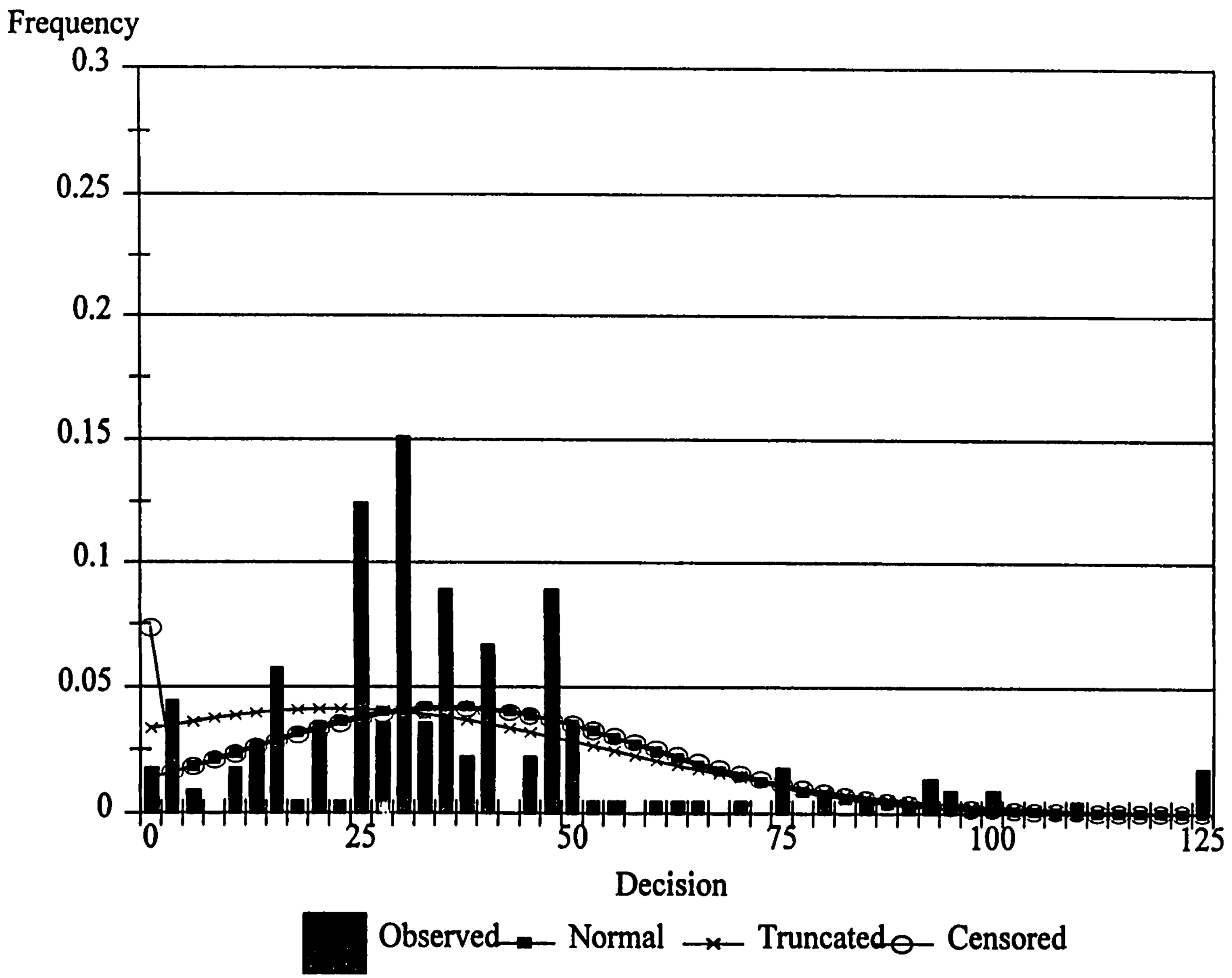


Figure 4.7.3: Actual and Fitted Distributions of Individual Decisions, Small Capacity Subjects

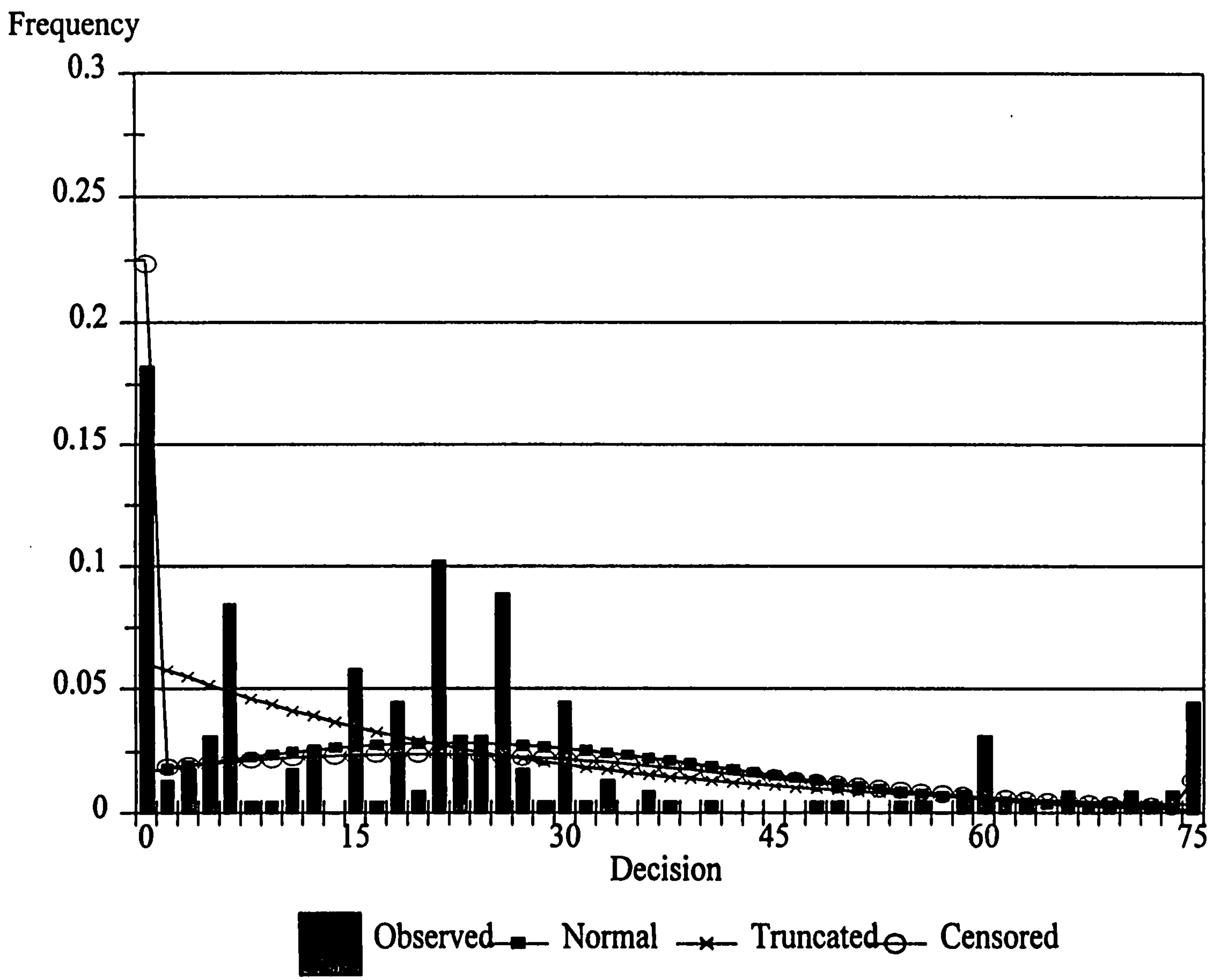


Figure 4.7.4: Actual and Fitted Distributions of Individual Decisions, Medium Capacity Subjects

