Principal Agent Models of Bureaucratic and Public Decision Making

Thesis by

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Dedication

To Gina

Acknowledgements

In writing this dissertation I have incurred many debts. In lieu of (and given the impossibility of) repaying them, I will simply recount them in hopes that my debtors will let me off the hook.

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Abstract

In this thesis I investigate three situations in which a principal must make a public decision. The optimal decision from the principal's point of view depends on information held only by agents, who have different preferences from the principal about how the information is used.

In the first two situations (Chapters 2 and 3) the principals and agents — legislatures and bureaus, respectively — are each part of the government and interact to create public policy. In Chapter 2 the bureau has private information about the cost of a public project, performed for multiple legislative principals who can each seek out cost information through oversight. The multiplicity of principals can cause the level of oversight to be inefficiently low due to a collective action problem. Further, the inefficiency becomes more likely as oversight becomes a more important part of the principals' utility functions, and as the oversight technology becomes more effective. For some parameters an increase in the effectiveness of the auditing technology reduces the welfare of the principals collectively.

In Chapter 3 the bureau has substantive expertise about the effects of various policy choices. The principal can delegate policy making authority to the bureau to tap its expertise, but bureaus are imperfectly controlled by statutory restrictions. On the other hand, the scope for delegation can be reduced endogenously if the legislature chooses to acquire its own substantive expertise. I examine how strategic accounting

for both bureaucratic subversion and costly development of legislative expertise affect the legislature's delegation decision. I also show that legislatures may in fact want subversion to be "cheap," while bureaucrats may want their own authority constrained and subversion to be costly.

In the third situation (Chapter 4) the information desired by the principal is the valuation of an excludable public good for each member of society. I experimentally compare three collective choice procedures for determining public good consumption and cost shares. The first, Serial Cost Sharing, has attractive incentive properties but is not efficient; the other two are "hybrid" bidding procedures that never exclude any agents but are manipulable. I characterize Bayesian Nash equilibria in the hybrid mechanisms, and prove some more general properties as well. Serial Cost Sharing tends to elicit values successfully, but is outperformed on several efficiency criteria by a hybrid mechanism – despite its incentive problems and coordination problems due to multiple equilibria.

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Chapter 1 Introduction

Many important instances of public decision making involve principal agent relationships. Likewise, asymmetric information is the rule in public decision making. Whether their motivations are selfish or benevolent, public decision makers usually operate in a world where other agents with conflicting preferences have key pieces of information. These facts can have important impacts on the design of public decision making processes, and the quality of their outcomes. In this thesis I examine several facets of this general problem.

For two decades the formal political economy literature has recognized legislative-bureaucratic interaction as having qualities of a principal agent relationship. Agents with delegated authority may have better information than legislative principals, but they also generally have different preferences. This introduces a control problem. The "congressional dominance" literature (e.g., Fiorina 1981, 1982; Weingast and Moran 1983; Weingast 1984, Calvert, Moran, and Weingast 1987; see the review in Moe 1987) has freely invoked the principal-agent metaphor and similar ideas to assume away the control problem and argue that legislatures, as designers of bureaucratic structures, would be not be subject to the rent extraction noted by Niskanen (1971). Instead, to paraphrase Fiorina (1981), as creators of bureaucracies, legislatures would have exactly the bureaucracy they want. Political economists have used formal principal agent models to probe the merits and limitations of the principal agent metaphor. A direct application of mechanism design with adverse selection (Spencer 1980, 1982; deFigueiredo, Spiller and Urbiztondo 1999; also see Moe 1987) reminds us that while legislative principals need not be the feckless victims postulated by Niskanen and can extract information from better informed bureaucrats, this comes at a cost to principals. As usual in models where agents produce output at privately known cost, when information rents are taken seriously, principals cannot get both exactly the policy they desire and information revelation. Taking the mechanics of agent control in bureaucratic politics more seriously, McNollgast (1987, 1989, 1999) and Bawn (1995) have argued that "deck stacking," legislative design of administrative procedures and allocation of lobbying rights, can serve a similar purpose to the incentives a principal provides an agent. Careful design of bureaucratic structures and processes can allow legislatures to control agents remotely.

The incentives approach of mechanism design theory is one way of modeling solutions to the control problem induced by delegation of decision making authority from principals to agents. Another is monitoring of agent activities. For example, Baron and Besanko (1984) analyze this in the context of a bilateral principal agent model with adverse selection; McCubbins and Schwartz (1984) argue that congressional responses to interest group complaints ("fire alarms") constitute a more efficient form of legislative oversight than constant monitoring of bureaucrats ("police patrols"). As has been emphasized in the contracting literature, these approaches can work in concert.

In policy making involving public bureaucratic agents, an important consideration is how the multiplicity of legislative (or other) principals affects the efficacy of monitoring (which can be understood as oversight in that context). Chapter 2 analyzes this. An agent performs a project for multiple legislative principals (e.g., congres-

sional committees) at a total cost that is publicly observable, but that is composed of an exogenous parameter and endogenous actions that are each observed only by the bureaucrat. The principals can design incentive schemes to induce the agent to reduce costs, and through oversight can each gather information about the exogenous cost parameter for use in designing their incentive schemes.

Specifically, each principal can purchase a stochastically independent, noisy signal about the agent's type; with some probability the signal reveals the agent's type, and otherwise it reveals nothing. Because of information leakages in oversight among principals, oversight by one principal benefits all principals. This creates a positive externality, and thus the level of oversight activity can be inefficiently low. This supports a version of Ogul's (1976) argument that all oversight is subject to underprovision. Moreover, I show that as oversight becomes a more important part of the principals' utility functions, and as the oversight technology becomes more effective (the probability of an informative signal rises), the collective action problem among the principals gets "worse" – in the sense that more audit costs lead to inefficiently low levels of auditing, and that, for some audit costs, an increase in the probability of a successful audit can reduce collective welfare among the principals. This suggests that with multiple principals, principals may have an interest in limiting the effectiveness of their oversight technologies. Oversight may be halting and ineffective because principals are better off that way.[1]

Another way principals can cope with the control problem they face when delegat-

[1]Contrast this with the McCubbins and Schwartz logic, which holds that oversight is actually not halting and ineffective – only a specific, costly variety of it is.

ing to agents, in addition to direct incentive schemes, deck stacking, and monitoring, is to restrict the choice set available to agents. [2] Along these lines, Epstein and O'Halloran (1994, 1995,1996, 1999) initiated a new way of viewing delegation from principals toagents like bureaucrats with substantive expertise about the connection between choices and outcomes. By restricting the portion of the policy space from which the bureaucratic agent can select a policy, the principal can help alleviate the control problems associated with delegation. Then the agent will not simply be able to choose whichever policy happens to yield her most preferred outcome, given the relationship between policies andoutcomes.

However, this approach leaves out important aspects of the problemprincipals face. In the first place agents are not perfectly controlled by the restrictions principals place on the choice set. In politics bureaucratic subversion of legislative dictates is typically possible. While agents would face (at least probabilistically) a cost for subversive actions, they can take steps to hide them, or commit (through staffing decisions, say) to vigorously defend legal action against subversive policies by third parties such as interest groups. Thus even with the restrictions legislatures place on the discretion of agents to choose among policy alternatives, agents retain some residual discretion. Strategic legislators should account for this residual subversion ability in making delegation decisions, so ignoring subversion leaves out an important part of the story.

[2] Indeed the optimal mechanisms literature can be viewed in this way as well. In the typical optimal incentive scheme the principal offers a limited menu of options (usually one for each agent type) such as output-compensation pairs, among which the agent selects. That selection reveals the agent's private information.

Moreover, monitoring the information available to the agent is a possibility in this context as well. In the U.S., the Environmental Protection Agency and the State Department (for example) are full of career experts who know more about the relationship between available policy alternatives and actual outcomes (in terms of human health, environmental quality, or international stability) than generalist legislators. But legislators need not take this information asymmetry as given. They can ameliorate it, but at a cost to themselves. Like subversion, that possibility of investigation also affects their willingness to restrict the agent's choice set or to delegate at all; thus it is an important part of the delegation decision.

Chapter 3 brings these elements of subversion and the endogenous development of legislative expertise together in one model. As in Epstein and O'Halloran's work, the principal chooses for the agent a "delegation window," a (compact, connected) subset of the unidimensional policy space from which the agent can make a choice. That choice is then added to a random shock to determine the actual outcome, over which principal and agent have given preferences. After deciding whether to purchase a signal about the random shock, the legislature chooses the location and size of the delegation window. The agent can then choose any policy, but faces a cost for policies outside the delegation window that is increasing in the distance from the window. This captures the "wiggle room" open to agents due to subversion.

Interestingly, agencies will not necessarily prefer subversion to be "cheap," and legislatures will not generally prefer it to be "too" difficult, according to the model. Subversion alters the equilibrium relationship between principal and agent; in accounting for subversion the principal can force the agent to "buy" policies that it could, with higher subversion cost, choose at lower or no cost – because delegated authority would be greater. For its part the principal responds to lower subversion costs by shifting the location of the delegation window to the edge of the policy space, so that agency subversion can actually be in the legislature's interest.

In Chapters 2 and 3, the information required to make a first best efficient decision is contained within the government itself. Principals and agents are both part of that government, interacting ccording to political institutions and policy processes as captured by extensive form games. Moreover, principals and agents may be motivated by narrow political gains, broader social concern, or something else entirely; the positive political theory of legislative-bureaucratic interaction does not have to take a stand on the source of preferences. It is enough that the preferences, and preference conflicts, be defined in the appropriate space, and that decision rights be specified as part of an extensive form game.[3] But as has long been noted (e.g., Mirrlees 1971, Hurwicz1972, Green and Laffont 1979), the same information asymmetries and incentive problems affect a more idealized, benevolent, and abstract public decision maker. In addition, the information required for first best decisions is not always dispersed among conflicting parties within the government; sometimes the agents holding this information are the populace. In Chapter 4 I theoretically and experimentally analyze several mechanisms available to a principal in such a context.

More specifically, in that chapter a small group must decide which members will

[3]Of course to add empirical content it may be both useful and necessary, depending on the model, to say more about the sources of preferences (e.g., reelection concerns, budget maximization).

consume a binary excludable public good, and how to split its cost. The cost of the public good is commonly known but the valuation of each group member is known only to him or herself. Thus a principal faces a problem of deciding consumption levels and cost shares, while only the agents know the information required for a first best efficient decision. Many collective decision procedures are available to the principal in such an environment. Some that have appeal on incentive, simplicity, transparency, or equity grounds will not achieve theoretical efficiency limits for the given environment. Moreover, for mechanisms with multiple equilibria, an important part of evaluation is necessarily empirical.

In Chapter 4 I experimentally examine three different collective decision procedures (formally, mechanisms) in a given economic environment. The procedures are Serial Cost Sharing (SCS), a well known mechanism that is strategy proof, budget balanced, individually rational, but not efficient; and two hybrid voluntary cost sharing procedures called Proportional Cost Sharing (PCS) and No Rebates (NR). In the latter two, agents submit bids of the maximum cost they will pay for the public good, conditional on production. If the sum of all group members' bids exceeds the cost of the good, it is produced. Furthermore, under PCS, bids in excess of the cost of the good are refunded in proportion to bid, while under NR they are not refunded. Both of these are individually rational and PCS is budget balanced. Neither is strategy proof. However, both avoid aspects of SCS that cause inefficiency. In particular, different consumers may have different cost shares, and no agent is ever excluded from consuming the public good. I analyze some theoretical properties of PCS and NR –

both of which have multiple Bayesian Nash equilibria – for the small group setting, and compare the mechanisms on collective grounds based on laboratory experiments.

Despite its attractive incentive properties, and the fact that it worked "as advertised" in the experiments, and despite the incentive and coordination problems PCS faced, SCS was outperformed on two efficiency criteria by PCS: proportion of surplus extracted and probability of efficient decision. Comparisons of SCS and NR are more subtle. On some efficiency measures, such as probability of efficient decision or consumers' surplus extracted, SCS performed better. But when total surplus extraction is the criteria, so excess contributions in NR are not regarded as waste, NR and SCS are comparable. The reason for the performance difference between NR and PCS comes down to the rebates. PCS lowers the cost of higher bids relative to NR, a fact which subjects recognized and responded to with higher bids, more efficient collective decisions, and more surplus extracted.

Previous experimental research on public goods provision has emphasized variation in the environmental parameters for a given mechanism, the voluntary contributions mechanism (see Ledyard 1995). For example, experimenters have varied group size, marginal per capita return, number of repetitions of the game, communication possibilities, subject experience, and even gender of the subjects to estimate the impacts of these variables on contribution patterns. However, most of this literature has focused on games of complete information, and even more on pure public goods. While this has given experimentalists a common ground to probe in detail, it cannot be suggested that this focus is due to the unimportance of other environments. In fact *technological* excludability is common among public goods, from parks and stadiums to security to roads and fisheries. Instead this focus of the experimental literature leaves important other public goods problems uninvestigated. Chapter 4 is an effort to address that.

As a whole these chapters form a contribution to the study of how the task of principals making public decisions is affected and complicated by information asymmetries. Public decisions are interesting and contentious often because of limited or dispersed information. Policy makers may lack important information about the consequences of available policy choices. Different policy makers or participants in public decision making, be they members of a formal government organization or members of the public, may have different information and conflicting preferences about how to use it. This thesis illustrates some pathologies that can arise in political institutions as a result of the information asymmetries principals face (e.g., oversight in a multicameral legislature),and how principals can deal with information asymmetries (and associated phenomena such as subversion) in specific economic and political environments.

Chapter 2 Multiple Principals and Outside Information in Bureaucratic Policy Making

Abstract

I examine a model in which a bureaucrat performs a project for multiple legislative principals. The cost of the project is publicly observable but the bureaucrat's (exogenous) efficiency and (endogenous) cost reducing activities are not. The principals can each perform a costly audit of the bureaucrat's type for use in the design of incentive schemes, and the information may also be useful for nonoversight activity. Due to information leakages between principals, the information about the agent obtained from one audit will benefit all principals. For some values of the audit costs, there is a collective action problem in auditing among the principals. Thus, for some model parameters the multiplicity of principals causes the level of this form of oversight to be inefficiently low. The collective action problem gets worse as the principals care more about oversight, and as the auditing technology becomes more effective. In addition, more effective oversight technologies can reduce the collective welfare of the principals.

2.1 Introduction

An enduring question in the politics of policy making is the "balance of power" between legislatures and bureaucrats. Since policy making in advanced democracies is fundamentally about these sorts of linkages between institutions, this question is not only enduring, but important. Niskanen (1971) modeled the problem as a bilateral one where the bureaucrat is a monopoly producer of output valued by the unitary legislature. The legislature's demand function is common knowledge, but the bureaucrat's cost function is known only by the bureaucrat. In Niskanen's model the bureaucrat makes a take-it-or-leave-it offer to the legislature about the cost of supporting output, and thereby extracts most or all of the rent of the transaction from the legislature.

Scholars have critiqued this model by noting that legislatures need not be so passive in relations with bureaucrats,[1] and that legislators can use oversight to obtain outside information and limit the information asymmetry.[2] Moreover, bureaucrats care about variables besides their budgets, such as reputations, relationships with superiors, and stability.[3] Finally, and perhaps most important, bureaucrats face multiple legislative principals.[4] For example, bicameralism, the appropriations-authorization process, and entrepreneurial committees all present multiple principals to bureaus.

In this chapter I develop a model that addresses these concerns. I use a common

[1]See especially Spencer (1980); Fiorina (1981); Miller and Moe (1983); McNollgast (1987, 1989); Bendor, Taylor, and van Gaalen (1987); Banks (1989); and deFigueiredo, Spiller, and Urbiztondo (1999).

[2]See especially Ogul (1976), McCubbins and Schwartz (1984), Banks (1989), Aberbach (1990), and Banks and Weingast (1992).

[3]Fenno (1966), Kaufman (1981), Wilson (1989).

[4]See e.g. Mitnick (1980), Wilson (1989), West (1995), and Waterman and Meier (1998).

agency formalization with both hidden information and hidden actions based on that of Laffont and Tirole (1991, 1993) in regulatory economics. The bureaucrat performs a project at some cost for legislative principals, who can each obtain costly information about the cost before offering the agent an incentive scheme. The model shows that the multiplicity of legislative principals attenuates legislative control over bureaucracy. The results still occupy a middle ground between "congressional dominance" and the dominated Congress of the monopoly bureau model.

In the model, any oversight of bureaucrats for which legislators have to trade resources — be it "fire alarm" or "police patrol," formal or informal, latent or manifest — may be underprovided due to collective action problems, which in turn arise from the multiplicity of principals. As Ogul (1976, p. 181) noted, while members of Congress desire more oversight at the collective level, individual incentives often dictate leaving it to someone else. In this sense the model supports a version of Ogul's argument that all oversight, be it latent or manifest, is subject to underprovision. On the other hand, for some model parameters the level of oversight captured here is efficient, so as Aberbach (1990) has argued, oversight is not necessarily "Congress's neglected function." Thus, these diametrically opposed views of oversight can in fact be understood as equilibrium outcomes in one model.

Furthermore, the more principals use their information networks for oversight purposes, and the more effective the oversight technology is, the worse the collective action problem will be. In addition, a more effective oversight technology may reduce the principals' collective welfare.

The seminal work on common agency with adverse selection is due to Martimort (1992) and Stole (1997). Dixit (1996) developed a common agency model with moral hazard in legislative-bureaucratic interaction. Several other models or frameworks recognized multiple principals (e.g., Mitnick 1980, Wood and Waterman 1994, Maltzman 1997) but prevented the principals from strategically accounting for each other.

The rest of the chapter is organized as follows. Section 2.2 motivates the model and lays it out formally. Section 2.3 analyzes the multiple principals model with general beliefs about the agent's type. In Section 2.4 I investigate optimal auditing by the principals and welfare effects of parameter changes. Section 2.5 concludes. Proofs are contained in the Appendix.

2.2 The Model

2.2.1 Modeling Issues

For the formal common agency approach, each principal must be able to offer its own incentive scheme to the agent. Budgets are a common focus in the discussion of legislative control of bureaucracy (e.g., Banks 1989; Banks and Weingast 1992; deFigueiredo, Spiller, and Urbiztondo 1999; but see Ting 2001), and of course, a legislature can offer only one budget to an agency. The perspective here is instead that the legislative principals each have at their disposal other, nonbudgetary incentives (e.g., perks or abuse at the hands of a committee), which they are free to offer as they see fit,[5] and which for simplicity the bureaucrat treats as equivalent to money.[6]

The empirical literature (e.g., Fenno 1966, Wildavsky 1978, Kaufman 1981, Wilson 1989, Aberbach 1990) documents that bureaucrats are interested in these sorts of incentives under the control of individual committees, not just budgetary incentives of committees acting in concert. Kaufman (1981) documents that avoiding embarassment, of the kind congressional committees are capable of inflicting, is a key priority of public administrators. This is not only because of any intrinsic cost of it, cost to personal reputation, or loss of outside opportunities, but also because it makes it more difficult to manage and motivate subordinates within the bureau. Moreover, perhaps because it acts in part as a signal in environments with incomplete information, it damages the interaction of bureaus with other stakeholders, such as interest groups, other federal or state bureaus, and the Executive Office of the President at the federal level.

Legislative principals find it costly to provide these incentives, positive or negative, for the bureaucrat. It takes time from other legislative activity, fundraising, or case work. Since these activities have electoral payoffs, there is some opportunity cost of time taken from them.[7]

Cost reducing activity ("effort") is costly for the bureaucratic agent. Effort spent on any project has opportunity costs—for example, if time constraints bind and it takes time from other valuable policy initiatives. Moreover, any organization,

[5]Baron (2000) uses a similar approach in a bilateral agency model of legislative organization.

[6]This is not restrictive if, for example, the bureaucrat cares about budgets and contumely, is risk neutral in both, and has an additively separable utility function. Then the assumption amounts to a choice of units.

[7]Cameron and Rosendorff (1993) use a similar perspective on the cost to Congress of discipline measures in a signaling model of legislative oversight, as does Baron (2000).

government bureau or not, has waste due to imperfect coordination that is difficult to identify and eliminate. In addition, projects involving subcontracting with private firms may involve incentive problems of their own that are costly to reduce. Thus, consistent with Brehm and Gates (1997), the assumption of costly effort need not imply that bureaucrats like to shirk or are lazy.

The oversight or outside information available to the legislative principals is costly. It may require valuable legislative concessions if provided by interest groups, or valuable time for case work, each of which have opportunity costs. Or, if formally provided by legislative support agencies like the General Accounting Office at the federal level or presented in formal hearings, and especially if of a technical nature, it will take time to consume and distill.

Outside information gathered by one principal is observed by and beneficial to all principals. This formalizes Aberbach's (1990) observation that congressional committees keep tabs on other committees' oversight activities. Given that oversight increasingly occurs on the public record, a piece of intelligence about an agency is likely to makes its way to multiple principals. On the other hand, nonoversight benefits of information networks can be more proprietary, such as the development of innovative policy on topical issues for which legislators can personally claim credit and enjoy publicity.