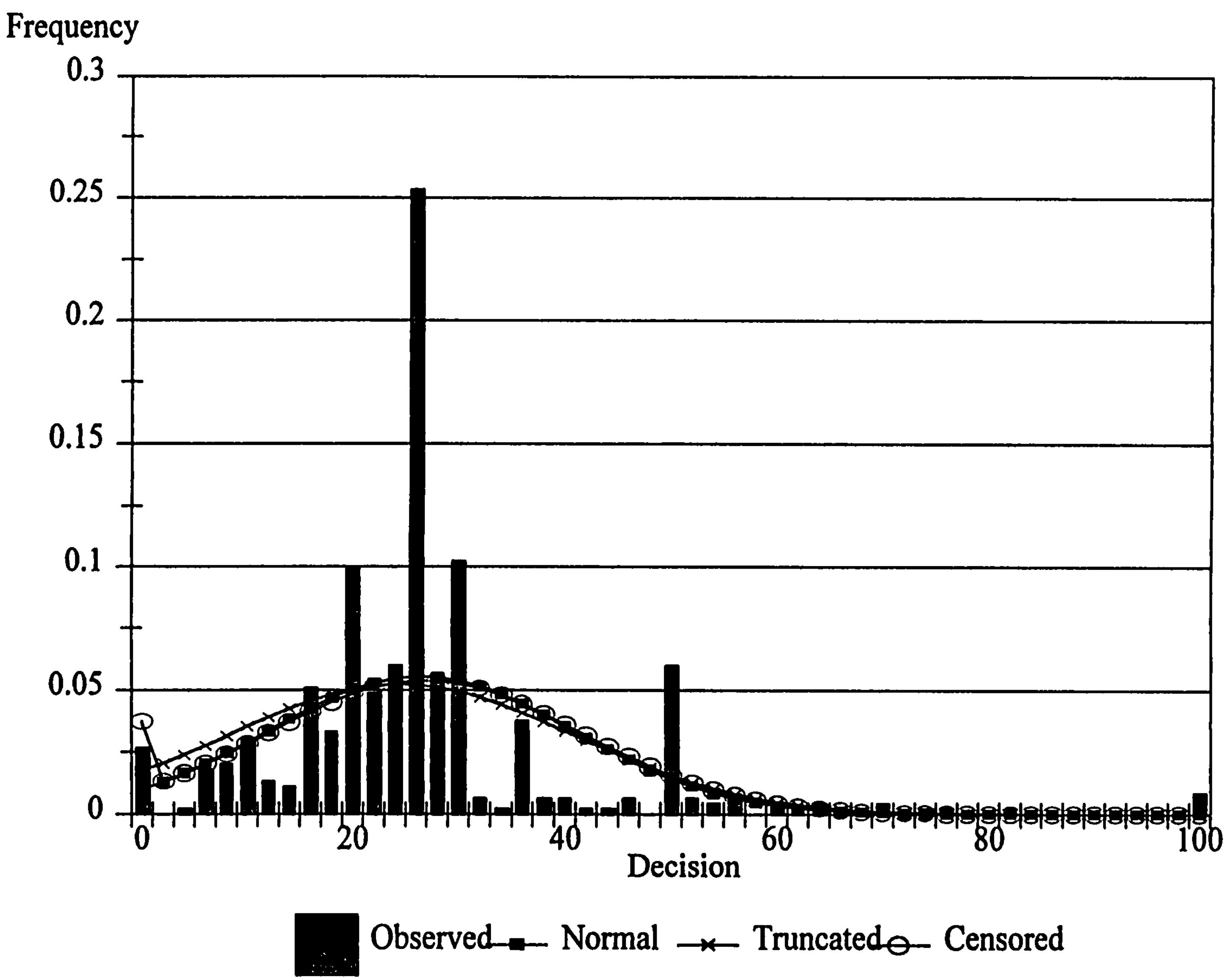


Figure 4.7.5: Mean Individual Decisions by Capacity by Five Period Intervals

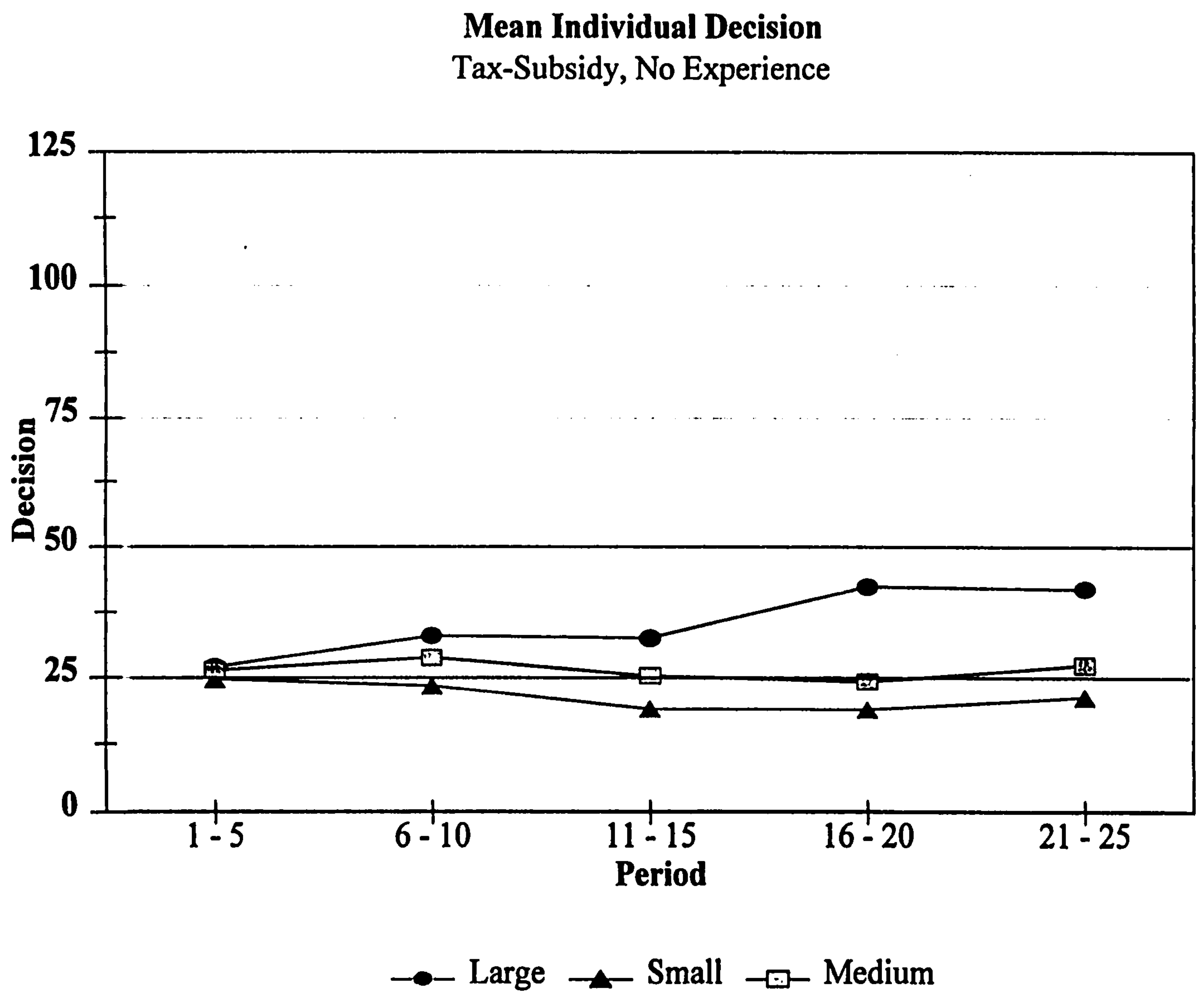


Figure 4.7.6: Average and Predicted Decision Numbers, Large Capacity Subjects

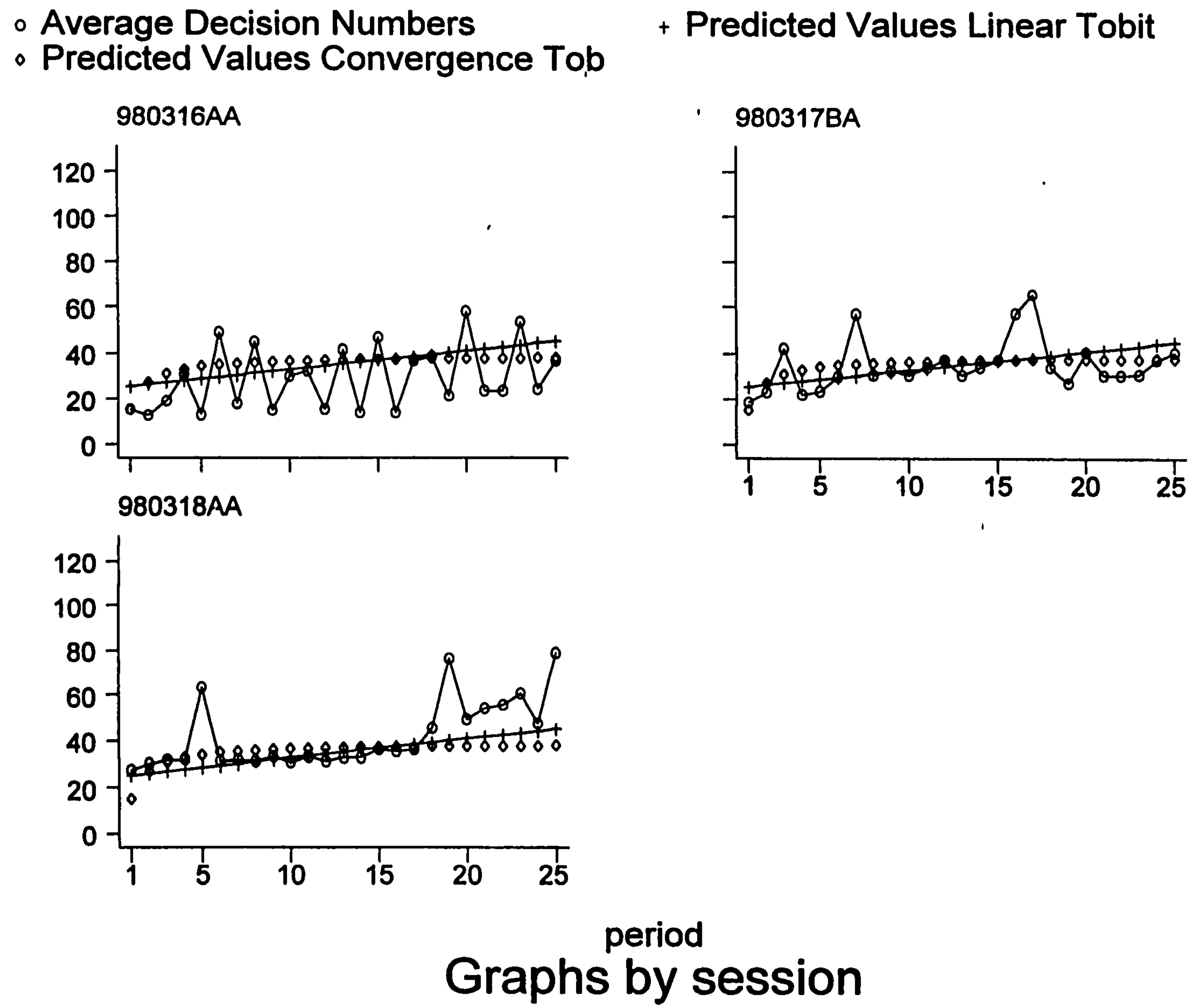


Figure 4.7.7: Average and Predicted Decision Numbers, Small Capacity Subjects

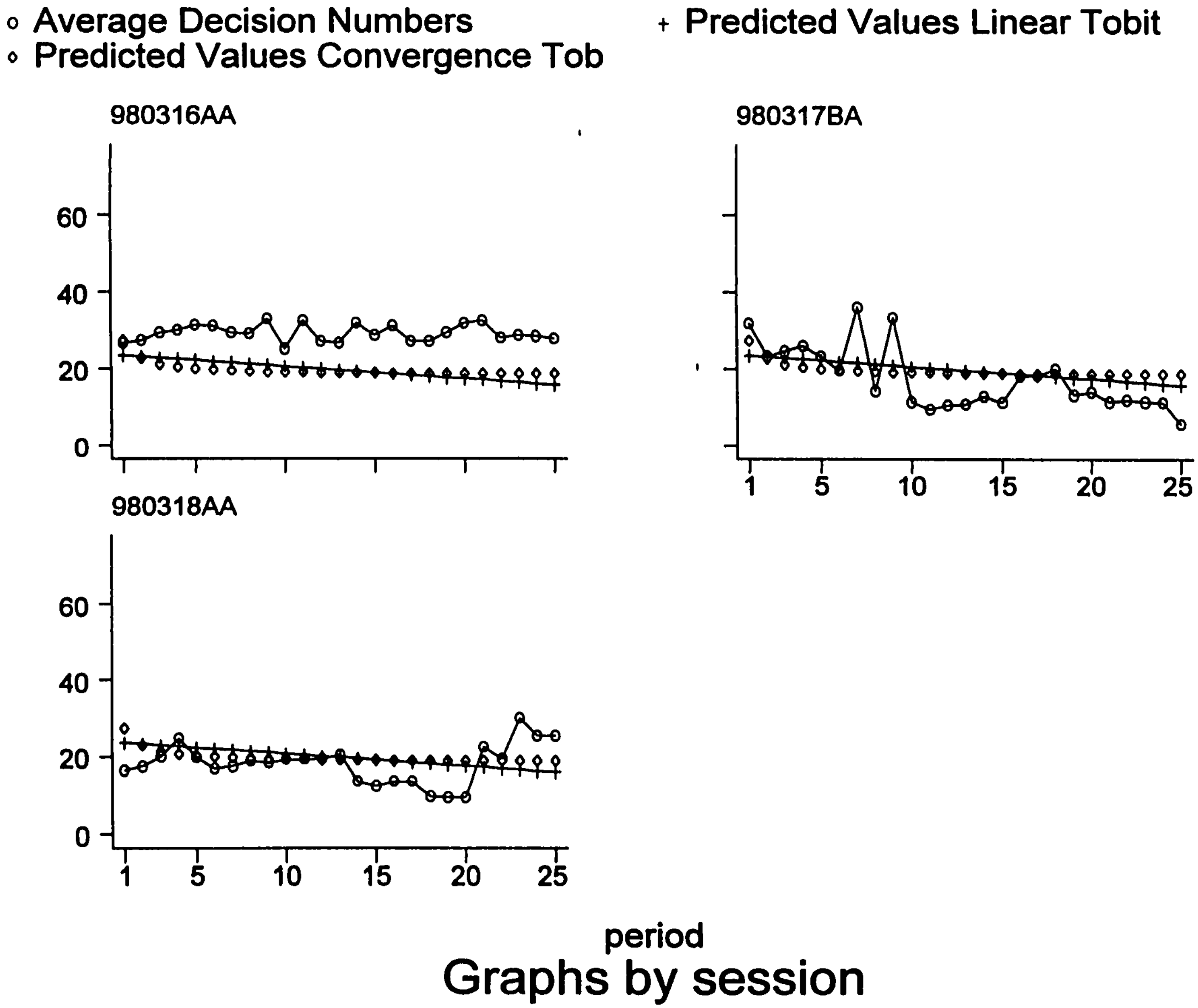


Figure 4.7.8: Average and Predicted Decision Numbers, Medium Capacity Subjects

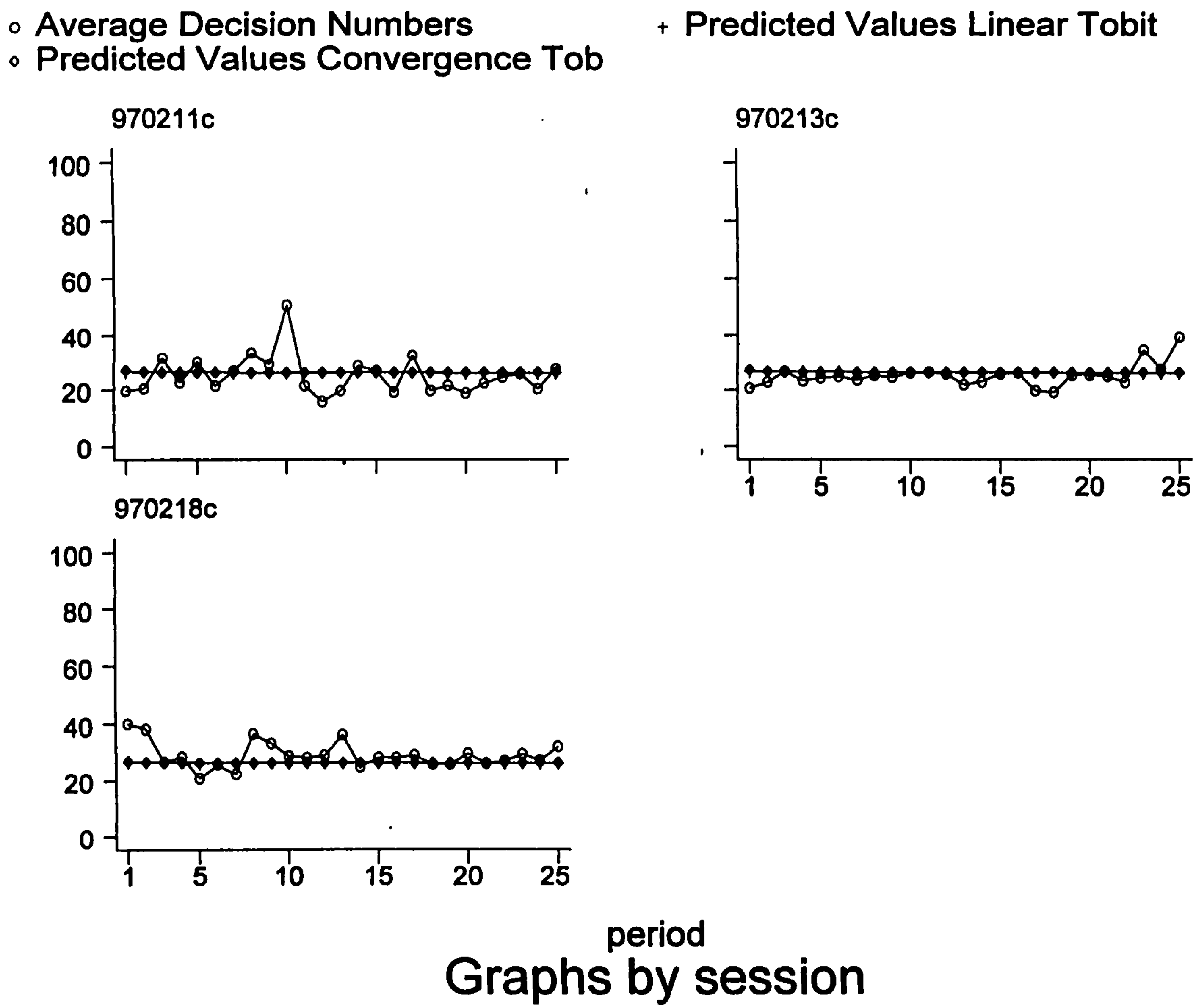
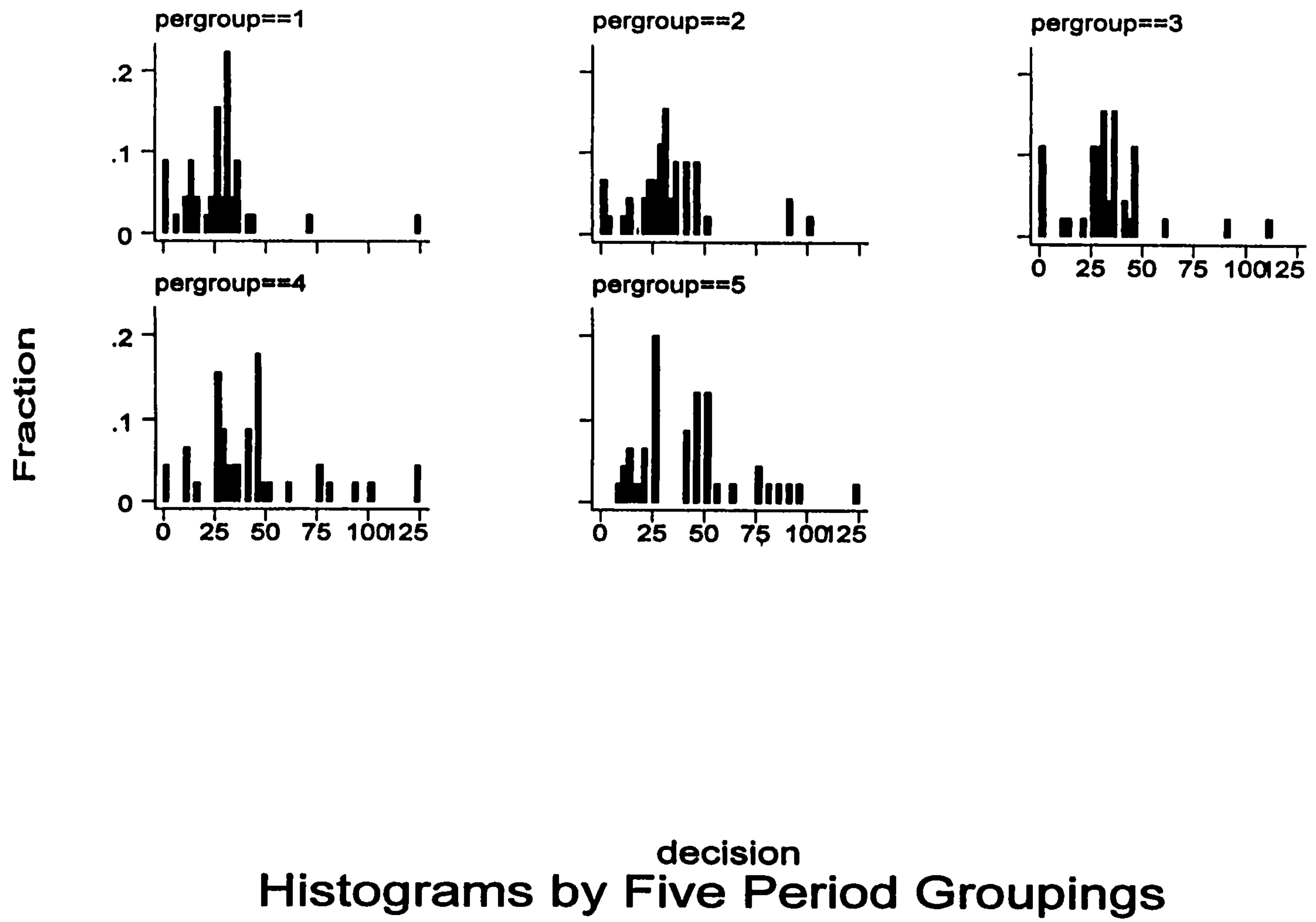
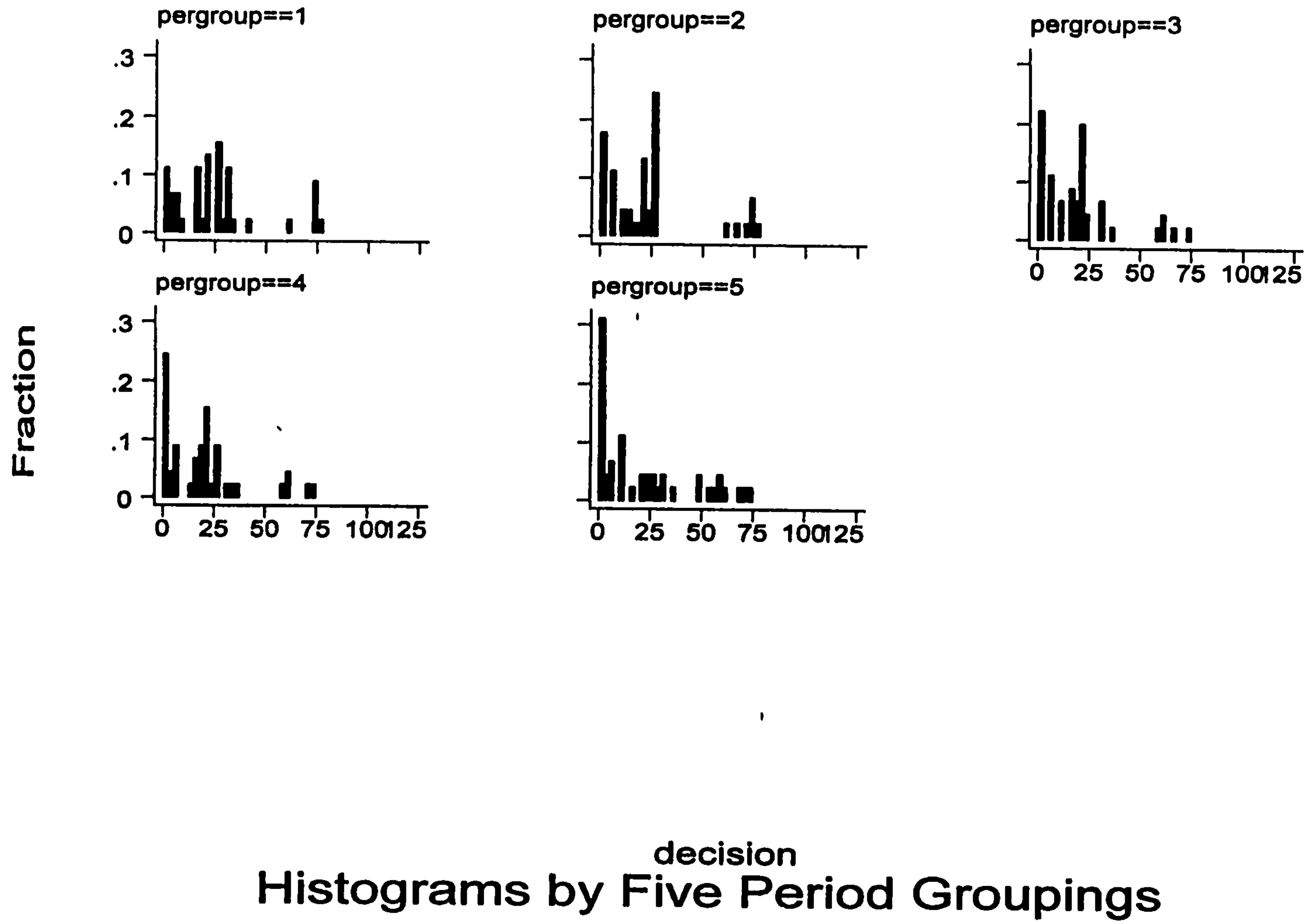