2.2.2 Formal Structure

Let there be two principals, P_1 and P_2, and one agent A. The situation here is one of "intrinsic" common agency (Bernheim and Whinston 1986), so the agent can contract either with both principals or neither. For simplicity I assume both principals are "contracting" with the agent over a single project. Furthermore, the incentive scheme of a given principal can be based only on the report of the agent's efficiency parameter, and not features of the other principal's contract. This would be the case if, for example, one principal's incentive scheme was not observable by another, because it was not a matter of public record.

The agent can perform the project for the principals at cost $D = \theta - \xi$. $\theta \in (\underline{\theta}, \overline{\theta}) \subset \Re$ is A's privately known efficiency parameter, and $\xi \in \Re$ is A's "effort." P_i's prior belief is that θ is distributed according to some CDF F with strictly positive density f. Assume F has a monotone hazard rate: $d(\frac{F(\theta)}{f(\theta)})/d\theta > 0$.[8] D is publicly observable, but neither θ nor ξ is: all players know the total cost of the project, but the principals cannot disentangle how much is beyond the agent's control. Effort is costly for A, with the effort cost given by $e(\xi)$, $e' > 0$, $e'' > 0$, $e''' \geq 0$.[9] The function e is commonly known. Let $t_i(D)$ be the transfer function for P_i, representing the transfer to A given cost observation D. Let the agent's utility function be $u(\theta) = t_1(D(\theta)) + t_2(D(\theta)) - e(\xi(\theta))$. Thus by convention the principals pay the cost of the project, and can independently offer perks and other benefits to the agent. I assume

[8] This assumption helps ensure that the principals do not want to induce pooling, whereby different types of agent perform the project at the same cost. Many common distributions (e.g., normal, logistic, uniform, exponential) have a monotone hazard rate.

[9] $e''' \geq 0$ has a primarily technical purpose and helps to avoid complications with stochastic incentive schemes.

these t functions are differentiable, and therefore focus on differentiable equilibria.

The project, if realized, has value $V_i > 0$ to P_i. The rewards $t_i(D)$ are costly for principals to offer, so P_i's utility is $V_i - t_i - s_i D$ when the project is performed, where $s_i > 0$ is the share of the project's cost borne by P_i, and 0 when the project is not performed. $\sum_i s_i \leq 1$, so the principals collectively internalize some of the project's cost. Yet they may pass some on to the rest of the legislature, as with congressional committees in some models of legislative organization.

Each principal is able to audit the agent, and thereby with some probability discover to what extent the cost D is beyond the agent's control (i.e., due to the efficiency parameter θ). The auditing technology for P_i is as follows. With some probability π, an audit reveals A's true state θ. With probability $1 - \pi$, the audit reveals nothing and principals keep their prior beliefs. If both principals audit, their results are statistically independent. P_i can purchase an audit with cost C, regardless of its results. As will be described shortly, the fixed cost of the audit may yield benefits for oversight activity that accrues to all overseeing principals, and benefits for nonoversight activity accruing to the auditing principal only.

Denote by $p(s)$ the posterior beliefs held by the principals when $s = \{s_1, s_2\}$, $s_i \in \{\varnothing\} \cup (\underline{\theta}, \overline{\theta})$, is the vector of audit signals to P_1 and P_2. Thus $p(\varnothing) \equiv p(\{\varnothing, \varnothing\}) = F(\theta)$ (the prior); $p(\widehat{\theta}) \equiv p(\{\varnothing, \widehat{\theta}\}) = p(\{\widehat{\theta}, \varnothing\}) = p(\{\widehat{\theta}, \widehat{\theta}\})$ is given by $\Pr(\theta) = 1$ if $\theta = \widehat{\theta}$ and $\Pr(\theta) = 0$ otherwise. So in the auditing stage before the "contracting" stage, information leakage from one principal to another is complete.

The game proceeds as follows (see Figure 2.1). Nature draws A's type θ and *shows A. The principals simultaneously decide whether to audit by choosing numbers* $n_1 = 1$ if P_1 audits and 0 otherwise, and similarly for n_2. P_i and P_j observe the signal from P_i's audit. Then each principal is simultaneously allowed to select an incentive scheme to offer the agent, associating a reward $t_i(D)$ with each cost observation D. Following this the agent chooses an effort level ξ. Finally the game ends and payoffs are distributed according to the t_i functions chosen by the principals.

Let the choices of n_i for any continuation utilities be called an auditing game. Let $V_i(\theta)$ be the equilibrium utility to P_i in the common agency subgame when P_i begins that subgame knowing the true state θ. Let $\overline{V}_i(F)$ be the *ex ante* equilibrium expected utility in the common agency subgame when P_i begins that game with uncertain beliefs F about θ.[10]

P_i's audit has oversight benefits common to all principals and nonoversight benefits to P_i only. Let $W_i^a(n)$, $n = 0, 1$ or 2, be the expected utility to P_i from the entire game with oversight when $n = n_1 + n_2$ audits are purchased. Let $W^a(n) = W_1^a(n) + W_2^a(n)$. For general π, we have

$$W_i^a(2) = [\pi^2 + 2\pi(1-\pi)][\int_{\underline{\theta}}^{\overline{\theta}} V_i(\theta)dF(\theta)] + (1-\pi)^2(\overline{V}_i(F));$$

$$W_i^a(1) = \pi[\int_{\underline{\theta}}^{\overline{\theta}} V_i(\theta)dF(\theta)] + (1-\pi)(\overline{V}_i(F));$$

$$W_i^a(0) = \overline{V}_i(F).$$

Let $W_i^b(n_i)$ be the exogenous nonoversight benefits, which depend only on P_i's

[10]Thus I am assuming some predetermined selection from the continuum of equilibria entailing different splits by the principals of the cost of meeting the agent's constraints.

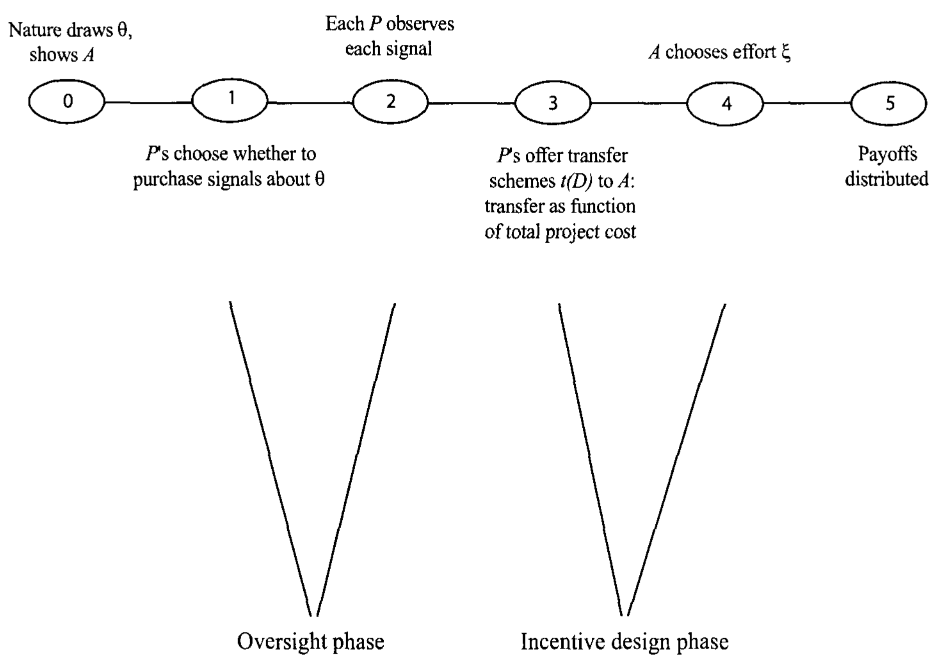

Figure 2.1: Timing of the game

audit. Let

$$W_i(n_1, n_2) = vW_i^a(n) + (1 - v)W_i^b(n_i)$$

be the total benefit to P_i of the auditing decisions. Thus $v \in [0, 1]$ parameterizes the importance of oversight in the committees' functions. Let $W(n_1, n_2) = W_1(n_1, n_2) + W_2(n_1, n_2)$.

2.3 Incentive Subgame with Multiple Principals

In this section I analyze the common agency subgame played by the principals and the agent for any given beliefs, and therefore, audit results. This is a benchmark case to review the results when multiple principals each offer incentive schemes to an agent whose performance they all care about, and it defines continuation values of the larger game with auditing that will be analyzed later.

The agent with type θ makes a report $\widehat{\theta}$ to each principal; the principals then recommend an effort level ξ and give transfers t to the agent as a function of the announced $\widehat{\theta}$.[11] Analytically the principals are choosing the function ξ for the agent, and must choose this function and (noncooperatively) choose transfers such that an agent of type θ is better off reporting θ than any other type $\widehat{\theta}$. Thus the principals must respect the bureaucrat's feasibility (individual rationality, IR) constraints and, if separation is desired, incentive compatibility (IC) constraints.

Let

[11] An important issue is how the revelation principle applies in incentive design games with multiple principals. Given a mechanism by P_j, there is no loss of generality in restricting P_i to direct mechanisms. Martimort (1996b) and Martimort and Stole (1997) discuss this in more detail.

$$v(\theta,\widehat{\theta}) \equiv t_1(\widehat{\theta}) + t_2(\widehat{\theta}) - e(\theta - D(\widehat{\theta}))$$

be A's rent as a function of the true type θ and the announced type $\widehat{\theta}$ and

$$U(\theta) \equiv v(\theta,\theta)$$

be the rent of type θ.

Lemma 2.1 *The first order condition for incentive compatibility (IC-1) is* $\frac{dU(\theta)}{d\theta} = -e'(\xi(\theta)),\ \forall\theta \in [\underline{\theta},\overline{\theta}]$.

Together with IC-2, the second order condition for incentive compatibility, IC-1 is sufficient for A's optimization problem, which we shall return to shortly.

$$\frac{dD(\theta)}{d\theta} > 0. \tag{IC-2}$$

The individual rationality constraint says that no type earns negative rent:

$$U(\theta) \geq 0,\ \forall\theta. \tag{IR}$$

Because IC-1 implies utility is nonincreasing in θ, the IR constraints can be replaced by $U(\overline{\theta}) = 0$.

Proposition 2.1 *Equilibrium effort under common agency with imperfectly informed principals is given by* $e'(\xi^{CA}(\theta)) = s_1 + s_2 - \frac{2F(\theta)}{f(\theta)}e''(\xi^{CA}(\theta))$.

The transfer functions implementing this effort are obtained by integrating the first order conditions from the principals' maximization problems, yielding

$$t_1(\theta - \xi^{CA}(\theta)) = \int_\theta^{\overline{\theta}} \{(e'(\xi^{CA}(\widehat{\theta})) + \frac{F(\widehat{\theta})}{f(\widehat{\theta})} e''(\xi^{CA}(\widehat{\theta})) - s_2) \quad (1 - \frac{\partial \xi(\widehat{\theta})}{\partial \widehat{\theta}}) d\widehat{\theta}\} + t_1(\overline{\theta} - \xi^{CA}(\overline{\theta})) \tag{2.1}$$

$$t_2(\theta - \xi^{CA}(\theta)) = \int_\theta^{\overline{\theta}} \{(e'(\xi^{CA}(\widehat{\theta})) + \frac{F(\widehat{\theta})}{f(\widehat{\theta})} e''(\xi^{CA}(\widehat{\theta})) - s_1) \quad (1 - \frac{\partial \xi(\widehat{\theta})}{\partial \widehat{\theta}}) d\widehat{\theta}\} + t_2(\overline{\theta} - \xi^{CA}(\overline{\theta})). \tag{2.2}$$

Thus we can state necessary conditions for equilibrium as Proposition 2.1, (2.1), and (2.2).

It is useful to consider briefly how these differ from the benchmark results of the bilateral principal-agent model.

Proposition 2.2 *The equilibrium effort in the incentive game with multiple principals and asymmetric information is distorted downward relative to the second best effort, which itself is distorted downward relative to the first best effort.*

Proposition 2.2 is a standard result in common agency models with adverse selection (Martimort 1992, Stole 1997). Given the first and second best outcomes described below, it follows straightforwardly from $e'' > 0$, so its proof is omitted from the Appendix.

The "first best" result with principals behaving cooperatively and complete information on θ is

$$e'(\xi^{FB}(\theta)) = s_1 + s_2. \tag{2.3}$$

A unit increase in effort is costly for the agent, but allows the principals to save s_1+s_2. This says the marginal cost of effort to the agent is equal to its total marginal benefit to the principals. Furthermore, for all θ the agent is indifferent between performing the project and not. This is also the result in common agency with complete information about θ.

The "second best" result with principals behaving cooperatively but facing uncertainty about θ described by $F(\theta)$ is

$$e'(\xi^{SB}(\theta)) = s_1 + s_2 - \frac{F(\theta)}{f(\theta)}e''(\xi^{SB}(\theta)). \tag{2.4}$$

Bringing effort for any type closer to first best has a benefit, but also a cost: it makes it more attractive for more efficient types to behave untruthfully. Equation 2.4 says that at the optimum the principal's expected marginal benefit, $f(\theta)(s_1 + s_2)$, of increasing the effort of a type in $[\theta, \theta + \delta\theta)$ is equal to the expected marginal cost, the effort cost to the type in question plus the increased informational rent of all agents with type in $[\underline{\theta}, \theta)$.

The extra distortion in the under common agency is due to a contractual externality among the principals. The information asymmetry on θ creates the tradeoff between efficiency and rent extraction common in bilateral models. This calls for downward distortion of the agent's effort, relative to the first best. If one principal's contract causes further downward distortion in effort, this leads to lower effort for other principals too. But since these other principals in turn are distorting effort downward, an increase in effort benefits them. This creates a negative externality across principals and leads to excessive downward distortion.

This approach implies that principals trade less desirable policy outcomes (production levels) from inefficient agents for lower informational rents to efficient ones (c.f. deFigueiredo, Spiller, and Urbiztondo 1999). Therefore, principals will always be dissatisfied with the performance of bureaucrats; but provided some of each type of agent exists, only some of this dissatisfaction stems from the information asymmetry. Common agency implies two sources of dissatisfaction with agency policy: the tradeoff with informational rents, and the existence of other principals. Only the former benefits any principal.

Propositions 2.1 and 2.2 are based on differentiable t functions. With incomplete information, there are also equilibria with nondifferentiable t functions. The simplest transfer functions that illustrate this have each P offer a payment t^* when project cost D meets some target D^*, and $-\infty$ otherwise. A optimizes by accepting if $2t^* > e(\theta - D^*)$ and rejecting otherwise. Accepting agents simply meet the target cost. As θ falls below that of the type just willing to accept, agents capture more rent because less effort is needed to meet the target. The principals choose the cutoff type to economize on the slack left to the agent types that do produce. In equilibrium, the marginal cost of the rent will equal the lost surplus of the marginal agent type.

The key is that the principals' utility is higher with complete information than under differentiable or nondifferentiable equilibria with incomplete information. There would be no slack left to agents more efficient than the cutoff type; that payment would be retained by the principals. Moreover, unlike in the nondifferentiable equilibria, all agent types would produce some surplus for the principals. Thus, what follows is robust to consideration of nondifferentiable equilibria.

2.4 Noncooperative Auditing

Now I turn to a representation of oversight of bureaucrats by legislators. I focus on a form of oversight, auditing of bureaucrats by nonstrategic third parties, that, while simple, still captures many different types of relationships. The important point is that legislators must trade some resources, whether direct opportunity costs or legislative concessions, for the information in the audit. The key is that since an audit by either legislator will mitigate the adverse selection problem faced by both legislators, the legislators face a collective action problem about who will become informed. Sometimes the signal will not be purchased even when it would be beneficial to the legislators collectively.

While a collective action problem in oversight can arise for any audit accuracy, it is different, as will become clear, for the case of perfectly and imperfectly informative signals. Thus I treat these cases separately. Following this analysis I examine the welfare effects of increasing π, and discuss the benchmark case of integrated principals and no collective action problem.

2.4.1 Perfectly Informative Audits

Let the audit be perfectly informative, so $\pi = 1$. In this case it is impossible for one principal's signal to be beneficial to the principals collectively, given purchase by the other principal. This induces, at the auditing stage, a one-of-two contributions game with complete information. The efficient outcome requires purchase either by one principal or by neither, depending on the audit cost C.

P_i chooses $n_i = 1$ if and only if $C < W_i(1, n_j) - W_i(0, n_j)$. It is clear that for any strictly positive auditing costs, no equilibrium entails auditing by both principals with certainty: when $\pi = 1$, $W_i(1,1) = W_i(0,1)$. Whether any audits are done depends on $C \gtrless W_i(1,0) - W_i(0,0)$, $i = 1,2$. Assume that for a given C the equilibrium actually played in any auditing game is selected from the set of Pareto efficient equilibria in that game.[12] This simply stacks the deck in favor of efficiency in the auditing game.

For notational simplicity let $X_i = W_i^a(1,0) - W_i^a(0,0)$ (the marginal oversight benefit of auditing to P_i given that P_j does not audit) and $Y_i = W_i^a(1,1) - W_i^a(0,1)$ (the marginal oversight benefit of auditing to P_i given that P_j does audit). Let $Z_i = W_i^b(1) - W_i^b(0)$ (the marginal nonoversight benefit of an audit to P_i). By definition $X_i = \pi(\int_{\underline{\theta}}^{\overline{\theta}} V_i(\theta) dF(\theta) - \overline{V}_i(F))$ and $Y_i = 0$.

There are three ranges of C to consider, and one that leads to an inefficient level

[12] In particular, the C region where the collective action problem arises has a unique auditing game equilibrium. The region with efficient auditing has three equilibria; two are asymmetric pure strategy equilibria and are efficient.

of auditing.

Proposition 2.3 *When $\pi = 1$, the level of auditing is inefficiently low if and only if $C > \max_i(X_i + Z_i)$, and $C < X_1 + X_2 + Z_i$ for some i.*

Since only one audit can be useful, the inefficiency arises when the cost of an audit is less than its collective oversight benefit plus the nonoversight benefit to some principal, but greater than the total (selfish) benefit to either principal. When $\pi = 1$ and C is either very low or very large, the level of auditing is what it would be if principals were integrated or accounted for the effects of their audits on each other. This proposition says that only for intermediate values of C can the collective action problem arise. The ones where it does arise are simply the ones for which auditing is selfishly irrational but still collectively beneficial.

2.4.2 Imperfectly Informative Audits and Symmetric Principals

In this subsection I assume $V_1 = V_2$, $s_1 = s_2$, $W_1 = W_2$, and that the principals split equally the cost of the agent's informational rent. This simplifies the analysis of general values of π and focuses attention only on the multiplicity of principals, rather than any differences between them. In this case all the marginal auditing benefits are equal across principals: $X_1 = X_2$, $Y_1 = Y_2$, and $Z_1 = Z_2$. Symmetry at this stage therefore implies a selection from the multiple equilibria in the incentive subgame with common agency where the principals share equally the costs of the agent's rents.

When the signal is imperfect in the sense that $\pi < 1$, the collective action problem in the previous subsection can still arise. However, an additional difficulty exists. Now it is possible that $W^a(1,1) > W^a(0,1)$, because of the probability $(1-\pi)$ event that when only principal i audits, the audit is uninformative. Thus purchase by both principals can, in expectation, contribute to their collective welfare. That is, $Y = (\pi - \pi^2)(\int_{\underline{\theta}}^{\overline{\theta}} V(\theta)dF(\theta) - \overline{V}(F))$ and X is the same as above. Therefore, $X > Y$ when $\pi > 0$, and the marginal oversight benefit of the first audit exceeds that of the second. Further, if $\pi > \frac{1}{2}$, then $X > 2Y$, and if $\pi \leqslant \frac{1}{2}$, then $X \leqslant 2Y$.

Proposition 2.4 explicitly relates C to the efficiency of the information gathering process. Assume again that for a given C the equilibrium actually played in any auditing game is selected from the set of Pareto efficient equilibria.[13]

Proposition 2.4 *(i) With symmetric principals and $\pi \in (\frac{1}{2}, 1]$, the level of auditing is inefficiently low if and only if $C \in [Y+Z, 2Y+Z]$ or $C \in [X+Z, 2X+Z]$. (ii) With symmetric principals and $\pi \in [0, \frac{1}{2}]$, the level of auditing is inefficiently low if and only if $C \in [Y+Z, 2X+Z]$.*

Proposition 2.3 (restricted to symmetric principals) then is a special case of this one; in that case $Y = 0$. With perfectly informative audits, only $C \in [X+Z, 2X+Z]$ is a source of inefficiency. Note also that the welfare loss does not vanish as C approaches the boundaries of the C regions associated with inefficiency.

[13]The regions where one audit is performed (whether one or two are efficient) have symmetric, inefficient equilibria. Qualitatively, the results below hold *a fortiori* if inefficient equilibria are selected, but the size of the C interval leading to inefficient results would obviously grow.

This result is illustrated in Figure 2.2. In the $C - \pi$ plane, the figure shows lines depicting when zero, one, or two audits are efficient and are in the most efficient auditing game equilibrium. In the large medium gray area on the right, one audit is efficienct, but zero are performed. In the small light gray area, two audits are efficiency, but zero are performed. In the black area, two audits are efficienct and one is performed. In the white areas the level of auditing is efficient.