Figure 4.7.9: Distributions of Individual Decisions by Five Period Interval, Large Capacity Subjects



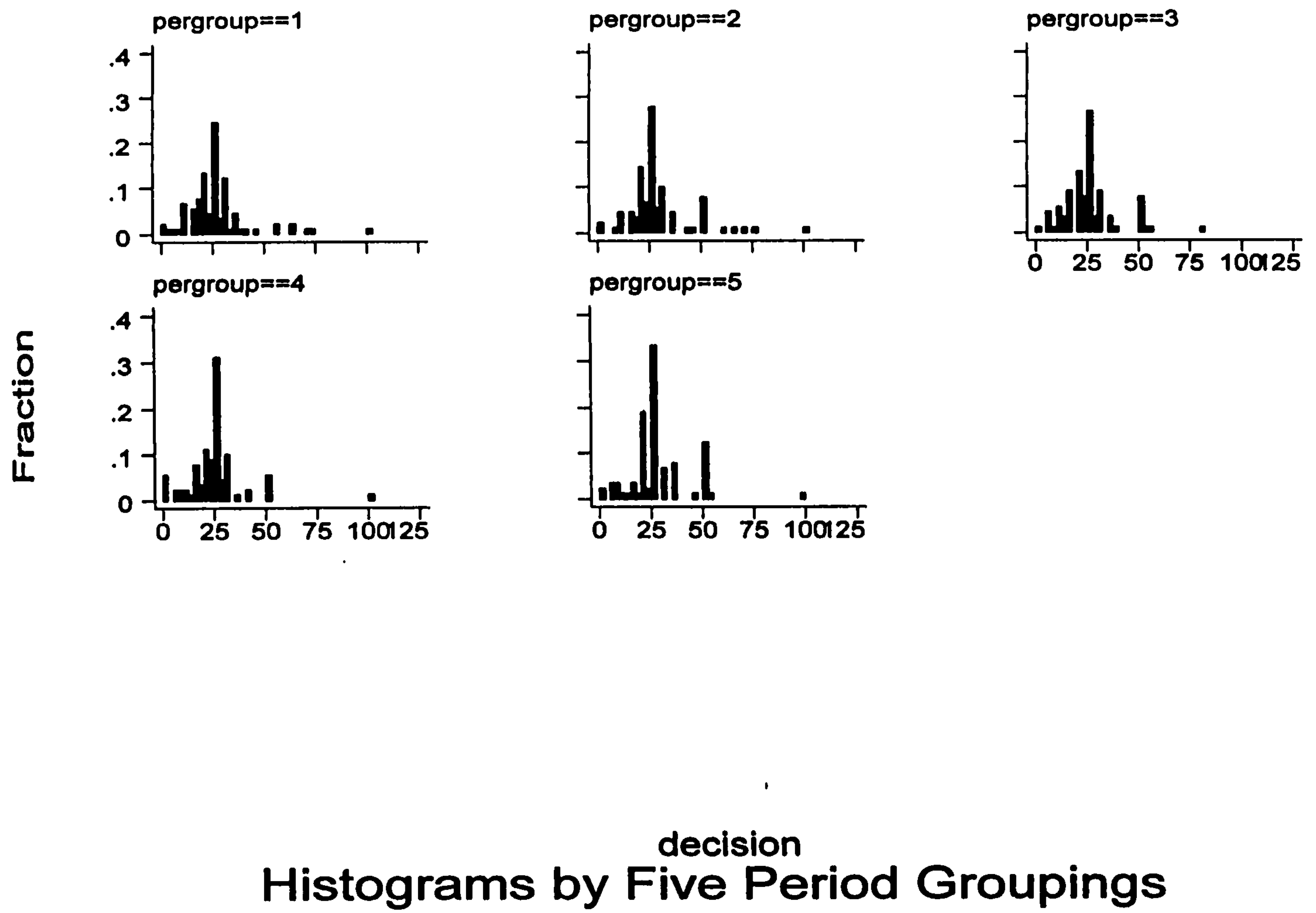
Note: pergroup 1 refers to periods 1 to 5, pergroup 2 refers to periods 6 to 10, pergroup 3 refers to periods 11 to 15, pergroup 4 refers to periods 16 to 20 and pergroup 5 refers to periods 21 to 25.

Figure 4.7.10: Distributions of Individual Decisions by Five Period Intervals, Small Capacity Subjects



Note: pergroup 1 refers to periods 1 to 5, pergroup 2 refers to periods 6 to 10, pergroup 3 refers to periods 11 to 15, pergroup 4 refers to periods 16 to 20 and pergroup 5 refers to periods 21 to 25.

Figure 4.7.11: Distributions of Individual Decision Numbers by Five Period Intervals, Medium Capacity Subjects



Note: pergroup 1 refers to periods 1 to 5, pergroup 2 refers to periods 6 to 10, pergroup 3 refers to periods 11 to 15, pergroup 4 refers to periods 16 to 20 and pergroup 5 refers to periods 21 to 25.

Chapter 5

Conclusions

5.1 Summary and Conclusions

In order to implement emission permit markets to reduce pollution in a wide range of situations, it is important to develop instruments which are able to overcome the group moral hazard problem. This dissertation provides an empirical test of exogenous targeting instruments which are designed to do just this. The results are mixed, but overall there is reason to be optimistic with regard to the ability of these instruments to mitigate the problem of moral hazard in groups.

The second chapter shows that instruments which theoretically are able to implement the socially optimal outcome as a dominant strategy Nash equilibrium are indeed able to induce a group of agents with identical payoff functions to choose the socially optimal outcome at the aggregate level. This result is robust to uncertainty in the aggregate decision number as well as experience with the environment. There are some caveats to this result. The first is that instruments which theoretically result in multiple Nash equilibria are not able to induce groups to choose the target outcome. Secondly, these contracts may prove very costly for the regulator if individuals are able to collude. Finally, while on average individuals choose the socially optimal outcome, this outcome is actually chosen less than fifty percent of the time. This results in the observation of bankruptcies.

The third chapter considers a more complicated case where individuals have heterogeneous payoff functions. This case is also more realistic as non-point source polluting firms may not necessarily be identical. The results with heterogeneous groups are similar to those of homogeneous groups. The instruments which theoretically implement the socially optimal outcome as a dominant strategy Nash equilibrium are able to induce the group to choose the target outcome at the aggregate level. The instruments which theoretically implement the socially optimal outcome as one of multiple Nash equilibria is not able to induce the group to choose the target outcome consistently. A second important result observed in this chapter is that the large capacity subjects reduce their decision numbers significantly more than the small capacity subjects. This observation is consistent with Chan et al.'s (1996, 1997) observation in a public good environment with heterogeneous agents.

The fourth chapter investigates the individual data to determine whether or not it is statistically consistent with standard preference and decision error explanations for non-Nash behaviour. The results show that the data is consistent with preferences for equity and a censored error distribution. This is consistent with the investigation of boundary effects by Chan et al. (1994) and heterogeneity by Chan et al. (1997). There is also evidence that dynamic considerations are important and that it is possible under these instruments for individuals to take advantage of the other members of their group.

The policy implications of these results are that a great deal of care should be taken in the implementation of these types of exogenous targeting instruments. The fact that these instruments are able to induce both homogeneous and heterogeneous groups to comply with a target suggests that they are a viable tool for solving the group moral hazard problem. However, that they do not induce subjects to choose the socially optimal outcome suggests that they might result in more harm than good. Even if the participants were to choose the socially optimal outcome, these instruments provide another dimension in which firms can compete with each other. Under these instruments a company could put its rivals out of business by choosing not to reduce its emissions level. All of the firms would receive the same fine, but this fine would be more costly to the firms that had reduced their emissions as they not only have to pay the fine but also pay to reduce their emissions. This observation suggests that future research should be focussed on the model suggested by Xepapadeas (1995) where individuals self-report their emission levels and pay a Pigouvian tax on the reported emission level and then face penalties on any emissions which exceed the aggregate reported level.

Appendix A

A.1 Instructions for Exogenous Targeting Experiment with Homogeneous Agents.

This is an experiment in the economics of decision making. During the experiment your payoffs will be reported in lab dollars. It is possible that you could lose money in this experiment. As a result everyone will be given an opening balance of 250 lab dollars. If at anytime your cumulative payoff (which includes this opening balance) falls below 0 lab dollars you will be excused from the experiment and will receive nothing. Despite this if you follow the instructions carefully you may earn a considerable amount of money. This research has been funded by various agencies.

Before we begin the actual experiment please fill out the form labelled lotteries which will be found in your folder. For each choice please put an X in the column beside Option A or Option B. After today's session one of the choices will be selected at random, the lottery will be conducted and you will be paid depending on your choice and the outcome from the lottery. Once you have completed the form raise your hand and it will be collected.

<u>Overview</u>

Today's session will be conducted using the computer network located in our laboratory. The session will consist of 2 parts which will each last 25 periods. We will begin after everyone has finished reading the instructions and completed 5 practice periods. Please refrain from talking during the experiment. Each period will proceed as follows.

What the Computer does	What you do
Start period.	
	Choose a "decision number" and enter it in the appropriate box on your computer screen.
Collect decision numbers, Calculates individual payoffs, and returns results	
	Check your payoff and cumulative payoff

Start next period or end section	

Now here are the details.

Part 1

You have been assigned to a group of six (yourself and five other) participants. This will be your group for the entire experiment. Everyone in your group has the same instructions. This part will consist of 25 periods. In each period you (and the others in your group) will be asked to choose a number between 0 and 100 and to enter it into the computer. This is your **Decision Number**.

Your Total Payoff for each period is the sum of your Private Payoff and your Group Payoff:

Total Payoff = Private Payoff + Group Payoff

Your Private Payoff depends only on your own Decision Number. Table 1 in your folder shows the Private Payoff for each possible Decision Number. For example if your Decision Number were 60 Table 1 shows that your Private Payoff would be 21.80 lab dollars. Or if you had chosen 30 your Private Payoff would be 15.20 lab dollars. Notice that the higher your Decision Number the higher your Private Payoff.

The Group Payoff depends only on the Group Total and is the same for everyone in the group. If the Group Total is less than or equal to 150 then the Group Payoff will be zero. If the Group Total is greater than 150, the Group Payoff is -24. The Group Payoff can be written as the following function of the Group Total:

$$\text{Group Payoff} = \begin{cases} -24 & \text{if Group Total} > 150 \\ 0 & \text{if Group Total} \leq 150 \end{cases}$$

For example if the Group Total were 200 then the Group Payoff for every member of the group would be -24 lab dollars. Whereas, if the Group Total were 100 then the Group Payoff for every member of the group would be 0 lab dollars.

As a simple example, suppose that you chose 60 and everyone else in your group chose 20. The Group Total would be 160 (the sum of your decision number and the decision numbers of everyone else in your group), your Private Payoff would be 21.80, the Group Payoff would be -24, and your Total Payoff would be -2.20 lab dollars.

Now suppose, that you had chosen 30 in the above example. The Group Total would be 130, your Private Payoff 15.20, the Group Payoff would be 0, and your Total Payoff would be 15.20 lab dollars. Notice that the higher your Decision Number the higher your Private Payoff. But, the higher your Decision Number the higher the Group Total and the lower the Group Payoff.

Your payment for this session will be the sum of your earnings in each of the 25 periods. Your earnings will be converted from lab dollars to Canadian at the rate of 0.025 Canadian dollars per Lab dollar (each lab dollar is worth 2 ½ cents Canadian). In the event that you do lose your opening balance you will be informed by the computer that you are Bankrupt and will not be able to participate in the rest of this part of the experiment. At this point the rest of the people in your group will be informed that there is now one less person whose decision number is being added into the group total.

Please answer the following question:

Use table 1 to fill in the portion of the record sheet below assuming that you chose 75, the group total was 125 and the group payoff is -24 if the group total is above 150 and zero otherwise.

Period	Decision Number	Private Payoff	Group Total	Group Payoff	Total Payoff	Cumulative Payoff
Practice						

Please raise your hand when you are done so that the monitor can check your answer.

Before we begin we will conduct five practice periods. These practice periods are intended to help you understand today's experiment. Any earnings you make during the practice periods will not be included in your payment at the end of the session. The practice periods will differ from the actual periods in that the Group Total will be your decision number plus a random number chosen by the computer. The Group Total in the practice periods will be your decision number plus a random number between 0 and 500. This random number is chosen by the computer so that each number between and including 0 and 500 has an equal chance of being selected.

Once the first practice period starts you will notice that the game window on the computer screen has three sections. The first section describes the Group Payoff function. This function is the same as described in the instructions above. The second section is labelled Scratch Pad. Using the Scratch Pad, you will be able to determine your payoff from different combinations of values for your Decision Number and the Group Total. Notice that you can change the Decision Number and the Group Total by typing numbers into the edit boxes or by using the arrow buttons located beside the edit boxes. Also notice that changing the Decision Number changes the Group Total. This is because the Group Total is the sum of your Decision Number and the Decision Number of those in your group and as a result when your Decision Number increases so does the Group Total. The third section of the screen is where you type your Decision Number. Once you have chosen your Decision Number and typed it into the edit box click on the Ok button to complete this part of the period. Please feel free to raise your hand and ask any questions you may have.

To help you understand the Scratch Pad please pick any number between 0 and 100 and type it into the box beside Your Decision Number on the scratch pad. Now pick a bigger number and type it into the box beside Group Total. Notice that the Group Total will always be bigger than your Decision Number as it is the sum of the Decision Numbers of everyone in your group. Now use the arrow buttons beside the box where you typed Your Decision Number to increase or decrease Your Decision Number. Notice the effect of these changes on your Total Payoff.

Once the practice periods have been completed we will begin the 25 periods for which you will be paid at the end of today's session.

Part 2 - Instructions

This phase of the experiment will also consist of 25 periods. You (and everyone else) are in the same group as you were before. The only difference from the previous section is in how the Group Payoff is calculated

As before, in each period you (and the others in your group) will be asked to enter a number between 0 and 100 on your computer screen. This is your **Decision Number**.

Your Total Payoff for the period is the sum of a Private Payoff and a Group Payoff:

Total Payoff = Private Payoff + Group Payoff

Your Private Payoff is determined by Table 1 as before. For example if your Decision Number were 60 Table 1 shows that your private payoff would be 21.80 lab dollars. Or if you had chosen 30 your Private Payoff would be 15.20 lab dollars.

Notice that the higher your Decision Number the higher your Private Payoff.

The Group Payoff depends only on the Group Total and is the same for everyone in the group. If the Group Total is greater than 150 then the Group Payoff will be zero. If the Group Total is less than or equal to 150, the Group Payoff is a positive value equal to 30% of the difference between 150 and the Group Total, plus 22.50. The Group Payoff can be written as the following function of the Group Total:

$$\text{Group Payoff} = \begin{cases} 0 & \text{if Group Total} > 150 \\ 0.3*(\ 150 - \text{Group Total}\ ) + 22.50 & \text{if Group Total} \leq 150 \end{cases}$$

For example if the Group Total were 130 then the Group Payoff for every member of the group would be 0.3*(150-130) + 22.50 = 28.50 lab dollars. Similarly if the Group total were 100 then the Group Payoff for every member of the group would be 0.3*(150 -100) + 22.50 = 37.50 lab dollars. Notice that the lower the Group Total is below 150 the more positive (higher) the Group Payoff.

As a simple example, suppose that you chose 60, everyone else in your group chose 20. The Group Total would be 160 (the sum of your decision number and the decision numbers of everyone else in your group), your Private Payoff would be 21.80, the Group Payoff would be Zero, and your Total Payoff would be 21.80 lab dollars.

Now suppose, that you had chosen 30 in the above example. The Group Total would be 130, your Private Payoff 15.20, the Group Payoff would be 28.50, and your Total Payoff would be 43.70 lab dollars. Notice that the higher your Decision Number the higher your Private Payoff. But, the higher your Decision Number the higher the Group Total and the lower the Group Payoff.