The regions of inefficiency depend on whether π is such that $X > 2Y$. When $X > 2Y$, π is relatively large. Then given one relatively effective audit and information leakage, a second one is not very valuable. On the other hand, the first audit is fairly valuable because it is likely to reduce the information asymmetry. This means there are audit costs where one audit is selfishly beneficial for a principal, but two audits are not even collectively beneficial enough to outweigh marginal cost. In other words, for an interval of C's there are auditing game equilibria where one audit is efficient and one is performed. But if C falls far enough, two audits will again be efficient (the black region in Figure 2.2 for $\pi > \frac{1}{2}$); if it grows enough, no audits will be performed even though one would be efficient (the medium gray region in Figure 2.2 for $\pi > \frac{1}{2}$ – see Proposition 2.3).

When $X < 2Y$, the first audit is less likely to succeed, so a second audit is relatively more valuable. As C increases beyond $X + Z$ in this case, there is still a region where it is below $2Y + Z$ (the light gray region in Figure 2.2 for $\pi < \frac{1}{2}$). In that region no principal will audit, even though two audits are efficient. The induced auditing game for these C's is simply a prisoners' dilemma. But the marginal benefit

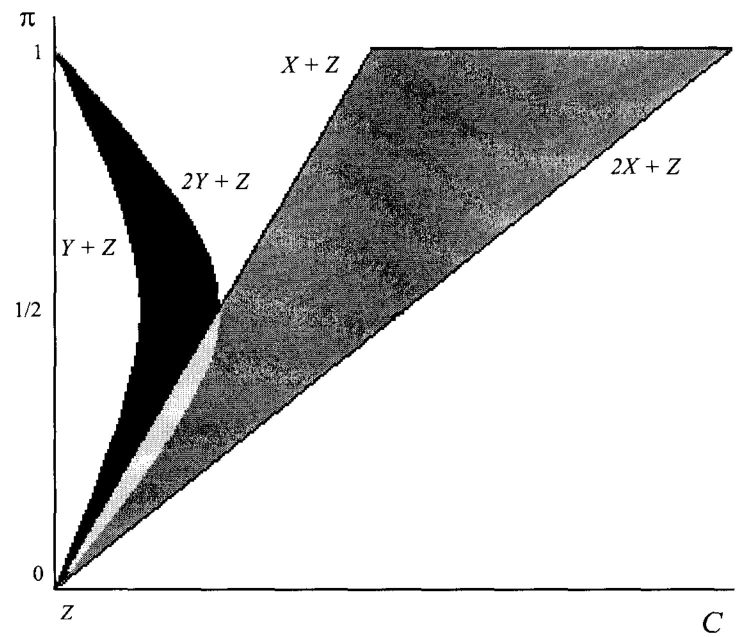

Figure 2.2: Efficiency of the auditing game

of the first audit exceeds that of the second, so as C increases enough to make two audits collectively inefficient, one audit can still be efficient even though none will be performed (medium gray region in the figure). On the other hand, even if C declines enough so one audit is selfishly rational, two audits may still be efficient (black region).

Thus collective action can weaken oversight as a tool of accountability. But a legislature faced with this problem, and not wishing to undo its multiprincipal structure, could pursue several remedies. Two natural ones are increasing the effectiveness of the oversight technology and creating special oversight committees.

Proposition 2.5 *With symmetric principals and $\pi \in [0,1)$, the range of C's causing an inefficiently low level of auditing is increasing in π.*

A more effective auditing technology makes the collective action problem worse. As π increases, the benefit of an audit both to the auditing principal and to the other principal increases. But only the first benefit is taken into account in deciding to audit. As π increases the ignored externality also increases, making the collective action problem arise for more C values.

The following result on the importance of oversight to the principals applies for $\pi \in (0,1)$.

Proposition 2.6 *For $\pi \in (0,1)$, the range of C's causing an inefficiently low level of auditing is increasing in v.*

Thus when oversight is a more important part of the committees' functions — say, by making them into special oversight committees — in a sense the collective action problem gets worse. As v increases, an audit becomes more valuable for the auditing principal as well as the other principal. The first effect is accounted for in a principal's audit decision, but the second is not. As v increases this ignored external benefit increases.

Aberbach (1990, chapter 4) offers some suggestive evidence related to this. Oversight committees — for which oversight mattered most as part of the committee's function — tended to have less developed information networks and used them less effectively than nonoversight committees. In fact for the three groups of committees Aberbach presents, oversight committees have the least well developed information networks. New policy proposals tend not to originate in oversight committees, and thus their information networks are concentrated on oversight activity. This is not true for "substantive" committees, which can use information networks for a variety of purposes, some more "proprietary" than oversight (like the development of innovative policy).

Taking the previous two propositions together, some intuitive and practically important ways of eliminating the collective action problem in oversight do not necessarily have the desired effect. Both more effective audits and principals more concerned with oversight make the collective action problem worse.

2.4.3 Welfare Effects of Audit Success Probability

Viewing the welfare gains from auditing as a pie, the previous results say that the share of the pie extracted declines in relative terms as π grows. It is also important to analyze the absolute size of the share extracted — that is, whether welfare can ever actually decrease as π grows. Interestingly in some cases increases in π are welfare reducing.

Proposition 2.7 *If for any π the equilibrium selected in the induced auditing game is efficient, then for $C \in [Z, Y+Z]$ there is a $\pi^*(C)$ where the principals' equilibrium utility declines in π.*

The probability $\pi^*(C)$ is the $\pi > \frac{1}{2}$ such that for $\pi < \pi^*(C)$, two audits are efficient and two are performed, while for $\pi > \pi^*(C)$, two audits are efficient but one is performed.[14] At $\pi^*(C)$, an additional audit would therefore necessarily be welfare enhancing for the principals. But at $\pi^*(C) - \epsilon$, two audits are performed and are only infinitesimally less effective than at $\pi^*(C)$. This welfare dominates the equilibrium at $\pi^*(C)$.

Figure 2.3 illustrates this result. The solid curves depict the principals' collective utility from 0, 1, and 2 audits, and the bold segments trace out their utility in the most efficient auditing game equilibrium. For the indicated range of C values, there is a positive measure of π's above $\pi^*(C)$ such that collective welfare in equilibrium is higher at π's just below $\pi^*(C)$.

[14] There are π's less than $\frac{1}{2}$ with this property, but fixing C, one can only get further from them as π increases. When $\pi > \frac{1}{2}$, an increase in π lowers the marginal value of a second audit, so it is efficient only for lower C values. See Figure 2.2.

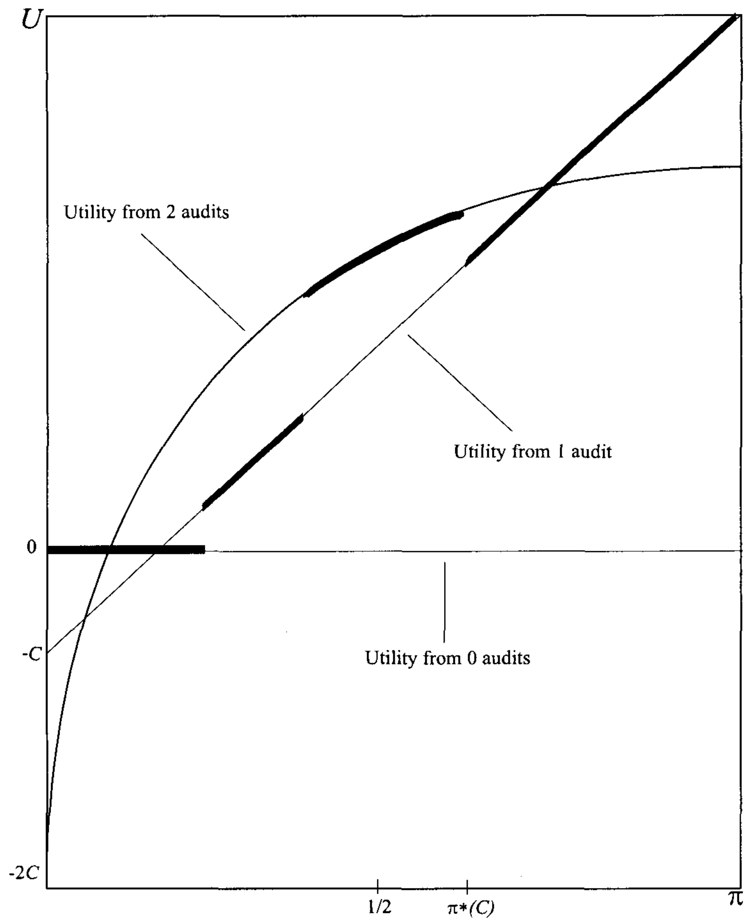

Figure 2.3: Utility from 0, 1, and 2 audits, as a function of π

The discontinuity in equilibrium utility at $\pi^*(C)$ that causes this result cannot be avoided with an appropriate selection from the set of equilibria in the auditing game. In addition, the size of the jump in utility at $\pi^*(C)$ may change, but it can only increase. For $\frac{1}{2} < \pi < \pi^*(C)$, the unique auditing game equilibrium entails two audits. For $\pi^*(C) < \pi < \pi^e$ (see Appendix, Proof of Proposition 2.7), the auditing game has three equilibria: two asymmetric ones where one principal audits with certainty, and a symmetric, mixed strategy equilibrium where each principal audits with some probability.

The principals' utility in the mixed equilibrium is lower than their utility in the asymmetric equilibria. Moreover, it is obviously lower than their utility with two audits at π^*: the mixed equilibrium utility is an average over the utility from zero, one, and two audits. Thus, the same intuition as in Proposition 2.7 can be applied when the (inefficient) symmetric equilibrium is selected in this region. The key is the uniqueness of equilibrium below $\pi^*(C)$. Since Proposition 2.7 depends on moving from this equilibrium to the most efficient one above $\pi^*(C)$, moving from this equilibrium to a less efficient one above $\pi^*(C)$ will not help.[15]

If $\pi < \frac{1}{2}$, total welfare among the principals is clearly increasing in π. Extra audits are never welfare reducing in the auditing game's most efficient equilibrium. When $\pi < \frac{1}{2}$ increases in π never reduce the number of audits and sometimes increase it, while the probability that they are informative rises. Furthermore, if C is large enough, the principals' collective equilibrium welfare is at least weakly increasing in

[15]Furthermore, there are obviously other selections from the set of auditing game equilibria where increases in π reduce equilibrium utility for other values of π as well. For example, some equilibria have too many audits when $\pi > \frac{1}{2}$, and selecting these can reduce welfare for some increases in π.

π.