Your payment for this part of the experiment will be the sum of your earnings in each of the 25 periods. Your earnings for this part will be converted from lab dollars to Canadian at the rate of 0.017 Canadian dollars per Lab dollar (each lab dollar is worth 1.7 cents Canadian).

Please answer the following question:

Use table 1 to fill in the portion of the record sheet below assuming that you chose 75, the group total was 125 and the group payoff is 30% of the difference between 150 and the group total plus 22.50 if the group total is below 150 and zero otherwise.

Period	Decision Number	Private Payoff	Group Total	Group Payoff	Total Payoff	Cumulative Payoff
Practice						

Please raise your hand when you are done so that the monitor can check your answer.

Table A.1.1 Private Payoff Schedule

Choice	Private Payoff	Choice	Private Payoff
0	5.00	51	20.20
1	5.40	52	20.39
2	5.79	53	20.58
3	6.18	54	20.77
4	6.57	55	20.95
5	6.95	56	21.13
6	7.33	57	21.30
7	7.70	58	21.47
8	8.07	59	21.64
9	8.44	60	21.80
10	8.80	61	21.96
11	9.16	62	22.11
12	9.51	63	22.26
13	9.86	64	22.41
14	10.21	65	22.55
15	10.55	66	22.69
16	10.89	67	22.82
17	11.22	68	22.95
18	11.55	69	23.08
19	11.88	70	23.20
20	12.20	71	23.32
21	12.52	72	23.43
22	12.83	73	23.54
23	13.14	74	23.65
24	13.45	75	23.75
25	13.75	76	23.85
26	14.05	77	23.94
27	14.34	78	24.03
28	14.63	79	24.12
29	14.92	80	24.20
30	15.20	81	24.28
31	15.48	82	24.35
32	15.75	83	24.42
33	16.02	84	24.49
34	16.29	85	24.55
35	16.55	86	24.61
36	16.81	87	24.66
37	17.06	88	24.71
38	17.31	89	24.76
39	17.56	90	24.80
40	17.80	91	24.84
41	18.04	92	24.87
42	18.27	93	24.90
43	18.50	94	24.93
44	18.73	95	24.95
45	18.95	96	24.97
46	19.17	97	24.98
47	19.38	98	24.99
48	19.59	99	25.00
49	19.80	100	25.00
50	20.00	101	25.00

Lotteries Participant Number: ________

For Each of the following nineteen choices put an X in the column following either Option A or B. One of the choices will be selected at random and the lottery to determine your payment will be conducted at the end of the experiment. At the end of the experiment the 19 balls numbered 1 through 19 will be placed in the lottery game. The first ball selected by the machine will determine which option will determine your payoff. Then 20 balls numbered 1 through 20 will be placed in the machine and another ball will be selected to determine the outcome of the lottery in option B.

Choice	Option A		Option B	
1	$5 for sure		$10 if the number is greater than 1 (95% chance) versus $0 if the number is 1 (5% chance)	
2	$5 for sure		$10 if the number is greater than 2 (90% chance) versus $0 if the number is 2 or less (10% chance)	
3	$5 for sure		$10 if the number is greater than 3 (85% chance) versus $0 if the number is 3 or less (15% chance)	
4	$5 for sure		$10 if the number is greater than 4 (80% chance) versus $0 if the number is 4 or less (20% chance)	
5	$5 for sure		$10 if the number is greater than 5 (75% chance) versus $0 if the number is 5 or less (25% chance)	
6	$5 for sure		$10 if the number is greater than 6 (70% chance) versus $0 if the number is 6 or less (30% chance)	
7	$5 for sure		$10 if the number is greater than 7 (65% chance) versus $0 if the number is 7 or less (35% chance)	
8	$5 for sure		$10 if the number is greater than 8 (60% chance) versus $0 if the number is 8 or less (40% chance)	
9	$5 for sure		$10 if the number is greater than 9 (55% chance) versus $0 if the number is 9 or less (45% chance)	
10	$5 for sure		$10 if the number is greater than 10 (50% chance) versus $0 if the number is 10 or less (50% chance)	

11	$5 for sure		$10 if the number is greater than 11 (45% chance) versus $0 if the number is 11 or less (55% chance)	
12	$5 for sure		$10 if the number is greater than 12 (40% chance) versus $0 if the number is 12 or less (60% chance)	
13	$5 for sure		$10 if the number is greater than 13 (35% chance) versus $0 if the number is 13 or less (65% chance)	
14	$5 for sure		$10 if the number is greater than 14 (30% chance) versus $0 if the number is 14 or less (70% chance)	
15	$5 for sure		$10 if the number is greater than 15 (25% chance) versus $0 if the number is 15 or less (75% chance)	
16	$5 for sure		$10 if the number is greater than 16 (20% chance) versus $0 if the number is 16 or less (80% chance)	
17	$5 for sure		$10 if the number is greater than 17 (15% chance) versus $0 if the number is 17 or less (85% chance)	
18	$5 for sure		$10 if the number is greater than 18 (10% chance) versus $0 if the number is 18 or less (90% chance)	
19	$5 for sure		$10 if the number is greater than 19 (5% chance) versus $0 if the number is 19 or less (95% chance)	

Comments and Suggestions

Thank you for participating in this experiment. Please take the time to answer the following questions. You do not need to sign your name.

1/. Were the instructions clear?

2/. Were the practice periods helpful?

3/. How many periods did it take before you felt that you understood the first part?

4/. Please describe how you choose your Decision Numbers in the first part.

5/. How many periods did it take before you felt that you understood the second part?

6/. Please describe how you choose your Decision Numbers in the second part.

7/. If we were to play the game for another 25 periods which part would you choose to play?

Part 1 Part 2 Either Neither

8/. Do you have any comments or suggestions about the experiment in which you just participated?

Appendix B

B.1 Instructions for Exogenous Targeting Experiment with Heterogeneous Agents

This is a session in an experiment in the economics of decision making. During this session your payoffs will be reported in lab dollars. It is possible that you could lose money in this session. As a result everyone will be given an opening balance of 250 lab dollars. If at anytime your cumulative payoff (which includes this opening balance) falls below 0 lab dollars you will be excused from this part of the session. Despite this if you follow the instructions carefully you may earn a considerable amount of money. This research is being funded by the Social Sciences and Humanities Research Council of Canada and McMaster Universities Arts Research Board.

Lottery

Before we begin the actual session please fill out the form labelled lotteries which will be found in your folder. For each choice please put an X in the column beside Option A or Option B. After today's session one of the choices will be selected at random, the lottery will be conducted and you will be paid depending on your choice and the outcome from the lottery. Once you have completed the form raise your hand and it will be collected.

Overview

Today's session will be conducted using the computer network located in our laboratory. The session will consist of 2 parts which will each last 25 periods. We will begin after everyone has finished reading the instructions and completed 5 practice periods. Please refrain from talking during the session. Each period will proceed as follows.

What the Computer does	**What you do**
Start period.	
	Choose a "decision number" and enter it in the appropriate box on your computer screen.
Collect decision numbers, Calculates individual payoffs, and returns results	
	Check your payoff and cumulative payoff
Start next period or end section	

Now here are the details.

Part 1

You have been assigned to a group of six (yourself and five other) participants. This will be your group for the entire session. This part will consist of 25 periods. In each period you (and the others in your group) will be asked to choose a number and to enter it into the computer. This is your **Decision Number**.

Your Total Payoff for each period is the sum of your Private Payoff and your Group Payoff:

Total Payoff = Private Payoff + Group Payoff

Your Private Payoff depends only on your own Decision Number. You have been randomly assigned to a player type. Half (3) of the people in your group must choose their Decision Number between 0 and 125. The other half of the people in your group must choose their Decision Number between 0 and 75. The payoffs are also different for both types of people so that the Private payoff to choosing 10 for people whose decision numbers can range between 0 and 125 is different than the payoff to choosing 10 for people whose decision number can range between 0 and 75.

Table 1 in your folder shows the Private Payoff for each of your possible Decision Numbers. For example if you were to choose 30 Table 1 shows your Private Payoff for choosing that Decision Number.

If your Decision Numbers must be less than 125 Table 1 shows you that your Private Payoff for choosing 30 would be 6.95 lab dollars.

If your Decision Numbers must be less than 75 Table 1 shows you that your Private Payoff for choosing 30 would be 20.95 lab dollars.

Notice that the higher your Decision Number the higher your Private Payoff.

Table 2 in your folder shows the Private Payoffs for each of the possible Decision Numbers for someone of the other type. For example Table 2 shows the Private Payoff to a participant of the other type who chose 30.

If the participant of the other type's Decision Numbers are always less than 75 then Table 2 shows that their Private Payoff for choosing 30 is 20.95 lab dollars.

Or, if the participant of the other type's Decision Numbers are always less than 125 Table 2 shows their Private Payoff for choosing 30 is 6.95 lab dollars.

Notice that the higher their Decision Number the higher their Private Payoff.

The Group Total is the sum of your decision number and the decision numbers of the five other people in your group. Since three of the people in your group must choose their decision numbers between 0 and 125 and three must choose between 0 and 75 the group total must be between 0 and 600.

The Group Payoff depends only on the Group Total and is the same for everyone in the group. If the Group Total is less than or equal to 150 then the Group Payoff will be a positive value equal to 30% of the difference between 150 and the Group Total. If the Group Total is greater than 150, the Group Payoff is a negative value equal to 30% of the difference between 150 and the Group Total. The Group Payoff can be written as the following function of the Group Total:

$$\text{Group Payoff} = \begin{cases} 0.3*(\ 150 - \text{Group Total}\ ) & \text{if Group Total} > 150 \\ 0.3*(\ 150 - \text{Group Total}\ ) & \text{if Group Total} \leq 150 \end{cases}$$

For example if the Group Total were 170 then the Group Payoff for every member of the group would be 0.3*(150 - 170) = -6.00 lab dollars. Similarly if the Group Total were 140 then the Group Payoff for every member of the group would be 0.3*(150-140) = 3.00 lab dollars. Notice that the higher the Group Total the lower the Group Payoff.

As a simple example, suppose that you chose 30, and everyone else in your group chose 20. The Group Total would be 130 (the sum of your decision number and the decision numbers of everyone else in your group), your Private Payoff would be 6.95 if your decision numbers must be less than 125 and 20.95 if your decision numbers must be less than 75, the Group Payoff would be 6.00, and your Total Payoff would be 12.95 if your decision numbers are always less than 125, and 26.95 lab dollars if your decision numbers are always less than 75.

Now suppose, that you had chosen 70 in the above example. The Group Total would be 170, your Private Payoff 18.95 if your decision numbers are always below 125 and 24.95 if your decision numbers are always below 75, the Group Payoff would be -6.00, and your Total Payoff would be 12.95 or 18.95 lab dollars depending on what type you are. Notice that the higher your Decision Number the higher your Private Payoff. But, the higher your Decision Number the higher the Group Total and the lower the Group Payoff.

Your payment for this session will be the sum of your earnings in each of the 25 periods. Your earnings will be converted from lab dollars to Canadian at the rate of 1 lab dollar is equal to 2 1/2 cents Canadian. In the event that you do lose your opening balance you will be informed by the computer that you are Bankrupt and will not be able to participate in the rest of this part of the experiment. At this point the rest of the people in your group will be informed that there is now one less person whose decision number is being added into the group total.

Please answer the following question:

Use TABLE 1 to fill in the portion of the record sheet below assuming that you chose 65, the Group Total was 400 and the group payoff is 30% of the difference between 150 and the Group Total if the Group Total is above 150 and 30% of the difference between 150 and the Group Total if the Group Total is less than or equal to 150

Period	Decision Number	Private Payoff	Group Total	Group Payoff	Total Payoff	Cumulative Payoff

Practice						

Please raise your hand when you are done so that the monitor can check your answer.

Before we begin we will conduct five practice periods. These practice periods are intended to help you understand today's experiment. Any earnings you make during the practice periods will not be included in your payment at the end of the session. The practice periods will differ from the actual periods in that the Group Total will be your decision number plus a random number chosen by the computer. The Group Total in the practice periods will be your decision number plus a random number between 0 and 500. This random number is chosen by the computer so that each number between and including 0 and 500 has an equal chance of being selected.

Once the first practice period starts you will notice that the game window on the computer screen has five sections. The first section describes the Group Payoff function. This function is the same as described in the instructions above. The second section is labelled Payoff for a Player of your type. Using this calculator you will be able to determine your payoff from different combinations of values for your Decision Number and the Group Total. Notice that you can change the Decision Number and the Group Total by typing numbers into the edit boxes or by using the arrow buttons located beside the edit boxes. Also notice that changing the Decision Number changes the Group Total. This is because the Group Total is the sum of your Decision Number, and the Decision Numbers of those in your group and as a result when your Decision Number increases so does the Group Total. The third section is labelled Payoff for a Player of the other type. Using this calculator you will be able to determine the payoff to a player of the other type from different combinations of values for their Decision Number and the Group Total. The fourth section of the screen is where you type your Decision Number. Once you have chosen your Decision Number and typed it into the edit box click on the Ok button to complete this part of the period. The fifth section of the screen contains two tabs which allow you to switch between the main screen and the history screen. If you click on the tab labelled history you will be able to see the outcome of all of the previous period in which you have participated. Please feel free to raise your hand and ask any questions you may have.

To help you understand the Scratch Pad please pick any valid decision number and type it into the box beside Your Decision Number on the scratch pad.

Now pick a bigger number and type it into the box beside Group Total. Notice that the Group Total will always be bigger than your Decision Number as it is the sum of the Decision Numbers of everyone in your group. Now use the arrow buttons beside the box where you typed Your Decision Number to increase or decrease Your Decision Number. Notice the effect of these changes on your Total Payoff.

Once the practice periods have been completed we will begin the 25 periods for which you will be paid at the end of today's session.

Part 2 - Instructions

This phase of the experiment will also consist of 25 periods. You (and everyone else) are in the same group as you were before. The only difference from the previous section is in how the Group Total is calculated. Once this part begins you will notice that you have an opening balance of 250 lab dollars. If you should lose your opening balance you will receive no payment for this part of the experiment.

Everyone will maintain the same private payoff tables in this phase of the experiment as they had before. Thus, if your Decision Numbers were between 0 and 125 in the first phase they will be between 0 and 125 in this phase, and if your Decision Numbers were between 0 and 75 in the first phase they will be between 0 and 75 in this phase.

Your Total Payoff for the period is the sum of a Private Payoff and a Group Payoff:

Total Payoff = Private Payoff + Group Payoff

Your Private Payoff is again determined by Table 1, and Table 2 tells you the payoffs of the people of the other type. Please note that for both player types higher Decision Numbers result in higher Private Payoffs.

The Group Total is the sum of your decision number and the decision numbers of everyone else in your group.

The Group Payoff depends only on the Group Total and is the same for everyone in the group. If the Group Total is less than or equal to 150 then the

Group Payoff will be zero. If the Group Total is greater than 150, the Group Payoff is -24. The Group Payoff can be written as the following function of the Group Total:

$$\text{Group Payoff} = \begin{cases} -24 & \text{if Group Total} > 150 \\ 0 & \text{if Group Total} \leq 150 \end{cases}$$

For example if the Group Total were 200 then the Group Payoff for every member of the group would be -24 lab dollars. Whereas, if the Group Total were 100 then the Group Payoff for every member of the group would be 0 lab dollars.

As a simple example, suppose that you chose 30, everyone else in your group chose 20. The Group Total would be 130 (the sum of your decision number and the decision numbers of everyone else in your group), your Private Payoff would be 6.95 if your decision numbers must be less than 125 and 20.95 if your decision numbers must be less than 75, the Group Payoff would be 0.00, and your Total Payoff would be 6.95 lab dollars if your decision numbers are always less than 125, and 20.95 if your decision numbers are always less than 75.

Now suppose, that you had chosen 70 in the above example. The Group Total would be 170, your Private Payoff would be 18.95 if your decision numbers are always below 125 and 24.95 if your decision numbers are always below 75, the Group Payoff would be -24.00, and your Total Payoff would be -5.05 lab dollars or .95 depending on what type you are. Notice that the higher your Decision Number the higher your Private Payoff. But, the higher your Decision Number the higher the Group Total and the lower the Group Payoff.

Your payment for this session will be the sum of your earnings in each of the 25 periods. Your earnings will be converted from lab dollars to Canadian at the rate of 1 lab dollar is equal to 2 1/2 cents Canadian. In the event that you do lose your opening balance you will be informed by the computer that you are Bankrupt and will not be able to participate in the rest of this part of the experiment. At this point the rest of the people in your group will be informed that there is now one less person whose decision number is being added into the group total.

Please answer the following question:

Use table 1 to fill in the portion of the record sheet below assuming that you chose 75, the group total was 125 and the group payoff is -24 if the group total is above 150 and zero otherwise.

Period	Decision Number	Private Payoff	Group Total	Group Payoff	Total Payoff	Cumulative Payoff
Practice						

Please raise your hand when you are done so that the monitor can check your answer.

Table B.1.1 Private Payoff Schedule

Choice	Private Payoff
0	-6.25
1	-5.75
2	-5.26
3	-4.77
4	-4.28
5	-3.80
6	-3.32
7	-2.85
8	-2.38
9	-1.91
10	-1.45
11	-0.99
12	-0.54
13	-0.09
14	0.36
15	0.80
16	1.24
17	1.67
18	2.10
19	2.53
20	2.95
21	3.37
22	3.78
23	4.19
24	4.60
25	5.00
26	5.40
27	5.79
28	6.18
29	6.57
30	6.95
31	7.33
32	7.70
33	8.07
34	8.44
35	8.80
36	9.16
37	9.51
38	9.86
39	10.21
40	10.55
41	10.89
42	11.22
43	11.55
44	11.88
45	12.20
46	12.52
47	12.83
48	13.14
49	13.45
50	13.75
51	14.05
52	14.34
53	14.63
54	14.92
55	15.20
56	15.48
57	15.75
58	16.02
59	16.29
60	16.55
61	16.81
62	17.06

Choice	Private Payoff
63	17.31
64	17.56
65	17.80
66	18.04
67	18.27
68	18.50
69	18.73
70	18.95
71	19.17
72	19.38
73	19.59
74	19.80
75	20.00
76	20.20
77	20.39
78	20.58
79	20.77
80	20.95
81	21.13
82	21.30
83	21.47
84	21.64
85	21.80
86	21.96
87	22.11
88	22.26
89	22.41
90	22.55
91	22.69
92	22.82
93	22.95
94	23.08
95	23.20
96	23.32
97	23.43
98	23.54
99	23.65
100	23.75
101	23.85
102	23.94
103	24.03
104	24.12
105	24.20
106	24.28
107	24.35
108	24.42
109	24.49
110	24.55
111	24.61
112	24.66
113	24.71
114	24.76
115	24.80
116	24.84
117	24.87
118	24.90
119	24.93
120	24.95
121	24.97
122	24.98
123	24.99
124	25.00
125	25.00

Table B.1.2 Private Payoff Schedule for Someone of the Other Type

Choice	Private Payoff
0	13.75
1	14.05
2	14.34
3	14.63
4	14.92
5	15.20
6	15.48
7	15.75
8	16.02
9	16.29
10	16.55
11	16.81
12	17.06
13	17.31
14	17.56
15	17.80
16	18.04
17	18.27
18	18.50
19	18.73
20	18.95
21	19.17
22	19.38
23	19.59
24	19.80
25	20.00
26	20.20
27	20.39
28	20.58
29	20.77
30	20.95
31	21.13
32	21.30
33	21.47
34	21.64
35	21.80
36	21.96
37	22.11

Choice	Private Payoff
38	22.26
39	22.41
40	22.55
41	22.69
42	22.82
43	22.95
44	23.08
45	23.20
46	23.32
47	23.43
48	23.54
49	23.65
50	23.75
51	23.85
52	23.94
53	24.03
54	24.12
55	24.20
56	24.28
57	24.35
58	24.42
59	24.49
60	24.55
61	24.61
62	24.66
63	24.71
64	24.76
65	24.80
66	24.84
67	24.87
68	24.90
69	24.93
70	24.95
71	24.97
72	24.98
73	24.99
74	25.00
75	25.00

Lotteries Participant Number: ________

For Each of the following nineteen choices put an X in the column following either Option A or B. One of the choices will be selected at random and the lottery to determine your payment will be conducted at the end of the experiment. At the end of the experiment the 19 balls numbered 1 through 19 will be placed in the lottery game. The first ball selected by the machine will determine which option will determine your payoff. Then 20 balls numbered 1 through 20 will be placed in the machine and another ball will be selected to determine the outcome of the lottery in option B.

Choice	Option A		Option B	
1	$5 for sure		$10 if the number is greater than 1 (95% chance) versus $0 if the number is 1 (5% chance)	
2	$5 for sure		$10 if the number is greater than 2 (90% chance) versus $0 if the number is 2 or less (10% chance)	
3	$5 for sure		$10 if the number is greater than 3 (85% chance) versus $0 if the number is 3 or less (15% chance)	
4	$5 for sure		$10 if the number is greater than 4 (80% chance) versus $0 if the number is 4 or less (20% chance)	
5	$5 for sure		$10 if the number is greater than 5 (75% chance) versus $0 if the number is 5 or less (25% chance)	
6	$5 for sure		$10 if the number is greater than 6 (70% chance) versus $0 if the number is 6 or less (30% chance)	
7	$5 for sure		$10 if the number is greater than 7 (65% chance) versus $0 if the number is 7 or less (35% chance)	
8	$5 for sure		$10 if the number is greater than 8 (60% chance) versus $0 if the number is 8 or less (40% chance)	
9	$5 for sure		$10 if the number is greater than 9 (55% chance) versus $0 if the number is 9 or less (45% chance)	
10	$5 for sure		$10 if the number is greater than 10 (50% chance) versus $0 if the number is 10 or less (50% chance)	

11	$5 for sure		$10 if the number is greater than 11 (45% chance) versus $0 if the number is 11 or less (55% chance)	
12	$5 for sure		$10 if the number is greater than 12 (40% chance) versus $0 if the number is 12 or less (60% chance)	
13	$5 for sure		$10 if the number is greater than 13 (35% chance) versus $0 if the number is 13 or less (65% chance)	
14	$5 for sure		$10 if the number is greater than 14 (30% chance) versus $0 if the number is 14 or less (70% chance)	
15	$5 for sure		$10 if the number is greater than 15 (25% chance) versus $0 if the number is 15 or less (75% chance)	
16	$5 for sure		$10 if the number is greater than 16 (20% chance) versus $0 if the number is 16 or less (80% chance)	
17	$5 for sure		$10 if the number is greater than 17 (15% chance) versus $0 if the number is 17 or less (85% chance)	
18	$5 for sure		$10 if the number is greater than 18 (10% chance) versus $0 if the number is 18 or less (90% chance)	
19	$5 for sure		$10 if the number is greater than 19 (5% chance) versus $0 if the number is 19 or less (95% chance)	

Comments and Suggestions

Thank you for participating in this experiment. Please take the time to answer the following questions. You do not need to sign your name.

1/. Were the instructions clear?

2/. Were the practice periods helpful?

3/. How many periods did it take before you felt that you understood the first part?

4/. Please describe how you choose your Decision Numbers in the first part.

5/. How many periods did it take before you felt that you understood the second part?

6/. Please describe how you choose your Decision Numbers in the second part.

7/. Do you have any comments or suggestions about the experiment in which you just participated?

Appendix C

Mathematical Appendix

C.1 Introduction

This appendix is organized into four sections. The first section discusses the basic model that the experiment in the proceeding chapters is based on. The second section describes the four different contracts discussed in the dissertation and the payoff maximizing Nash equilibria under each contract. The third section describes Nash equilibria under different possible preferences and the fourth section applies the McKelvey and Palfrey (1995) quantal response model to this environment.

C.2 Basic Model

The model involves N firms indexed $n=1,..,N$. An individual's private payoff or benefit function is given by

$$B(x_n) = \varepsilon_n - k_n(z_n - x_n)^2 \qquad \text{(C.2.1)}$$

where x_n denotes the subjects decision number, ε_n is the endowment, k_n is a parameter and z_n represents size. $B(x_n)$ is maximized when $x_n = z_n$. Subjects decisions are constrained to be between 0 and z_n. Thus the aggregate decision number $X = \sum_{n=1}^{N} x_n$ is constrained to be between 0 and $\sum_{n=1}^{N} z_n$

For the homogeneous study (Chapter 2), $\varepsilon_n = 25$, $k_n = 0.002$ and $z_n = 100$. For the heterogeneous study (Chapter 3), $z_n = 75$ for small type individuals and $z_n = 125$ for large type individuals.

I assume that social damages are linear in the aggregate decision numbers

$(D(X) = c \sum_{n=1}^{N} x_n)$ where c is a cost parameter and is equal to 0.3. The Social Planner's problem is to maximize the sum of the individual payoff functions $B(x_n)$ minus the social damage function $D(X)$:

$$\max_{x_1,\ldots,x_N} \left(\sum_{n=1}^{N} [\varepsilon_n - k_n(z_n - x_n)^2] - c\sum_{n=1}^{N} x_n\right). \tag{C.2.2}$$

The socially optimal decision number for firm n is given by the first order condition of the Social Planner's problem:

$$2k_n(z_n - x_n^*) - c = 0$$

$$\Rightarrow \qquad x_n^* = z_n - c/2k_n. \tag{C.2.3}$$

This implies that the socially optimal decision number is $x_n^* = z_n - 75$, since $c=0.3$ and $k_n=0.002\ \forall n$ in the experiments run to date. Thus, the socially optimal decision number for medium capacity subjects is 25 (since z_n =100), 50 for large capacity subjects (since z_n = 125) and 0 for small capacity subjects (since z_n =75).

C.3 Instruments

All of the instruments investigated are exogenous targeting instruments of the form suggested by Kathleen Segerson (1988):

$$T(X) = \begin{cases} t_n(X-X^*) + \tau_n & \text{if } X>X^* \\ s_n(X-X^*) - \beta_n & \text{if } X\leq X^* \end{cases} \tag{C.3.1}$$

where $X^* := \sum_{n=1}^{N} x_n^*$, t_n denotes a tax on the difference between the observed and the optimal sum of the decision numbers (or group total), s_n is a subsidy based on the difference between the observed and optimal group total, τ_n is a lump-sum fine and

β_n is a lump-sum bonus. ($T(X)$ enters negatively into the individual payoff function). Since these instruments depend on not only an individual's decision but the decisions of the other individuals strategic uncertainty is introduced. Therefore, subjects beliefs or expectations of what others choose may be important. An individual's expected payoff function is given by the benefit function minus the value of the instrument:

$$\pi_n(x_n) = [\varepsilon_n - k(z_n - x_n)^2] - [t_n(X-X^*) + \tau_n]Prob(X > X^*)$$
$$- [s_n(X-X^*) - \beta_n][1 - Prob(X > X^*)]. \qquad \text{(C.3.2)}$$

$Prob(X>X^*)$ refers to an individual's expectation that $X > X^*$ or, since an individual's own decision is known to them, Prob$(X_{-n} + \upsilon > X^* - x_n)$, where $X_{-n} = \sum_{i \neq n} x_i$ represents strategic uncertainty (the uncertainty about others' decisions, Rapoport and Sulieman 1993) and υ accounts for environmental uncertainty (in the homogeneous study there is a uncertainty treatment where $\upsilon \sim$ U[-40, 40]).

There are three cases for individual's expectations

I. **Subject n expects that $X > X^*$ no matter what she chooses.**

$$X_{-n} > X^* \quad \rightarrow Prob(X_{-n} + \upsilon > X^* - x_n) = 1 \;\; \forall x_n \in (0,..,z_n)$$

II. **Subject n expects that $X < X^*$ no matter what she chooses.**

$$X_{-n} < X^* - z_n \quad \rightarrow Prob(X_{-n} + \upsilon > X^* - x_n) = 0 \;\; \forall x_n \in (0,..,z_n)$$

III. **Subject n expects that her decision does matter** (the sum of everyone else's decision falls between the optimal decision minus subject n's maximum decision and the optimal decision).

$$X^* - z_n < X_{-n} \leq X^* \rightarrow 0 < Prob(X_{-n} + \upsilon > X^* - x_n) < 1 \;\; \forall x_n \in (0,..,z_n)$$

In what follows I present the Nash equilibria for each of the three cases under the four different instruments, Tax-Subsidy, Tax, Subsidy, and Group Fine, discussed throughout the dissertation.

C.3.1 Tax-Subsidy

$$T(X) = \begin{cases} t(X\text{-}X^*) & if\, X > X^* \\ t(X\text{-}X^*) & if\, X \leq X^* \end{cases} \qquad \text{(C.3.1.1)}$$

The first instrument is referred to as the Tax-Subsidy instrument. This is the basic Segerson instrument (C.3.1) with $t_n = s_n = t$, and $\tau_n = \beta_n = 0$. As a result, individual n's expected payoff function is given by

$$\pi_n(x_n) = \varepsilon_n - k(s_n - x_n)^2 - t(X\text{-}X^*)Prob(X_{-n} + \upsilon > X^* - x_n)$$

$$- t(X\text{-}X^*)[1 - Prob(X_{-n} + \upsilon > X^* - x_n)]$$

$$= \varepsilon_n - k(s_n - x_n)^2 - t(X\text{-}X^*). \qquad \text{(C.3.1.2)}$$

Notice that the individual's expected payoff function does not depend on Prob$(X>X^*)$ and so neither expectations nor uncertainty in X are important. As a result, individual n's Nash equilibrium decision is independent of her expectations over the other subjects' decisions and so an individual's decision is identical for all three of the expectation cases. Differentiating the expected payoff function with respect to x_n we see that the first order condition of the individual's decision problem is

$$\partial\pi_n(x_n^*)/\partial x_n = 2k(z_n - x_n^*) - t = 0 \tag{C.3.1.3}$$

which is identical to the first order condition for the social planners' problem (C.2.2) if $t = \partial D(X)/\partial x_n = c$. This condition is independent of the heterogeneity parameters ε_n, k_n and s_n, and the individual's expectations. As a result, the value of the tax and subsidy t is chosen equal to c (0.3). The Nash equilibrium under this contract is found by solving the first order condition for x_n^*

$$x_n^* = z_n - t/2k. \tag{C.3.1.4}$$

Recall that t=0.3 and k=0.002. Thus, the dominant strategy for medium capacity subjects is $x_n = 100 - 0.3/0.004 = 25$, for large capacity subjects is $x_n = 125\text{-}0.3/0.004 = 50$, and for small capacity subjects is $x_n = 75\text{-}0.3/0.004 = 0$ which is identical to the socially optimal outcome.

C.3.2 Tax

$$T(X) = \begin{cases} t(X-X^*) & \text{if } X_{-n} > X^* \\ 0 & \text{if } X_{-n} \leq X^* \end{cases} \tag{C.3.2.1}$$

The second instrument discussed in the dissertation is the Tax instrument. Again it is based on the Segerson instruments (C.3.1) with $t_n = t,\ s_n = \tau_n = \beta_n = 0$. The expected payoff function for this instrument is

$$\pi_n(x_n) = \varepsilon_n - k(z_n - x_n)^2 - t(X-X^*)Prob(X_{-n} + \upsilon > X^* - x_n). \tag{C.3.2.2}$$

This implies that the first order condition of the individual's decision problem does depend on the individual's expectations. For all three of the expectation cases the first order condition for the payoff maximizing decision number ($\hat{x}_n$) is the same:

$$\partial\pi_n(\hat{x}_n)/\partial x_n = 2k(z_n-\hat{x}_n) - tProb(X>X^*) - t(\hat{X}-X^*)\partial Prob(X>X^*)/\partial x_n = 0$$

$$\rightarrow 2kz_n - 2k\hat{x}_n - tProb(X>X^*) - t\hat{x}_n\partial Prob(X>X^*)/\partial x_n$$

$$- t(X_{-n}-X^*)\partial Prob(X>X^*)/\partial x_n = 0$$

$$\rightarrow \hat{x}_n = \frac{2kz_n - tProb(X>X^*) - t(X_{-n}-X^*)\partial Prob(X>X^*)/\partial x_n}{[2k+t\partial Prob(X>X^*)/\partial x_n]}$$

Assume $Prob(X>X^*)$ is constant with respect to x_n. Then

$$\hat{x}_n = \frac{2kz_n - tProb(X>X^*)}{2k} \qquad \text{(C.3.2.4)}$$

Case I: ***$Prob(X_{-n} + \upsilon > X^* - x_n) = 1$*, subject *$n$* believes *$X > X^*$* no matter what she chooses.**

In this case $\hat{x}_n = \dfrac{2kz_n - t}{2k} = z_n - t/2k = x_n^*$ which is identical to the first order condition for the social planner's problem (C.2.2) if $t = \partial D(X)/\partial x_n = c = 0.3$. Again, this condition is independent of the heterogeneity parameters ε_n and z_n. Thus, if subjects believe that $X > X^*$, they will choose $x_n^* = z_n - t/2k = z_n - 0.3/0.004$ which is the socially optimal decision number. Thus, if subjects expect that $X>X^*$ they should choose the socially optimal outcome (x_n^* $\forall$ n) which implies that $X=X^*$. Thus there is no Nash equilibrium where subjects expect $X>X^*$.