2.4.4 Cooperative Auditing and Other Solutions to the Collective Action Problem

This collective action problem in oversight does suggest other remedies the principals might pursue to solve it, such as designing their own internal mechanisms. Without an external designer their ability to do so would be limited, however. For example, the prisoners' dilemma problems mentioned above cannot be solved in this way. One might also think of principals in bilateral bargains, trading legislative concessions for oversight duties. However, this introduces a new aspect to the cost of oversight, in addition to probable information problems that plague efficient resolution of these bargains. The standard remedies of repeated play (which increases the benefits of long term service on oversight committees, even when seniority would allow for a jump to "substantive" committees) and an external enforcer in the legislative or party leadership also suggest themselves. The upshot is that recognizing that there is a collective action problem to be solved helps to make the institutional structure of a legislature more intelligible: rather than revealing a problem with this model, it suggests interesting new directions.

Assuming some effective remedy were found and the principals' decision problems were integrated, the problem is straightforward and useful as a benchmark. First, as noted in Section 2.3, the principals would face a second, not third, best situation in the incentive design phase.

Second, while this would reduce the agent's effort distortion, oversight would still be beneficial, and oversight decisions would be fully efficient. There would not be any external benefit; all benefits would be accounted for in the oversight decision. For any π and C these decisions can be read off of Figure 2.2. The line $2X + Z$ and the curve $2Y + Z$ would determine when to purchase one and two audits respectively (Z would have to be modified to account for the new constituency).

Third, equilibrium utility would be continuous and increasing in π.[16] For all C, as π increases, the principals would switch from two audits to one just when the first audit was so effective that the second was inefficient. In general this equality will hold for any change in the number of audits; it is a simple consequence of efficiency, and ensures continuity.

2.4.5 Timing of the Audit

This chapter has examined oversight in an ex ante sense of costly information about a bureau's production processes or expertise, information that is used to design incentive schemes. One can also think of oversight in an ex post sense, such as oversight in response to "waste, fraud, and abuse" by administrators. One way to capture this is by altering the game order so the agent makes a report, and the principals audit and offer transfers as a function of that report. This is similar to the structure in Baron and Besanko (1984) in a bilateral agency model.

More specifically, suppose the principals announce auditing-transfer scheme pairs $(n_i(\widehat{\theta}), t_i(\widehat{\theta}))$, followed by a report $\widehat{\theta}$ by the agent. The auditing policy $n_i(\widehat{\theta})$ associates

[16] At least weakly: for C large enough utility is constant in π because there is never an audit.

with each report an audit decision 0 or 1. The audit, if informative, reveals A's type to both principals and results in production at the first best cost. If the audit is uninformative, the principals make transfers to the agent according to the t_i functions. As before, auditing has cost C and success probability π.

Two features of this formulation stand out. The principals are still better off with more information, and there is still an externality among them due to information leakage. In deciding to set $n_i(\widehat{\theta}) = 0$ in response to any given report $\widehat{\theta}$, P_i accounts for the benefit of an informative audit to itself only. There is also of course a benefit to P_j as well, which continues to drive a wedge between the selfish and efficient audit decisions, leaving the collective action problem intact.

In this game the principals simply trade C for a chance at the first best outcome for all audited types. But eliminating the rent of any agent reporting $\widehat{\theta}$ changes the benefit from falsely claiming $\widehat{\theta}$, and changes the incentive constraints, as well as the objective functions of the principals. Thus, the common agency incentive schemes will be different. However, the contractual externality responsible for the distortion from second best is still present. Because of the t function of P_j in A's utility, P_i can still reduce the information rent that P_i itself must pay to types with positive production by distorting effort downward. Thus, the qualitative feature of extra distortion remains intact as well.

2.5 Conclusion

This model has shown that multiplicity of legislative principals attenuates the control they have collectively over a bureaucratic agent. When multiple principals each offer incentive schemes to a bureaucratic agent and can audit the agent's type, it is possible for a collective action problem to make the level of auditing inefficiently low. On the other hand, this is by no means guaranteed. For some model parameters the level of auditing is efficient. Moreover, the more committees use their information for oversight purposes, and the more likely it is that the audit is informative, the worse the collective action problem will be. Finally, for some audit costs C, there is a range of audit success probabilities π where the principals' equilibrium utility is lower than it would be at lower values of π.

The model could be generalized by allowing nonzero correlation in audit results, different probabilities of informative audits for P_1 and P_2, and strategic auditors. It seems likely that these elements will complicate the exposition and alter the parameter ranges where different cases hold, but should not overturn the intuition.

Likewise, partial (rather than full) information leakage among principals should be treated. For example, one principal may only observe a (nondegenerate) garbling of another's audit results. Or, audit results per se may not leak at all, but may be partially revealed in the incentive subgame through the incentive schemes offered. Treating these cases will require a model of common agency with differentially informed principals. Moreover, this model did not consider strategic considerations in information transmission among the principals, which could certainly also be interesting.

The model assumed simultaneous contract offers and audit decisions by the principals, but this is not responsible for the results. Martimort (1999) has shown that a similar distortion from common agency remains with sequential offers of incentive schemes. With sequential audits, the external benefits of a principal's audit would remain as well, given the information leakage. These external benefits would still increase with audit success probability and the importance of oversight. The non-monotonicity of equilibrium utility is also not tied to simultaneity. The result does not depend on coordination failures, an inefficiency that can be eliminated with sequential moves in public good provision problems. Instead it requires that the marginal benefit of a second audit decline in π when π is relatively large, and a selfish reckoning of when to audit or not. Given these features, then certain increases in π will make a second audit irrational for either principal before it becomes inefficient. For such increases in π there is a slightly smaller increase that leads in equilibrium to more but only slightly less effective audits. That is the key to the result, and is not related to simultaneous moves.

Applications of an optimal mechanisms approach to politics bring with them some important, and not necessarily desirable, assumptions (c.f. Laffont 2000). In particular, each principal commits to an incentive scheme. One common way to think of this is that reputation matters and engenders commitment (c.f. Bendor, Taylor, and Van Gaalen (1987) or Baron (2000)). For example, legislative principals interact with a sequence of smaller bureaus in any budget cycle, and across legislative sessions.

Nevertheless the robustness of the results to the commitment assumption should be examined.

The model developed here can apply, with some modification, to regulation as well — that is, conceiving of (multiple) bureaucrats themselves as principals and regulated firms as agents. Similar issues to those examined here (but different from those in other regulation models with auditing) arise when regulation is controlled by different agencies that can each solicit advice from third parties.

Appendix: Proofs

Proof of Lemma 2.1: The necessary condition for incentive compatibility is

$$\frac{\partial v(\theta,\widehat{\theta})}{\partial\widehat{\theta}} = t'(\theta) + e'(\theta - D(\theta))D'(\theta) = 0$$

for all but a measure zero set of types θ; using this in $\frac{dU(\theta)}{d\theta} = t'(\theta) - e'(\theta - D(\theta))(1 - D'(\theta))$ gives IC-1. ∎

Proof of Proposition 2.1: Writing $t_1(D(\theta)) = U(\theta) - t_2(D(\theta)) + e(\xi(\theta))$, taking t_2 as given, and ignoring IC-2 for the moment, P_1 wants to solve

$$\max_{\xi(\theta)} \int_{\underline{\theta}}^{\overline{\theta}} [V_1 - e(\xi(\theta)) - s_1(\theta - \xi(\theta)) - U(\theta) + t_2(\theta - \xi(\theta))]dF(\theta)$$

subject to IC-1 and $U(\overline{\theta}) = 0$. The Hamiltonian is

$$H_1 = (V_1 - e(\xi(\theta)) - s_1(\theta - \xi(\theta)) - U(\theta) + t_2(\theta - \xi(\theta)))f(\theta) - \mu(\theta)e'(\xi(\theta)).$$

The Pontryagin Maximum Principle implies $\frac{\partial\mu(\theta)}{\partial\theta} = -\frac{\partial H}{\partial U} = f(\theta)$. Integrating this and using the transversality condition $\mu(\underline{\theta}) = 0$ gives $\mu(\theta) = F(\theta)$. Using this and rearranging $\frac{\partial H}{\partial\xi}$ gives the first order condition for P_1's problem:

$$e'(\xi^{CA}(\theta)) = s_1 - t_2'(\theta - \xi^{CA}(\theta)) - \frac{F(\theta)}{f(\theta)}e''(\xi^{CA}(\theta)).$$

P_2's problem leads to an analogous necessary condition. The Hamiltonians for the principals' problems are concave in ξ so the second order conditions for the principals are satisfied. The necessary conditions are also sufficient.

Since in equilibrium these necessary conditions must have the same effort, we can add them and use the incentive compatibility condition to yield the conditions to determine A's effort in each state. Differentiating $t_1(\theta - \xi(\widehat{\theta})) + t_2(\theta - \xi(\widehat{\theta})) - e(\xi(\widehat{\theta}))$ with respect to $\widehat{\theta}$ and setting the result equal to zero at θ yields the first order condition for incentive compatibility in terms of transfers,

$$-t_1'(\theta - \xi(\theta)) - t_2'(\theta - \xi(\theta)) = e'(\xi(\theta)).$$

Substituting this into the sum of the principals' first order conditions gives the equation defining the agent's equilibrium effort.

The equation in the proposition must hold for all θ, so using its derivative with respect to θ, the monotone hazard rate assumption, and $e''' \geq 0$ implies that $\xi' \leq 0$. Thus $D'(\theta) = 1 - \xi'(\theta) \geq 0$ and A's second order condition (IC-2) is satisfied. ∎

Proof of Proposition 2.3: If $C > X_1 + X_2 + Z_i$, $i = 1, 2$, there is no inefficiency: auditing is too expensive relative to its collective benefits to the principals, and neither principal will audit. If $C > \max_i(X_i + Z_i)$ and $C < X_1 + X_2 + Z_i$ for either $i = 1$ or 2, the audit should be purchased from a collective point of view, but will not be in equilibrium, which entails that neither principal audit. If $C < X_i + Z_i$ for either $i = 1$ or 2, the audit will be purchased by one principal, as efficiency requires. ∎

Proof of Proposition 2.4: (i) For $C \in [Y + Z, 2Y + Z]$ one principal will audit but an audit by both would be collectively beneficial. For $C \in [X + Z, 2X + Z]$ neither principal will audit, but by construction an audit by one would be collectively beneficial. If $C < Y + Z$, $C \in (2Y + Z, X + Z)$, or $C > 2X + Z$, the equilibrium level of auditing is the efficient level (two, one, or zero audits respectively). (ii) When $\pi \in [0, \frac{1}{2}]$, $X \leqslant 2Y$. This case adds the possibility that neither principal audits but two audits are collectively beneficial. ∎