Case II: ***$Prob(X_{-n} + \upsilon > X^* - x_n) = 0$*, subject *$n$* believes *$X < X^*$* no matter what she chooses.**

The individual payoff maximizing decision in this case is given by $\hat{x}_n = \dfrac{2kz_n}{2k} = z_n$ which is inconsistent with there being a symmetric Nash equilibrium since if $x_n = z_n$ for all n, $X = 600 > X^*$. Therefore there are no symmetric Nash equilibria where $Prob(X_{-n} + \upsilon > X^*) = 0$.

Case III: $0 < Prob(X_{-n} + \upsilon > X^* - x_n) < 1$, subject n believes her decision does matter.

Under certainty, this case lies between Cases I and II.

$$\hat{x}_n = \frac{2kz_n - tProb(X > X^*)}{2k}. \tag{C.3.2.5}$$

As $Prob(X > X^*)$ approaches 0, $\hat{x}_n$ approaches z_n, and as $Prob(X > X^*)$ approaches 1, $\hat{x}_n$ approaches x_n^*. Thus, for intermediary values of $Prob(X > X^*)$, $\hat{x}_n$ lies between x_n^* and z_n. But if $\hat{x}_n > x_n^* \; \forall \, n$, $Prob(X > X^*) = 1$ which implies $\hat{x}_n = x_n^*$. Therefore, the socially optimal outcome $\hat{x}_n = x_n^* \;\; \forall \, n$ is the unique Nash equilibrium, and $\hat{x}_n = x_n^*$ is the dominant strategy for player n.

For the uncertainty session in the homogeneous study where $\upsilon \sim U[-40,40]$

$$\begin{aligned} Prob(\upsilon \le X^* - X) &= (X^* - X - (-40))/(40 - (-40)) \\ &= (190 - X)/80 \end{aligned} \tag{C.3.2.6}$$

by the definition of a uniform distribution, which implies $\partial[Prob(\upsilon \le X^* - X)]/\partial x_n = -1/80$, and

$$\begin{aligned} \pi_n(x_n) &= \epsilon_n - k(z_n - x_n)^2 - t(X - X^*)[1 - Prob(\upsilon \le X^* - X)] \\ &= \epsilon_n - k(z_n - x_n)^2 - t(X - X^*)[1 - (190 - X)/80] \end{aligned} \tag{C.3.2.7}$$

$$\partial\pi_n(x_n)/\partial x_n = 2k(z_n - x_n) - t(X - X^*)/80 - t[1 - (190 - X)/80] = 0 \tag{C.3.2.8}$$

Notice that the second derivative (substituting in the values of the parameters)

$$\partial^2\pi_n/\partial x_n^2 = -0.004-0.0225-0.0225 < 0 \qquad \text{(C.3.2.9)}$$

satisfies the second order condition for a maximum throughout its entire range (using the parameter values from the experiment). I can solve this by assuming agents make symmetric decisions. Assume $x_n^U = z_n$ - a (recall $x^*_n = z_n - 75$ from (C.2.2)) and then calculate a. Notice that this definition implies that $X = \sum^6_{n=1}(z_n - a) = \sum^6_{n=1} z_n - 6a$, and since $\sum^6_{n=1} z_n = 600$, $X = 600 - 6a$

$$\partial\pi_n/\partial x_n = 0.004(z_n - z_n + a) - 0.3(\sum^6_{n=1} z_n - 6a - X^*)/80$$

$$- 0.3(1-(190-\sum^6_{n=1} z_n + 6a)/80) = 0$$

$$\Rightarrow \quad 0.004a^* - 0.3(600)/80 + 0.3(6)a^*/80 + 0.3(150)/80$$

$$- 0.3 + 0.3(190)/80 - 0.3(600)/80 + 0.3(6)a^*/80 = 0$$

$$\Rightarrow \quad 0.049a^* - 3.525 = 0 \Rightarrow a^* = 71.94. \qquad \text{(C.3.2.10)}$$

Therefore, there is a symmetric dominant strategy Nash equilibrium under the Tax instrument and uncertainty. For the homogeneous study $z_n = 100, x_n = 28$, for small type individuals $s_n = 75, x_n = 3$, for large type individuals $s_n = 125, x_n = 53$ and X = 168 for both studies.

In summary, under certainty, Symmetric Compliance (where all subjects choose the socially optimal decision number x_n^*) is the unique Nash equilibrium. It is also the case that choosing the socially optimal decision number is a dominant strategy. Under uncertainty, the Tax contract is "weaker" in that the unique Nash equilibrium is for the medium capacity subjects in the homogeneous studies to choose $x_n = 28$ which is slightly greater than the socially optimal decision number ($x_n^* = 25$).

C.3.3 Subsidy

$$T(X) = \begin{cases} 0 & X > X^* \\ s_n(X - X^*) - \beta_n & X \leq X^* \end{cases} \qquad \text{(C.3.3.1)}$$

The Subsidy contract provides a proportional as well as a lump-sum subsidy if X is less than X^*, $t_n = \tau_n = 0$, $s_n = s$, $\beta_n = \beta$. The expected payoff function is

$$\pi_n(x_n) = \varepsilon_n - k(z_n - x_n)^2 - [s(X - X^*) - \beta_n][1 - Prob(X_{-n} + \upsilon > X^* - x_n)].$$

This implies that an individual's best response function is given by

$$\partial\pi_n(\hat{x}_n)/\partial x_n = 2k(z_n - \hat{x}_n) - s[1 - Prob(X > X^*)] + [s(X - X^*) - \beta]\partial Prob(X > X^*)/\partial x_n = 0$$

. Again, assuming $Prob(X > X^*)$ is constant with respect to x_n, this implies

$$\hat{x}_n = \frac{2kz_n - s[1 - Prob(X > X^*)]}{2k} \qquad \text{(C.3.3.2)}$$

Case I: ***$Prob(X_{-n} + \upsilon > X^* - x_n) = 1$*, subject *n* believes *$X > X^*$* no matter what she chooses.**

If subjects believe that no matter what they choose $X > X^*$ then their payoff maximizing strategy is to choose their maximum decision number z_n from (C.3.3.2). If everyone chooses z_n, then $X > X^*$, and this is a Nash equilibrium. This outcome is referred to as Symmetric Non-Compliance as subjects are choosing not to reduce their emissions from the maximum z_n.

Case II: ***Prob*($X_{-n} + \upsilon > X^* - x_n$) = 0, subject *n* believes $X < X^*$ no matter what she chooses.**

From equation (C.3.3.2) if subject n believes $X<X^*$ no matter what she chooses then $\hat{x}_n = z_n - s/2k = x_n^*$ which is identical to the first order condition to the Social Planner's problem if $s = c$. Thus, Symmetric compliance (all subjects choosing the socially optimal decision number) is also a Nash equilibrium under the Subsidy Contract.

Case III: **$0 < Prob(X_{-n} + \upsilon > X^* - x_n) < 1$, subject n believes her decision does matter.**

For this case as $Prob(X_{-n} + \upsilon > X^* - x_n)$ approaches 0, $\hat{x}_n$ approaches x_n^*. Further, as $Prob(X > X^*)$ approaches 1, $\hat{x}_n$ approaches z_n. Thus, for intermediary values of $Prob(X > X^*), \hat{x}_n$ lies between x_n^* and z_n. But if $\hat{x}_n > x_n^* \ \forall\, n$, $Prob(X > X^*) = 1$ which implies $\hat{x}_n = z_n$. Thus, Symmetric Non-Compliance is a Nash equilibrium if people believe that their decisions matter.

For the uncertainty session in the homogeneous study where $\upsilon \sim U[-40,40]$ $\text{Prob}(\upsilon \leq X^* - X) = (X^* - X - (-40))/(40 - (-40)) = (190 - X)/80$ which implies $\partial[Prob(.)]/\partial x_n = -1/80$, and

$$\pi_n(x_n) = \varepsilon_n - 0.002(s_n - x_n)^2 - s_n(X - X^*)[Prob(\upsilon \leq X^* - X)]$$

$$= \varepsilon_n - 0.002(s_n - x_n)^2 - 0.3(X - X^*)[(190 - X)/80] \qquad \text{(C.3.3.3)}$$

$$\partial\pi^e(x_n)/\partial x_n = 0.004(s_n - x_n) - .3(X - X^*)/80 - .3(190 - X)/80 = 0$$

Notice that the second derivative $\partial^2\pi^e/\partial x_n^2 = -0.004+0.0225+0.0225 > 0$ which does not satisfy the second order condition and so there is no symmetric Nash equilibrium when subjects expect that the sum of the other agents' decisions are within z_n of 150 under uncertainty.

Under certainty, both Symmetric Compliance and Symmetric Non-Compliance are Nash equilibria of the Subsidy Contract. Under uncertainty only Symmetric Non-Compliance is a Nash equilibria.

C.3.4 Group Fine

$$T(X) = \begin{cases} \tau & X > X^* \\ 0 & X \leq X^* \end{cases} \qquad \text{(C.3.4.1)}$$

The fourth instrument is referred to as the Group Fine instrument, $\tau_n = \tau$, and $t_n = s_n = \beta_n = 0$. The expected payoff function is

$$\pi_n(x_n) = \varepsilon_n - k(z_n - x_n)^2 - \tau Prob(X_{-n} + \upsilon > X^*) \qquad \text{(C.3.4.2)}$$

which implies the first order condition of the individual's decision problem is

$$\partial\pi^e(\hat{x}_n)/\partial x_n = 2k(z_n - \hat{x}_n) - \tau\, \partial[Prob(X_{-n} + \upsilon > X^* - \hat{x}_n)]/\partial x_n = 0. \qquad \text{(C.3.4.3)}$$

Assuming $Prob(X > X^*)$ is constant with respect to x_n implies $\hat{x}_n = z_n$ which is independent of expectations.

Under the uncertainty case where $\upsilon \sim U[-40,40]$, $Prob(\upsilon \leq X^* - X) = (X^* - X - (-40))/(40 - (-40)) = (190 - X)/80$ which implies $\partial[Prob(X > X^*)]/\partial x_n = -1/80$ using the properties of a uniform distribution. Therefore, to induce agents to the socially optimal outcome $\tau/80 = c \rightarrow \tau = c*80 = 24\ (c = 0.3)$. This result is independent of the heterogeneity parameters ε_n, k_n and s_n, but not expectation.

Case I: ***$Prob(X_{-n} + \upsilon > X^* - x_n) = 1$*, subject *n* believes $X > X^*$ no matter what she chooses.**

For this case subject *n*'s expected payoff function is

$$\pi_n(x_n) = \epsilon_n - k(z_n - x_n)^2 - \tau \tag{C.3.4.4}$$

which implies that the Nash equilibrium is Symmetric Non-Compliance ($x_n = z_n\ \forall\ n$).

Case II: ***$Prob(X_{-n} + \upsilon > X^* - x_n) = 0$*, subject *n* believes $X < X^*$ no matter what she chooses.**

This case implies that subject *n*'s expected payoff function is

$$\pi_n(x_n) = \varepsilon_n - k(z_n - x_n)^2 . \tag{C.3.4.5}$$

This again implies that Symmetric Non-Compliance is a Nash equilibrium ($x_n = z_n$ $\forall\ n$).

Case III: **$0 < Prob(X_{-n} + \upsilon > X^* - x_n) < 1$, subject n believes her decision does matter.**

In this case subject *n*'s expected payoff function is

$$\pi_n(x_n) = \varepsilon_n - k(z_n - x_n)^2 - \tau Prob(X_{-n} + \upsilon > X^*) \tag{C.3.4.5}$$

As discussed above, under uncertainty, τ and υ are chosen so that any set of decisions that sum to the target level (X=X^*) is a Nash equilibrium. These multiple equilibria are referred to as Asymmetric Compliance. Under certainty if subject *n* believes she can choose a decision number (x_n^{GF}) so that $X=X^*$ then she should and this is a Nash equilibrium. To prove that this is a Nash equilibrium, notice that it is not in subject n's best interest to change her decision number from x_n^{GF}, as decreasing it reduces her private payoff and increasing it ensures that $X>X^*$ which results in the fine being incurred. This is also the case for all of the other subjects in the group and so any set of decision numbers that sum to X^* is a Nash equilibria.

As a result there are multiple Nash equilibria under the Group Fine instrument under both certainty and uncertainty. It has been shown that Symmetric Non-Compliance is a Nash equilibrium under certainty and under uncertainty for Cases I and II. It has also been shown that if subjects believe their decisions can effect whether $X>X^*$ or not, then Asymmetric Compliance (which includes Symmetric Compliance) are also Nash equilibria.

C.4 Preferences

This section discusses the mathematics underlying the application of the different preference models discussed in Chapter 4 to the Tax-Subsidy instrument. Three different preference hypothesis are considered: altruism, warm-glow, and equity. Altruism (α_n) is modelled as the dependence of player n's utility on the payoffs of the other subjects in the group, warm-glow (g_n) is modelled as utility from reduced appropriation, and equity (e_n) is modelled as utility from choosing the average decision number.

$$U_n = \pi_n + g_n(x_n^{\max}-x_n) + \alpha_n \sum_{j \neq n}^{N} \pi_j - e_n|d_n|, \tag{C.4.1}$$

where $d_n = x_n - \dfrac{\sum_i^N x_i}{N}$.

For the Tax-Subsidy contract

$$U_n = \varepsilon - k(x_n^{\max}-x_n)^2 - t(X^e-X^*) + g_n(x_n^{\max}-x_n)$$
$$+ \alpha_n \sum_{j \neq n}^{N} (\varepsilon - k(s_j-x_j)^2 - t(X^e-X^*)) - e_n|d_n| \tag{C.4.2}$$

To eliminate the absolute value sign, we need to deal with the case where $d_n > 0$ and the case where $d_n < 0$ separately.

Case I: $d_n > 0$ (Large capacity subjects)

$$U_n = \varepsilon - k(x_n^{\max}-x_n)^2 - t(X^e-X^*) + g_n(x_n^{\max}-x_n)$$
$$+ \alpha_n \sum_{j \neq n}^{N} (\varepsilon - k(s_j-x_j)^2 - t(X^e-X^*)) - e_n(d_n)$$

$$U_n = \varepsilon - k(x_n^{\max}-x_n)^2 - t(X^e-X^*) + g_n(x_n^{\max}-x_n)$$
$$+ \alpha_n \sum_{j \neq n}^{N} [\varepsilon - k(s_j-x_j)^2 - t(X^e-X^*)] - e_n(x_n - \frac{\sum_{i=1}^N x_i}{N})$$

$$\partial U_n/\partial x_n = 2k(z_n - x_n^P) - t - g_n - (N-1)t\alpha_n - e_n(1-1/N) = 0$$

$$x_n^P = z_n - t/2k - \frac{g_n + (N-1)t\alpha_n + e_n(1-1/N)}{2k}$$

$$x_n^P = x_n^* - \frac{g_n + (N-1)t\alpha_n + e_n(1-1/N)}{2k}. \tag{C.4.3}$$

Case II: $d_n < 0$ (Large capacity subjects)

$$U_n = \varepsilon - k(x_n^{\max}-x_n)^2 - t(X^e-X^*) + g_n(x_n^{\max}-x_n)$$
$$+ \alpha_n \sum_{j \neq n}^{N} (\varepsilon - k(s_j-x_j)^2 - t(X^e-X^*)) + e_n(d_n)$$

$$U_n = \varepsilon - k(x_n^{\max}-x_n)^2 - t(X^e-X^*) + g_n(x_n^{\max}-x_n)$$

$$+ \alpha_n \sum_{j \neq n}^{N} [\varepsilon - k(s_j - x_j)^2 - t(X^e - X^*)] + e_n(x_n - \frac{\sum_{i=1}^{N} x_i}{N})$$

$$\partial U_n / \partial x_n = 2k(z_n - x_n^P) - t - g_n - (N-1)t\alpha_n + e_n(1 - 1/N) = 0$$

$$x_n^P = z_n - t/2k - \frac{g_n + (N-1)t\alpha_n - e_n(1-1/N)}{2k}$$

$$x_n^P = x_n^* - \frac{g_n + (N-1)t\alpha_n - e_n(1-1/N)}{2k}. \qquad \text{(C.4.4)}$$

These expressions are used in Chapter 4.

C.5. Decision Error

The decision error hypothesis, that decisions will be distributed logistically, assumes that individuals make decisions under the assumption that others also make errors (Anderson, Gorree, and Holt 1998). This results in the following density of individual decisions:

$$f_n(x_n) = \frac{\exp(\pi_n^e(x_n)/\mu)}{\int_0^{s_n} \exp(\pi_n^e(x)/\mu) dx} \qquad \text{(C.5.1)}$$

which is a truncated logistic distribution. For the Tax-Subsidy Contract π_n^e is given by equation (C.3.1.2) and as a result the quantal response equilibrium distribution is given by

$$f_n(x_n) = \frac{\exp[(\varepsilon_n - k(s_n - x_n)^2 - t(X - X^*))/\mu]}{\int_0^{s_n} \exp[(\varepsilon_n - k(s_n - x_n)^2 - t(X - X^*))/\mu] dx} \qquad \text{(C.5.2)}$$

Since $e^{a+b} = e^a e^b$ anything that does not depend on x_n can be eliminated from $f(x_n)$. Completing the square of π_n^e simplifies $f_n(x_n)$.

$$(\varepsilon_n - k(s_n - x_n)^2 - t(X-X^*)) = \varepsilon_n - k(s_n^2 - 2s_n x_n + x_n^2) - tx_n - t\textstyle\sum_{j\neq n} x_j + tX^*$$

$$= (2ks_n - t)x_n - kx_n^2 + C \qquad \text{(the constant will be eliminated)}$$

$$= k[2(s_n - t/2k)x_n - x_n^2 + C'] \quad \text{(completing the square)}$$

$$= -k[(x_n - (s_n - t/2k))^2 - (s_n - t/2k)^2 + C']$$

$$= -k\,(x_n - (s_n - t/2k))^2 + C''. \qquad \text{(C.5.3)}$$

also notice from the first order condition of the Social Planner's problem (C.2.2) that $s_n - t/2k = x^*$. Therefore

$$f(x_n) = \frac{\exp[(-k(x_n - x^*)^2)/\mu]}{\int_0^{s_n} \exp[(-k(x_n - x^*)^2)/\mu]dx}. \qquad \text{(C.5.4)}$$

Notice that

$$\int_0^{s_n} \exp[(-k(x_n - x^*)^2)/\mu]dx \qquad \text{(C.5.5)}$$

This has a similar functional form to the normal probability density function

$$\int_{-\infty}^{A} \frac{1}{\sqrt{2\pi}}\frac{1}{\sigma}\exp(-1/2(x-\bar{x})^2/\sigma^2)dx = \Phi(\frac{A-\bar{x}}{\sigma}). \qquad \text{(C.5.6)}$$

In this case $\bar{x} = x^*$ and $2\sigma^2 = \mu/k$

$$\sqrt{2\pi}\sqrt{\mu/2k})\int_0^{s_n} \frac{1}{\sqrt{2\pi}\sqrt{\mu/2k}}\exp(-(x-x^*)^2/(\mu/k))dx$$

$$= \sqrt{2\pi}\sqrt{\mu/2k}[\Phi(\frac{s_n - x^*}{\sqrt{\mu/2k}}) - \Phi(\frac{-x^*}{\sqrt{\mu/2k}})] \qquad \text{(C.5.7)}$$

Recall $x^* = s_n - 75$, so $s_n - x^* = s_n - s_n + 75 = 75$ and $-x^* = -s_n + 75$

Hence,

$$f(x_n) = \frac{\exp[(-k(x_n - x^*)^2)/\mu]}{\int_0^{s_n} \exp[(-k(x_n - x^*)^2)/\mu]dx}$$

$$= \frac{\exp[(-k(x_n - x^*)^2)/\mu]}{\sqrt{2\pi}\sqrt{\mu/2k}[\Phi(\frac{s_n - x^*}{\sqrt{\mu/2k}}) - \Phi(\frac{-x^*}{\sqrt{\mu/2k}})]} \qquad \text{(C.5.8)}$$

taking the *ln* of this (for the log likelihood)

$$\ln(f_n(x_n)) = -k(x_n - x^*)^2/\mu - \frac{1}{2}\ln(2\pi) - \frac{1}{2}\ln(\frac{\mu}{2k}).$$
$$- \ln[\Phi(\frac{s_n - x^*}{\sqrt{\mu/2k}}) - \Phi(\frac{-x^*}{\sqrt{\mu/2k}})] \qquad \text{(C.5.8)}$$

This is the log likelihood function for the truncated logistic regression. By truncating the distribution Anderson et al. (1998) have implicitly assumed that there are no boundary effects. This is to say that there are no individuals who chose either of the boundaries (0 or s_n) because higher or lower values were not available to them. If however, some subjects might like to choose numbers outside of the allowed decision space, a censored distribution should be used. For the censored distribution assume, that z_n is the subject's actual decision and x_n is the observed decision which is constrained to be between 0 and x_n^{max} so that

$$x_n = \begin{cases} 0 & \text{if} \quad z_n \leq 0 \\ z_n & \text{if} \quad 0 < z_n < x_n^{max} \\ z_n^{max} & \text{if} \quad z_n \geq x_n^{max}. \end{cases} \qquad \text{(C.5.9)}$$

Assume that z_n has the logistic distribution assumed for the quantal response model

$$g_n(x_n) = \begin{cases} \mathrm{Prob}(z_n \le 0) & \text{if} \quad x_n = 0 \\ \mathrm{Prob}(z_n \le x_n) & \text{if} \quad 0 < x_n < x_n^{max} \\ \mathrm{Prob}(z_n \ge x_n^{max}) & \text{if} \quad x_n = x_n^{max} \end{cases} \tag{C.5.10}$$

or

$$g_n(x_n) = \begin{cases} \Phi(-x^* / \sqrt{\mu/2k}) & \text{if} \quad x_n = 0 \\ (\exp[-k(x_n - x^*)^2/\mu])/(\sqrt{2\pi}\sqrt{\mu/2k}) & \text{if} \quad 0 < x_n < x_n^{max} \\ 1 - \Phi(x^{\max} - x^* / \sqrt{\mu/2k}) & \text{if} \quad x_n = x_n^{max}. \end{cases} \tag{C.5.11}$$

Thus the likelihood function for the censored logistic distribution is

$$\mathcal{L} = \prod_{x_n=0} \Phi(\frac{x^*}{\sqrt{\mu/2k}}) \prod_{0<x_n<x^{\max}} \frac{\exp(-k(x_n - x^*)^2/\mu)}{\sqrt{2\pi}\sqrt{\mu/2k}} \prod_{x_n=x^{\max}} (1 - \Phi(\frac{x^{\max} - x^*}{\sqrt{\mu/2k}})) \tag{C.5.12}$$

and the log likelihood is

$$l = \sum_{x_n=0} \ln(\Phi(\frac{x^*}{\sqrt{\mu/2k}})) + \sum_{0<x_n<x^{\max}} [(-k(x_n - x^*)^2/\mu) - \ln(\sqrt{2\pi})/2 - \ln(\sqrt{\mu/2k})/2]$$

$$+ \sum_{x_n=x^{\max}} \ln(1 - \Phi(\frac{x^{\max} - x^*}{\sqrt{\mu/2k}})). \tag{C.5.12}$$

This is the standard Tobit model which is used in the regressions in Chapter 4 (see StataCorp(1999c) Reference A-F p. 146, $\bar{x} = x^*$ and $\sigma = \sqrt{\mu/2k}$).

Appendix D

Maximum Likelihood Estimation

D.1 Estimation of the Truncated Logit Quantal Response Model

```
@ This was the ML program to estimate a logit model @
@ This was an Econometrics 768 Project Assigned by Lonnie in 1994 @
@ I have modified it to estimate the warm glow and decision @
@ error parameters for the logit quantal response model @

@ John Spraggon, August 26, 1998@

@ Set output file and output format@
output file=decwarm_out reset;
format /ro /m1 10,5;

@ Initialize library for Maximum Likelihood @
library maxlik;
#include maxlik.ext;
maxset;

@ Write a procedure to calculate the value of the likelihood function@
@ l=sum [-0.002(x-w+75+250g)^2 - ln(sqrt(lambda)) @
@       -ln(erf(1.12(3+10g)/sqrt(lambda))        @
@          -erf(0.04(-w+75+250g)/sqrt(lambda))) @
@ So far I need three sets of procedures,        @
@       llogit{m,s,l} estimate both the decision error & warm glow parameters@
@       llogit(M,S,L}1 estimates the decision error parameter alone @
@       llogit(M,S,L}2 estimates the warm glow parameter alone @

proc llogitm(b,x);
@ This estimates both the peak and the decision error parameter for medium@
@ capacity subjects@
      local m, m1, m2, m3, m4, m5, m6, m7;

    m1=(-0.002*(x-25+250*b[1])^2);
    m2=ln(sqrt(b[2]));
    m3=1.118033989*(3+10*b[1])/(sqrt(b[2]));
    m4=erf(m3);
```

```
      m5=1.118033989*(-1+10*b[1])/(sqrt(b[2]));
      m6=erf(m5);
        m7=ln(erf(m3)-erf(m5));
      m=m1-m2-m7;
        retp(sumc(m));
endp;

proc llogitl(b,x);
@ This estimates both the peak and the decision error parameter for large@
@ capacity subjects@
        local m, m1, m2, m3, m4, m5, m6, m7;

      m1=-0.002*(x-50+250*b[1])^2;
      m2=ln(sqrt(b[2]));
      m3=1.118033989*(3+10*b[1])/(sqrt(b[2]));
      m4=erf(m3);
      m5=2.236067978*(-1+5*b[1])/(sqrt(b[2]));
      m6=erf(m5);
      m7=ln(m4-m6);
      m=m1-m2-m7;
        retp(sumc(m));
endp;

proc llogits(b,x);
@ This estimates both the peak and the decision error parameter for small@
@ capacity subjects@
        local m, m1, m2, m3, m4, m5, m6, m7;

      m1=-0.002*(x+250*b[1])^2;
      m2=ln(sqrt(b[2]));
      m3=1.118033989*(3+10*b[1])/(sqrt(b[2]));
      m4=erf(m3);
      m5=11.18033989*b[1]/(sqrt(b[2]));
      m6=erf(m5);
      m7=ln(m4-m6);
      m=m1-m2-m7;
        retp(sumc(m));
endp;

proc llogitM1(b,x);
```

```
@ This estimates only the decision error parameter for medium@
@ capacity subjects holding the peak constant at the payoff maximizing level@
        local m, m1, m2, m3, m4, m5, m6, m7;

    m1=-(0.002*(x-25)^2)/b;
    m2=ln(sqrt(b));
    m3=3.354101967/(sqrt(b));
    m4=erf(m3);
    m5=1.118033989/(sqrt(b));
    m6=erf(m5);
    m7=ln(m4+m6);
    m=m1-m2-m7;
      retp(sumc(m));
endp;


proc llogitL1(b,x);
@ This estimates only the decision error parameter for large@
@ capacity subjects holding the peak constant at the payoff maximizing level@
        local m, m1, m2, m3, m4, m5, m6, m7;

    m1=-(0.002*(x-50)^2)/b;
    m2=ln(sqrt(b));
    m3=3.354101967/(sqrt(b));
    m4=erf(m3);
    m5=2.236067978/(sqrt(b));
    m6=erf(m5);
    m7=ln(m4+m6);
    m=m1-m2-m7;
      retp(sumc(m));
endp;


proc llogitS1(b,x);
@ This estimates only the decision error parameter for small@
@ capacity subjects holding the peak constant at the payoff maximizing level@
        local m, m1, m2, m3, m4;

    m1=-(0.002*x^2)/b;
    m2=ln(sqrt(b));
```

```
        m3=3.354101967/(sqrt(b));
        m4=erf(m3);
        m=m1-m2-m4;
          retp(sumc(m));
endp;

proc llogitM2(b,x);
@{x contains x, b contains g, lambda is hard coded}@
@I'm going to calculate it in stages@
          local m, m1, m2, m3, m4, m5, m6, m7;

        m1=(-0.002*(x-25+250*b[1])^2);
        m2=ln(1.0257);
        m3=1.118033989*(3+10*b[1])/(sqrt(1.0257));
        m4=erf(m3);
        m5=1.118033989*(-1+10*b[1])/(sqrt(1.0257));
        m6=erf(m5);
          m7=ln(m4-m6);
        m=m1-m2-m7;
          retp(sumc(m));
endp;

proc llogitL2(b,x);
@{x contains x, b contains g, lambda is hard coded}@
@I'm going to calculate it in stages@
          local m, m1, m2, m3, m4, m5, m6, m7;

        m1=-0.002*(x-50+250*b[1])^2;
        m2=ln(sqrt(4.2438));
        m3=1.118033989*(3+10*b[1])/(sqrt(4.2438));
        m4=erf(m3);
        m5=2.236067978*(-1+5*b[1])/(sqrt(4.2438));
        m6=erf(m5);
        m7=ln(m4-m6);
        m=m1-m2-m7;
          retp(sumc(m));
endp;

proc llogitS2(b,x);
@{x contains x, b contains g, lambda is hard coded}@
```

```
@I'm going to calculate it in stages@
        local m, m1, m2, m3, m4, m5, m6, m7;

      m1=exp(-0.002*(x+b[1])^2/4.1320);
      m2=19.81663650*sqrt(4.1320);
      m3=0.04472135956*(75+b[1])/(sqrt(4.1320));
      m4=erf(m3);
      m5=0.04472135956*b[1]/(sqrt(4.1320));
      m6=erf(m5);
      m7=(m4-m6);
      m=m1/(m2*m7);
        retp(sumc(m));
endp;

@ Read Data In, File contains decision numbers for@
@ Medium, Large and Small type subjects under the @
@ Tax-Subsidy contract, no experience, no uncertainty @
n=450;
load D[n,3]=decdata.dat;

x = d[.,1];
"Mean Decision Number, Medium Capacity Subjects";
sumc(x)/n;

@ Set starting values@
lmbdastrt=1;
b=lmbdastrt;
@Using the Maximum Likelihood package to estimate for Medium Size@
maxprt(maxlik(x,0,&llogitM1,b));

gstrt=.4;
"Starting Values";
gstrt;
b=gstrt;

@the small capacity subject's functions should be most stable@
@maxprt(maxlik(x,0,&llogitM2,b));@

n=225;
load D[n,3]=decdata.dat;
```

```
x = d[.,2];
"Mean Decision Number, Large Capacity Subjects";
sumc(x)/n;
b=5;
@ Large capacity subjects@
maxprt(maxlik(x,0,&llogitL1,b));

gstrt=.4;
b=gstrt;
@maxprt(maxlik(x,0,&llogitL2,b));@
@the small capacity subject's functions should be most stable@


x = d[.,3];
"Mean Decision Number, Small Capacity Subjects";
sumc(x)/n;
b=5;
@ Small capacity subjects@
maxprt(maxlik(x,0,&llogitS1,b));
gstrt=20;
b=gstrt;
maxprt(maxlik(x,0,&llogitS2,b));

end;
system;
```