Proof of Proposition 2.5: If $\pi > \frac{1}{2}$, the size of the range is $2X - X + 2Y - Y = X + Y = (2\pi - \pi^2)(\int_{\underline{\theta}}^{\overline{\theta}} V(\theta)dF(\theta) - \overline{V}(F))$. $\frac{\partial(X+Y)}{\partial\pi} = 2(\int_{\underline{\theta}}^{\overline{\theta}} v_i(\theta)dF(\theta) - \overline{V}(F))(1 - \pi) > 0$ for $\pi \in (\frac{1}{2}, 1)$. If $\pi \leqslant \frac{1}{2}$, the size of the range is $2X - Y = (\pi + \pi^2)(\int_{\underline{\theta}}^{\overline{\theta}} V(\theta)dF(\theta) - \overline{V}(F))$. $\frac{\partial(2X-Y)}{\partial\pi} = (1 + 2\pi)(\int_{\underline{\theta}}^{\overline{\theta}} V(\theta)dF(\theta) - \overline{V}(F)) > 0$. ∎

Proof of Proposition 2.6: Let $C_i^s = v[W_i^a(1, n_j) - W_i^a(0, n_j)] + (1 - v)[W_i^b(1) - W_i^b(0)]$ be the cost below which auditing is optimal for principal i. Let $C_i^p = v[W^a(1, n_j) - W^a(0, n_j)] + (1 - v)[W_i^b(1) - W_i^b(0)]$ be the cost below which auditing is collectively beneficial. $C_i^p - C_i^s = v[W_j^a(1, n_j) - W_j^a(0, n_j)]$ is increasing in v. ∎

Proof of Proposition 2.7: For any such C, let $\pi^*(C)$ be the $\pi \geqslant \frac{1}{2}$ such that for $\pi < \pi^*(C)$ two audits are efficient and two are performed, while for $\pi \geqslant \pi^*(C)$ two audits are efficient while one is performed. At $\pi^*(C)$, an additional audit would necessarily add a discrete welfare gain: the utility of 1 and 2 audits is equal at some

$\pi^e > \pi^*(C)$, the utilities from 1 and 2 audits as a function of π are continuous and increasing in π, and the utility from 1 audit increases faster in π than the utility from 2 audits when $\pi \geqslant \frac{1}{2}$. But an outcome with two audits at $\pi^*(C)$ is arbitrarily well approximated at $\pi^*(C) - \varepsilon$ for ε small enough: at $\pi^*(C) - \varepsilon$ there is a discrete gain in welfare compared to $\pi^*(C)$ because of the extra audit, and an infinitesimal loss in welfare due to the less informative audits. ∎

Chapter 3 Expertise, Subversion, and Bureaucratic Discretion

Abstract

This chapter examines a legislature's delegation of policy making authority to an imperfectly controlled, expert bureaucrat. The legislature can reduce the bureaucrat's expertise advantage through costly investigations of its own before delegating. Further, the bureaucrat is granted discretionary bounds by the legislature, but can subvert legislative dictates by stepping beyond them at some cost. I analyze the interaction of preference divergence, investigation cost to the legislature, and subversion cost to the bureaucrat on the decision to delegate. The model shows that, because of the equilibrium effect of subversion on discretion, bureaucrats will want subversion of legislative dictates to be difficult, while legislators want it to be relatively easy. It also highlights an indirect effect between preference divergence and discretion: preference divergence leads the legislature to become more expert on policy matters, which leads it to delegate less.

3.1 Introduction

Delegation of policy making authority from legislatures to bureaucrats poses fundamental questions about policy making in an administrative state. Some of these questions, such as why legislatures would ever delegate and how they can cope with the control problem delegation creates, have been extensively studied by economists and political scientists. An issue that has until recently received less attention is what explains the variation in delegation patterns across policy areas. This chapter is an effort to contribute to that part of the study of legislative-bureaucratic interaction.

Delegation has long been understood as a concession to expertise (e.g., Goodnow 1905); the cost of alternative forms of expertise is important in understanding this control problem. The extent of the bureaucracy's technical superiority does not arise exogenously. A legislature has a number of other institutional choices available to it, such as creating its own experts in the legislative branch, or acquiring expertise itself. The costs of other sources of expertise will vary with the technicalities of a policy issue; when delegating, strategic legislators should account for other sources of expertise with more sympathetic policy preferences.

Another approach to this control problem is to restrict an agent's ability to choose unauthorized policies. However, legislative dictates are often inherently vague, even with substantial effort by Congress to spell out the bounds on the agency's authority (Mashaw 1990, Schick 1983).[1] Even carefully designed administrative procedures are not perfect instruments of control, and leave some residual discretion or room for

[1]Or more generally with some sort of "equilibrium" (from an unmodeled game) vagueness.

"bureaucratic drift" (Bawn 1995; Hill and Brazier 1991; McNollgast 1987, 1989, 1999). For example, if agencies award grants using different factors or different weighting of factors than a legislature intended, this will be difficult to detect — even though it amounts to choosing a policy the legislature did not authorize. Thus a bureaucrat must retain some residual discretion to choose unauthorized policies, even if they subvert legislative wishes. The costs of this subversion will vary by policy area,[2] and strategic legislators should account for subversion in making delegation decisions.

In this chapter I model delegation from a legislature to an expert bureaucrat that is imperfectly controlled by legislative dictates, and how that delegation varies by policy area. The legislature decides whether to purchase a signal about a random shock affecting outcomes from a given policy choice. Then it decides on the discretionary bounds to place on a bureaucrat with a different ideal outcome, but perfect information about the random shock; the bureaucrat then chooses a policy.

Subversion is represented by allowing the agent to "buy" policies that are outside of its discretionary bounds. Agencies can choose policies legislatures did not authorize, but as they get further from the constraints, this is harder to hide ex ante, and subject to greater costs (loss of status or budgets (but see Ting 2001), lawsuits, depleted "political capital") ex post.

One interpretation of the subversion cost is as a "reduced form" legal costs model. Lawsuits by interest groups are a common way to stop bureaucrats from subverting

[2]Subversion costs will be affected by tort liability of agency officials, grants of standing to challenge agency decisions, Freedom of Information Act requirements, ideologies and the level of activism of courts granted review powers, technical factors limiting specificity, committees with oversight jurisdiction, etc. While some of these factors are endogenous to the political process as a whole, they are not all practically endogenous to every instance of delegation.

"legislative intent." Since that concept is itself vague, a court's perception of it can be malleable, and resources spent on legal action (or committed to legal action through human resource choices) can help a court to see things from an agency's point of view, or prevent a lawsuit entirely. However, the further agency policy is from its discretionary bounds, the more difficult and presumably costly it would be to connect that policy to a defensible standard of legislative intent. Alternatively, bureaucrats can influence the desire a legislature has to mete out punishments by rallying interest group or legislative support to get constraints overturned, or agency subversion ignored. This also comes at some opportunity cost to the agency.

The model shows that in addition to the direct effect of preference divergence on delegation (Epstein and O'Halloran 1994, 1996, 1999), an indirect effect of this difference also exists: agencies with more extreme policy preferences lead the legislature to gather more costly information itself, which reduces the value added of delegation and causes less of it. Subversion introduces selection bias in the agencies that receive policy making authority (c.f. Banks 1989, Banks and Weingast 1992): they are the ones for which subverting legislative dictates is not "too easy." In addition, subversion changes the equilibrium effect of preference divergence on discretionary grants. The model also suggests that legislatures may actually want to build some limited subversion ability into the administrative policy process. Agencies, by contrast, may want to prevent any subversion ability (and would by implication resist discretion if subversion were too easy), because legislatures will account for it when granting discretionary authority.

The general modeling apparatus is related to the work of Epstein and O'Halloran (1994, 1995, 1996, 1999). Indeed their delegation game (1999, ch. 4) is essentially a special case of this model, when investigations by the legislature are free and subversion is infinitely costly.[3] The legislative choice of discretion is also related to the work of a number of authors. In particular, Bawn (1995) models this with legislative choice of agency "independence" and the mean and variance of the agent's ideal point. McCubbins (1985) captures this with "effective discretion" afforded by varying regulatory forms. Ting (2001, 2002) analyzes budgetary slack as a way to enhance bureaucratic discretion ex ante.

Several authors note avenues open to bureaucrats attempting to circumvent specific legislative constraints (e.g., Brehm and Gates 1997; Hill and Brazier 1991; Kiewiet and McCubbins 1991; McNollgast 1987, 1989, 1999; Wood and Waterman 1994) — these ideas are related to the notion of subversion. Ting (2002) discusses ex post costs legislatures can mete out in response to bureaucratic noncompliance. Similar possibilities are captured here in the cost of subversion.

The rest of the chapter is organized as follows. In Section 3.2 I describe the formal model and notation. Section 3.3 contains results and discussion; Section 3.4 contains results on preferences over the possibility of subversion. Section 3.5 discusses some examples and illustrations of the model. Section 3.6 concludes. Derivations of decision rules and proofs of propositions are contained in the Appendices.

[3]The game below can just as easily be considered a different political perspective, in which the committee, not the floor of the legislature, is in charge of the delegation decision.

The model in this chapter does not include the president. Strictly speaking, to make the models fully nested the president's choice of agency ideal could be included without changing any results.

3.2 A Model of Delegation Patterns

The game has two players: a Legislature (L) and an Agency (A). The players have single peaked utility in outcomes and different ideal outcomes (see below), where the set of outcomes is $X = \Re$. L and A will denote both the players and their commonly known ideal points. I assume that $L = 0$ and $A \in (0,1)$. Outcomes, over which preferences are defined, are represented as $x = p + \omega$. p is the enacted policy, and ω a random error that A knows with certainty ex ante, but L does not. For example, given an ideal outcome, the optimal reduction of PCBs depends in part on their effects on human health, about which there is considerable uncertainty.

The game proceeds as follows:

1. Nature selects ω from $U[0,1]$ and reveals it to the agency.[4]

2. L chooses $v \in \{0,1\}$, where 0 means no investigation/signal and 1 means the legislature investigates (for which it pays a cost depending on an exogenous parameter) and updates beliefs as specified below.

3. L chooses a level of discretion $d \geqslant 0$ for the agent and a status quo policy $q \in \Re$.

4. If L delegates (i.e., $d > 0$), A names a policy $p \in \Re$ and the outcome is $x = p + \omega$. If L chooses no delegation ($d = 0$), the final outcome is $x = q + \omega$.[5] The game ends and payoffs are distributed.

[4]It might be objected that in fact A does not know the state variable with certainty. Surely this is often true, but the important point for this analysis is that A knows ω better than L knows it. Making A uncertain about ω—provided the uncertainty is less than that faced by L—would not change the intuition, but would complicate the exposition.

[5]Because of subversion ability, in equilibrium this will cause a discontinuity in outcomes at $d = 0$.