D.2 Estimation of the Tobit Model

```
@ This was the ML program to estimate a logit model @
@ This was an Econometrics 768 Project Assigned by Lonnie in 1994 @
@ I have modified it to estimate the peak and @
@ error parameters for the Tobit model@


@ John Spraggon, July 7, 1999@

@ Set output file and output format@
output file=tobit_out0708 reset;
format /ro /m1 10,5;
```

```
@ Initialize library for Maximum Likelihood @
library maxlik;
#include maxlik.ext;
maxset;

@ Write a procdure to calculate the value of the likelihood function@
@ This version uses the normal cdf to calculate the constant of int @
@ This program estimates lambda and x* (instead of g)          @
@ l=sum [exp(-0.002(x-xlarge*)^2/(lambda) @
@       /sqrt(2*pi)*sqrt(lambda/.004)]*[An Indicator for 0<x<xmax  @
@       + sum[(1-F((xmax-x*)/(sqrt(lambda/.004)))]*[An indicator x=xmax  @
@       + sum[F((-x*)/(sqrt(lambda/.004)))]*[An indicator x=0]     @
@                                                   @
@       ttobit(MSL) estimates the decision error parameter alone @
@       ttobit(MSL)2 estimates mean and decision error @
@       given that value for lambda... logit(M,S,L)1@
@ Ix is the indicator for 0<x<xmax, Ix0 is the indicator for x=0 @
@ and Ixmax is the indicator for x=xmax @

proc ttobitM(b,x);
@ This procedure calculates @
@ I'm going to calculate it in stages@
        local m, m1, m2, m3, m4, m5, m6, m7;
        m1=(-(0.002*(x[.,1]-25)^2)/b);
        m2=ln(2*pi)/2+ln(b/0.004)/2;
        m3=75/sqrt(b/0.004);
        m7=1-cdfn(m3);
        m4=ln(m7);
        m5=-25/sqrt(b/0.004);
        m6=ln(cdfn(m5));
        m=(m1-m2).*x[.,2]+m4.*x[.,4]+m6.*x[.,3];
        retp(sumc(m));
endp;


proc ttobitL(b,x);
@{x contains x , b lambda} Estimate holding g fixed from decerr2.ms@
@I'm going to calculate it in stages@
local m, m1, m2, m3, m4, m5, m6;
```

```
        m1=(-(0.002*(x[.,1]-50)^2)/b);
        m2=ln(2*pi)/2+ln(b/0.004)/2;
        m3=75/sqrt(b/0.004);
        m4=ln(1-cdfn(m3));
        m5=-50/sqrt(b/0.004);
        m6=ln(cdfn(m5));
        m=(m1-m2).*x[.,2]+m4.*x[.,4]+m6*x[.,3];
          retp(sumc(m));
endp;


proc ttobitS(b,x);
@{x contains x , b lambda} Estimate holding g fixed from decerr2.ms@
@ I'm going to calculate it in stages@
local m, m1, m2, m3, m4, m5, m6;

        m1=(-(0.002*(x[.,1])^2)/b);
        m2=ln(2*pi)/2+ln(b/0.004)/2;
        m3=75/sqrt(b/0.004);
        m4=ln(1-cdfn(m3));
        m5=0;
        m6=ln(cdfn(m5));
        m=(m1-m2).*x[.,2]+m4.*x[.,4]+m6*x[.,3];
          retp(sumc(m));
endp;

proc ttobitM1(b,x);
@{x contains x, Ix, Ix0, Ixmax, and b contains lambda and xmax} Estimate
holding g fixed @
@ I'm going to calculate it in stages@
          local m, m1, m2, m3, m4, m5, m6, m7;
          m1=(-(0.002*(x[.,1]-b[2])^2)/b[1]);
        m2=ln(2*pi)/2+ln(b[1]/0.004)/2;
        m3=(100-b[2])/sqrt(b[1]/0.004);
        m7=cdfn(m3);
          m4=ln(1-m7);
          m5=(-b[2])/sqrt(b[1]/0.004);
          m6=ln(cdfn(m5));
          m=(m1-m2).*x[.,2]+m4.*x[.,4]+m6.*x[.,3];
          retp(sumc(m));
```

```
endp;


proc ttobitL1(b,x);
@{x contains x , b lambda} Estimate holding g fixed from decerr2.ms@
@I'm going to calculate it in stages@
local m, m1, m2, m3, m4, m5, m6;

    m1=(-(0.002*(x[.,1]-b[2])^2)/b[1]);
    m2=ln(2*pi)/2+ln(b[1]/0.004)/2;
    m3=(125-b[2])/sqrt(b[1]/0.004);
    m4=ln(1-cdfn(m3));
    m5=(-b[2])/sqrt(b[1]/0.004);
    m6=ln(cdfn(m5));
    m=(m1-m2).*x[.,2]+m4.*x[.,4]+m6*x[.,3];
      retp(sumc(m));
endp;


proc ttobitS1(b,x);
@{x contains x , b lambda} Estimate holding g fixed from decerr2.ms@
@ I'm going to calculate it in stages@
local m, m1, m2, m3, m4, m5, m6;

    m1=(-(0.002*(x[.,1]-b[2])^2)/b[1]);
    m2=ln(2*pi)/2+ln(b[1]/0.004)/2;
    m3=(75-b[2])/sqrt(b[1]/0.004);
    m4=ln(1-cdfn(m3));
    m5=(-b[2])/sqrt(b[1]/0.004);
    m6=ln(cdfn(m5));
    m=(m1-m2).*x[.,2]+m4.*x[.,4]+m6*x[.,3];
      retp(sumc(m));
endp;



@ Read Data In, File contains decision numbers for@
@ Medium, Large and Small type subjects under the @
@ Tax-Subsidy contract, no experience, no uncertainty @
```

```
n=450;
load D[n,12]=decdata4.dat;
x = d[.,1]~d[.,2]~d[.,3]~d[.,4];

"Mean Decision Number, Medium Capacity Subjects";
mnx = sumc(x[.,1])/n;
mnx;
b=.5;
@ Medium capacity subjects@
maxprt(maxlik(x,0,&ttobitM,b));

b=.8~25;
maxprt(maxlik(x,0,&ttobitM1,b));

@Large Capacity@
n=225;
load D[n,12]=decdata4.dat;
x=d[.,5]~d[.,6]~d[.,7]~d[.,8];
mnx =sumc(x[.,1])/n;
mnx;
b=.5;
maxprt(maxlik(x,0,&ttobitL,b));

b=.5~25;
maxprt(maxlik(x,0,&ttobitL1,b));

@Small Capacity@
n=225;
load D[n,12]=decdata4.dat;
x=d[.,9]~d[.,10]~d[.,11]~d[.,12];
mnx=sumc(x[.,1])/n;
mnx;
b=.5;
maxprt(maxlik(x,0,&ttobitS,b));

b=.5~25;
maxprt(maxlik(x,0,&ttobitS1,b));
```

Appendix E

Data Appendix

E.1 Documentation

The file basicdata.dct included in a self extracting "zip" file called basicdata.exe on a floppy disk with this dissertation is an ASCII text file which contains a dictionary file which can be read directly into STATA (StataCorp 1999c) using the command infile (StataCorp 1999d). The data file contains all of the data used in the analysis presented in this dissertation. There are 9000 individual decisions in the dataset from 60 sessions with 6 subjects and 25 periods. The 60 sessions represent 3 replications of each of twenty different treatments 4 instruments by 2 order conditions by 2 certainty conditions with homogeneous agents (Chapter 2) and 2 instruments by 2 order conditions with heterogeneous agents (Chapter 3). For each of these observations there are 19 variables which are described in table E.1.1.

Table E.1.1
Data Description

Number	Variable Name	Data Type	Description
1	period	integer	period identifier 1-25
2	subject	integer	subject identifier 1-6
3	session	string	session identifier YYMMDDij[1]
4	treatmen	string	instrument identifier[2]
5	environm	string	certainty or uncertainty
6	conversi	real	conversion rate from lab dollars to Canadian dollars
7	decision	integer	subject's decision number 0 - 125
8	privatep	real	private payoff corresponding to decision number
9	randomno	integer	random number for uncertainty sessions
10	grouptot	integer	aggregate decision number (and random number for uncertainty sessions)
11	grouppay	float	payoff corresponding to the group total

[1] Where i represents order, A represents first (no experience), B represents second (experience) and j represents the time session took place A represents morning, B represents afternoon and C represents evening

[2] In this variable, fine represents the group fine, subsidy represents subsidy, tax represents tax and ts represents tax subsidy instrument.

12	payoff	float	total payoff (private + group)
13	cumulati	float	cumulative payoff
14	elapsedt	integer	time taken in period
15	bankrupt	real	1 if subjects cumulative payoff < 0
16	type	string	subjects capacity[3]
17	hom	byte	1 for homogeneous sessions
18	bank	float	1 of there are any bankruptcies in the session
19	order	float	Order of presentation[4]

[3]For this variable M - represents medium capacity, H - represents large capacity, and L represents small capacity.

[4]For this variable 0 represents first (no experience), 1 represents second (experience), 2 represents third (the computers crashed at some point during the experiment and an make-up 25 periods was conducted).

Bibliography

Anderson, Simon, Jacob Goeree, and Charles Holt, 1998. "A Theoretical Analysis of Altruism and Decision Error in Public Goods Games." *Journal of Public Economics*, 70, (2), 297-323.

Andolfatto, David and Ed Nosal, 1997. "Optimal team contracts." *Canadian Journal of Economics*, Vol. XXX No. 2 pp. 385-96.

Andreoni, James, 1995. "Warm Glow versus Cold-Prickle: The Effects of Positive and Negative Framing on cooperation Experiment", *Quarterly Journal of Economics*, 110, pp. 1-22.

Arrow, Kenneth J, 1985. "The Economics of Agency." in J. W. Pratt and R.S. Zeckhauser eds. *Principals and Agents: The Structure of Business* (Boston: Harvard Business School Press), pp. 37-35.

Bagnoli, M., and M. McKee, 1991. "Voluntary Contribution Games: Efficient Private Provision of Public Goods." *Economic Inquiry* Vol. XXIX, pp. 351-366.

Becker Gary, S., 1968. "Crime and Punishment: An Economic Approach." *The Journal of Political Economy*, 75, pp. 169-217.

Cabe R. and J. Herriges 1992, "The Regulation of Nonpoint-Source Pollution under Imperfect and Asymmetric Information." *Journal of Environmental Economics and Management*, 22, pp. 34-146.

Cadsby, Bram Charles and Elizabeth Maynes, 1999, "Voluntary provision of threshold public goods with continuous contributions: experimental evidence." *Journal of Public Economics*, 71, pp. 53-73.

Chan, Kenneth S., Stuart Mestelman, Rob Moir, and R. Andrew Muller 1996. "The Voluntary Provision of Public Goods Under Varying Income Distributions." *Canadian Journal of Economics* 29 (1), 54-69.

Chan, Kenneth S., Stuart Mestelman, Rob Moir, and R. Andrew Muller 1999. "Heterogeneity and the Voluntary Provision of Public Goods." *Experimental Economics* 2(1), pp.5-30.

Chan, Kenneth S., Robert Godby, Stuart Mestelman, and R. Andrew Muller, 1994. "Boundary Effects and Voluntary Provision of Public Goods." McMaster University Working Paper #94-03.

Chan, Kenneth S., Robert Godby, Stuart Mestelman, and R. Andrew Muller, 1997. "Equity Theory and the Voluntary Provision of Public Goods." *Journal of Economic Behavior and Organization* 32 (3), pp. 349-364.

Childs, Jason, James Chowhan, Chris Riddell, Michelle Vickers, and Angela Wier, 1997. "Ambient Pollution Contracts and Communication." McMaster University manuscript.

Cooper R., D. DeJong, R. Forsythe, and T. Ross, 1990. "Selection Criteria in coordination games: Some experimental results." *American Economic Review,* 80, pp. 218-33

van Egterne, Henry, and Marian Weber, 1996. "Marketable Permits, Market Power, and Cheating." Journal of Environmental Economics and Management 30, pp. 161-173.

Fukuyama, Kei, Marc, D. Kilgour, and Keith, W. Hipel, 1994. "Systematic Policy Development to Ensure Compliance to Environmental Regulations.", *IEEE Transactions on Systems, Man, and Cybernetics*, 24, 9, pp. 1289 - 1305.

Greene, William H., 1993. *Econometric Analysis,* Second Edition, Prentice-Hall, Inc.

Hackett, Steven, Edella Schlager, and James Walker, 1994. "The Role of Communication in Resolving Commons Dilemmas: Experimental Evidence with Heterogeneous Appropriators." *Journal of Environmental Economics and Management* 27, pp. 99-126.

Hoarn, Richard D., James S. Shortle, and David G. Abler, 1998. "Ambient Taxes when Polluters have Multiple Choices." *Journal of Environmental Economics and Management* 36, pp. 186-199.

Hizen, Yoichi, and Tatsuyoshi Saijo, 1998. "Designing GHG Emissions Trading Institutions in the Kyoto Protocol: An Experimental Approach, Forthcoming in *Environmental Modeling & Software*.

Holmstrom, Bengt R., 1982. "Moral Hazard in Teams." *Bell Journal of Economics*, 13, pp. 324-340.

Isaac, Mark R. 1999. *Research in Experimental Economics. Emissions Permit Experiments.* Volume 7, 1999, JAI Press Inc. Stanford, Connecticut.

Isaac, Mark R., David Schmidtz, and James M. Walker, 1989, "The assurance problem in a laboratory market," *Public Choice,* 62, pp. 217-236.

Keser, Claudia, 1996. "Voluntary Contributions to a Public Good when Partial Contribution is a Dominant Strategy." *Economics Letters*, 50, pp. 359-366.

Ledyard, John O., 1995. "Public Goods: A Survey of Experimental Research." In *The Handbook of Experimental Economics*, ed. John Kagel and Alvin Roth, Princeton University Press, Princeton NJ.

Livernois, John and C.J. McKenna,1999. "Truth or Consequences: Enforcing Pollution Standards with Self-Reporting." *Journal of Public Economics*, 71, pp. 415-440.

Malik, Arun, 1990. "Markets for Pollution Control when Firms are Noncompliant." *Journal of Environmental Economic Management*, 18, pp. 97-106.

Malik, Arun, 1993. "Self-Reporting and the Design of Policies for Regulating Stochastic Pollution." *Journal of Environmental Economic Management*, 24, pp. 241-257.

McAfee, Preston R. and John McMillan, 1991. "Optimal Contracts for Teams." *International Economic Review*, 32, 3, pp. 561-576.

McKelvey, Richard D., and Thomas R. Palfrey, 1995. "Quantal response equilibria for normal form games", *Games and Economic Behavior* 10, 6-38.

Muller, R. Andrew, and Stuart Mestelman 1998. "What have we learned from Emission Trading Experiments?" *Managerial and Decision Economics*, 19(4/5), pp. 225-238.

Nalbantian, Haig and Andrew Schotter, 1997. "Productivity Under Group Incentives: An Experimental Study," *American Economic Review* 87,3, pp. 314-41.

Noussair, C.N., Plott, C.R., and Riezman, R.G., 1995. "An Experimental Investigation of the Patterns of International Trade", *American Economic Review*, Vol. 85, pp. 462-491.

Offerman, Theo, Arthur Schram, and Joep Sonnemans, 1998, "Quantal Response Models in Step-Level Public Goods Games," *European Journal of Political Economy*, 14, pp. 89-100.

Osborne, Martin, J., and Ariel Rubinstein, 1994. *A Course in Game Theory.* Massachusetts Institute of Technology.

Palfrey R. Thomas and Jeffrey E. Prisbrey, 1997, "Anomalous Behaviour in Public Goods Experiments: How Much and Why?" *American Economic Review* 87, 5, pp. 829-846.

Rapoport, Amnon and Ramzi Suleiman, 1992, "Equilibrium Solutions for Resource Dilemmas", *Group Decision and Negotiation*, 1, pp. 269-294.

Rapoport, Amnon and Ramzi Suleiman, 1993. "Incremental Contribution in Step-Level Public Goods Games with Asymmetric Players," *Organizational Behavior and Human Decision Processes*, 55, pp. 171-94.

Roth, Alvin E., 1988. "Laboratory experimentation in economics: A methodological overview." *Economic Journal* 98: 974-1031.

Roth, Alvin E., 1995. "Introduction to Experimental Economics." In *The Handbook of Experimental Economics*, ed. John Kagel and Alvin Roth, Princeton University Press, Princeton NJ.

Russell, Clifford, 1990. "Game Models for Structuring Monitoring and Enforcement Systems." *Natural Resource Modeling*, 4,2, pp.143-173.

Schmalensee, Richard, Paul L. Joskow, A. Denny Ellerman, Juan Pablo Montero, and Elizabeth M. Bailey, 1998. "An Interim Evaluation of Sulfur Dioxide Emission Trading." *The Journal of Economic Perspectives*, 12, 3, pp. 53-68.

Sefton M. and R. Steinberg, 1996. "Reward Structures in Public Good Experiments." *Journal of Public Economics*, 61, pp. 263-287.

Segerson, Kathleen. 1988, "Uncertainty and incentives for nonpoint pollution control," *Journal of Environmental Economic Management,* 15, pp. 87-98.

Sonnemans, Joep, Arthur Schram., and Theo Offerman, 1998. "Public Good Provision and Public Bad Prevention: The Effect of Framing", *Journal of Economic Behavior and Organization*, 34, pp. 143-161.

StataCorp, 1999a. *Stata Users Guide Release 6.0,* College Station, TX: Stata Corporation.

StataCorp, 1999b. *Stata Graphics Manual Release 6.0,* College Station, TX: Stata Corporation.

StataCorp, 1999c. *Stata Statistical Software Release 6.0,* College Station, TX: Stata Corporation.

StataCorp, 1999d. *Stata Reference Manual Release 6.0 Volume 2 H-O,* College Station, TX: Stata Corporation.

Stavins, Robert N., 1998. "What Can We Learn from the Grand Policy Experiment? Lessons from SO_2 Allowance Trading." *The Journal of Economic Perspectives*, 12, 3, pp. 69-88.

Suleiman, Ramzi and Amnon Rapoport, 1992, "Provision of step-level public goods with continuous contribution." *Journal of Behavioral Decision Making*, 5, pp. 133-143.

Swierzbinski, Joseph, 1994. "Guilty until Proven Innocent - Regulation with Costly and Limited Enforcement." *Journal of Environmental Economic Management*, 27, pp. 127-146.

Tietenberg, Tom, 1996. *Environmental and Natural Resource Economics*. Fourth edition. HarperCollins.

Walster, Elaine, G. William Walster, and Ellen Bercheid, 1978. *Equity: Theory and Research*, Allyn and Bacon, Boston.

White, Halbert, 1980. "A Heteroskedasticity-Consistent Covariance Matrix Estimator and a Direct Test for Heteroskedasticity." *Econometrica*, 48(4), pp. 817-838.

Xepapadeas, A. P., 1991. "Environmental Policy under Imperfect Information: Incentives and Moral Hazard." *Journal of Environmental Economics and Management*, 20, pp. 113-126.

Xepapadeas, A. P., 1992, "Environmental Policy Design and Dynamic Nonpoint-Source Pollution." *Journal of Environmental Economics and Management*, 22, pp. 22-39.

Xepapadeas, A. P., 1995, "Observability and choice of instrument mix in the control of externalities." *Journal of Public Economics*, 55, pp. 485-489.