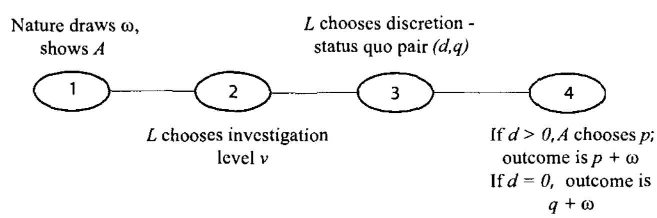

Figure 3.1: Timing of the game

The model yields equilibrium values of v, d, q and p as functions of each other and exogenous parameters. The equilibrium concept is sequential equilibrium.

The sequence of moves in the model roughly follows the stages of policy making on some given issue (see Figure 3.1). In particular, it does not exogenously fix the extent of the agent's information advantage with respect to the legislature. At the same time, ω is not costlessly revealed to L after the delegation decision is made. Moreover, the broad outlines of Congress's institutional choice are present, if in a stylized form. The legislature can delegate extensively, a bit, or not at all. L faces a genuine trade-off among possible locations of policy expertise. Finally, statutory control over agencies is imperfect.

Denoting by x the outcome, utilities are represented as follows. For the legislature,[6]

$$U_L = \begin{cases} -x^2 & \text{if } v = 0 \\ -(x^2 + b) & \text{if } v = 1 \end{cases}$$

where b is an exogenous cost L must pay for investigation. L's prior on the state is $\omega \sim U[0, 1]$. L is endowed with an "investigation technology," by which it chooses whether to obtain a costly, noisy signal about ω. If it does not investigate ($v = 0$), L simply "learns" that $\omega \sim U[0, 1]$. If it investigates ($v = 1$), L pays a cost b and learns which half of $[0, 1]$ contains the true state, i.e., whether $\omega \sim U[0, \frac{1}{2}]$ or $\omega \sim U[\frac{1}{2}, 1]$. It will be convenient to let z denote the posterior mean and let t denote half the posterior range.

For the agent,

[6] Quadratic utilities are convenient for obtaining first order conditions but the intuition for results does not depend specifically on this.

$$U_A = -((x - A)^2 + s(p; q, d))$$

where $s(p; q, d)$, the "subversion cost function" facing the agency, takes the form[7]

$$s(p; q, d) = \begin{cases} c(|p-q| - d)^2 & \text{if } |p-q| > d \\ 0 & \text{otherwise} \end{cases}$$

where the parameter $c > 0$ varies by policy area. L chooses a discretionary window of size $2d$ centered at q, which is the set from which A may choose policy at no cost. However, A can subvert L's dictates by choosing $|p - q| > d$. A may step outside its discretionary bounds, but pays a higher cost the further it steps.[8]

Notes on the Information Structure, Strategy Spaces, and Game Order

An important interpretive issue is why the legislature cannot observe that its dictates were subverted and infer information about ω from that fact. It is as if policy choices are made "today," but payoffs will not be distributed (and therefore the outcome known) until some point in the future—say an election—when it is too late for the legislature to do anything about what is discovered.

[7]The specific functional form is useful for explicit solutions but not necessary for comparative statics. A strictly increasing, continuous, strictly convex subversion cost function would have similar implications, as long as the agent's utility is strictly concave. Then the first order condition in the agent's subversion problem (see Section 3.3.1) would guarantee an interior optimum unless the agent's ideal outcome could be obtained with a policy p in the discretionary window. This is the key feature of the agent's policy choice that L accounts for when investigating and granting discretion.

[8]The subversion cost could be made endogenous by, for example, letting L observe a noisy signal of subversion – say, observing subversion with probability π and nothing otherwise, to use the technology from Chapter 2. Then L's choice comes down to the parameter c. L's preferences over c are discussed in Section 3.4. Other legislative choices, like judicial review provisions, can also be understood as affecting subversion cost; see Shipan (1997) for a treatment. Since many choices feed into subversion cost but involve design issues beyond the scope of this paper, it is convenient to leave them "black boxed."

Notice that, unlike the preceding chapter, there are no explicit transfers that the legislature has as an instrument of control. In part this is because limted side payments, and crude levers of control in general, are important in politics. The absence of transfers can be understood as one way to investigate how this matters analytically. Nevertheless, the subversion cost s has a similar impact on A's incentives as policy- (as opposed to outcome-) conditioned transfers. The main difference between this formulation and true policy-conditioned side payments, then, is that L does not take into account the negative of these transfers in its own optimization problem.

Given that L can only control its delegate by restricting the policies it can choose (for free), it is optimal for L to restrict A's choices to a connected interval, provided the distribution on ω is uniform and the policy space is unidimensional. Suppose that subversion is impossible and that the agent's choice set has a gap with endpoints r_l and r_h ($r_l < r_h$), both in the set of feasible policy choices.[9] Then there is an interval of ω's with midpoint ω_m such that for $\omega < \omega_m$, A chooses r_l, and for $\omega > \omega_m$, A chooses r_h. Thus, the induced outcome as a function of ω has slope 1 at all points in this interval, except for a discontinuity at ω_m. As a result, the induced outcome over this ω range has the same mean whether or not policies in (r_l, r_h) are available to A, and a higher variance when they are not. Since L is risk averse, it prefers that these points be included. Subversion only alters this argument by shrinking the effective gap A faces for any given $r_{l,h}$. Thus, given the other assumptions of this model, it is without loss of generality to restrict L to choosing a "delegation window."

Another difference between this model and the one in Chapter 2 is that there is

[9] A's choice set must be closed so an optimal choice can be guaranteed.

no stage between nature revealing ω to A, and L choosing an investigation level, at which L solicits a report of ω from A. This gets at the issue of whether L conditions on policy choices p or outcomes x, discussed above. L can ask for reports of ω, but if it cannot condition discretion on x and cannot offer outcome-conditioned transfers, L would have no levers to pull for incentive compatible reports.

With the same information structure, Crawford and Sobel (1982) show there may be partial separation even without transfers. In their model the agent makes a report to the principal, who then makes a policy choice that both principal and agent care about. However, in this setting one cannot argue that a reporting stage should be present on the grounds that the revelation principle shows it to be without loss of generality. Instead whether to have that stage depends more on the interaction one is attempting to model. In Crawford and Sobel the commonality of interests over the principal's policy choice induces the partial separation. However, if the principal does not make the final choice but determines from which (positive measure) region the agent will make it (or the costs the agent faces for making it in different regions), the incentive for partial separation disappears. As is shown below, L grants more discretion the wider is the support of its belief about ω – since A is better off in equilibrium with more discretion, types of A do not have an incentive to reduce L's uncertainty by separating.

If there were such a reporting stage *and* outcome-conditioned transfers of utility, L clearly would obtain the first best outcome with a "shoot the agent" mechanism. If L's transfers had meet an individual rationality constraint, L would sacrifice desir-

able outcomes for lower informational rents in the usual way. Indeed, since the single crossing property holds in this setting, we would have a standard bilateral mechanism design problem with adverse selection (c.f. Baron and Myerson 1982), with ω interpreted as the agent's type. In such a setting subversion is difficult to reconcile with the revelation principle, and the meaning of more or less discretion is not as clear as it is in this model. However, investigation could proceed much like it does here.

A Note on the Investigation Technology

It may be objected that the investigation technology described above limits the generality of results relative to an updating process with prior and data distribtutions combined by Bayes's rule. In this setting the most natural such process is as follows. L's prior on the state is $\omega \sim U[0,1]$. L chooses whether to obtain a costly, noisy signal y about ω from a Bernoulli($\frac{1}{2}$) distribution. The signal can either be "high" ($y = 1$, success) or "low" ($y = 0$, failure). If it does not investigate ($v = 0$), L simply "learns" that $\omega \sim U[0,1]$ and has posterior distribution and density $F_0 = \omega$ and $f_0 = 1$ respectively. If it investigates ($n = 1$), L pays a cost b, observes a signal about the true state, and updates beliefs to F_h or F_l after a high or low signal, respectively. The associated densities are $f_h = 2\omega$ and $f_l = -2\omega + 2$. More generally, L could obtain n signals from a Binomial(n, p) distribution and, after observing y high signals, update beliefs to a Beta$(y + 1, n - y + 1)$ distribution.

While this formulation is straightforward and intuitive, it causes tractability problems later on. With quadratic utilities, even when v can only be 0 or 1, the extra ω from the posterior density in the expected utility means that an analytically intractable (and particularly homely) system of equations must be solved to obtain the optimal discretion and status quo following investigation by L. Some other strictly concave utility (e.g. with a higher exponent or natural log) would *a fortiori* make the problem worse. The alternative, numerical simulation, seems to defeat the purpose of added analytical generality.

In any case, the intuition for the results on investigation (Propositions 3.3 and 3.4) is not inextricably linked to this particular technology. It is useful to obtain closed form solutions, but the comparative statics are more robust. It is evident from the proofs in Appendix A that the main requirements for them are that (*i*) as L is more certain it grants less discretion, and (*ii*) that as investigation cost rises L investigates less. From Section 3.3.2 the first is a property of L's optimal choice given its beliefs, however it forms them; the second is obviously robust to the technology.

3.3 Results

3.3.1 Agency Policy Making with Subversion

It is shown in Appendix A that for given values of subversion cost c, status quo q, and the discretionary window d, A's equilibrium policy with the possibility of subversion is

$$p^* = \begin{cases} q + d + (\frac{A-q-d-\omega}{c+1}) & \text{if } \omega < A - q - d \\ A - \omega & \text{if } A - d - q < \omega < A - q + d \\ q - d + (\frac{A-q+d-\omega}{c+1}) & \text{if } A - q + d < \omega. \end{cases}$$

So in different regions of the state space, A chooses different policies. In the intermediate region in the above expression, A can secure its ideal point without using all of its discretion. In the other two regions, A would like to choose a more extreme policy and must subvert to do so. A's optimal policy choice given d, q, and c is depicted in Figure 3.2. Note that for $\omega > A - q + d$, A's policy choice cannot possibly make L better off.

Thus unless the agent achieves its ideal point with a policy inside the discretionary window $q \pm d$, it will subvert the legislature's dictates at least to some extent (and L is aware of this), but never enough to achieve its ideal outcome. This is because subversion cost is a continuous, convex function of the distance between the actual policy choice and the edge of the discretionary window.

For the special case of $c = \infty$ the results collapse to the Epstein-O'Halloran ones. A is constrained to choose $p \in [q - d, q + d]$. It is straightforward to show that in this case,

$$p^* = \begin{cases} q + d & \text{if } \omega < A - q - d \\ A - \omega & \text{if } A - q - d < \omega < A - q + d \\ q - d & \text{if } A - q + d < \omega. \end{cases}$$

When (for example) ω is relatively small, the agent would like to choose p relatively large. Now, however, it is not permitted to choose $p > q + d$, so it chooses the largest policy in its feasible set.

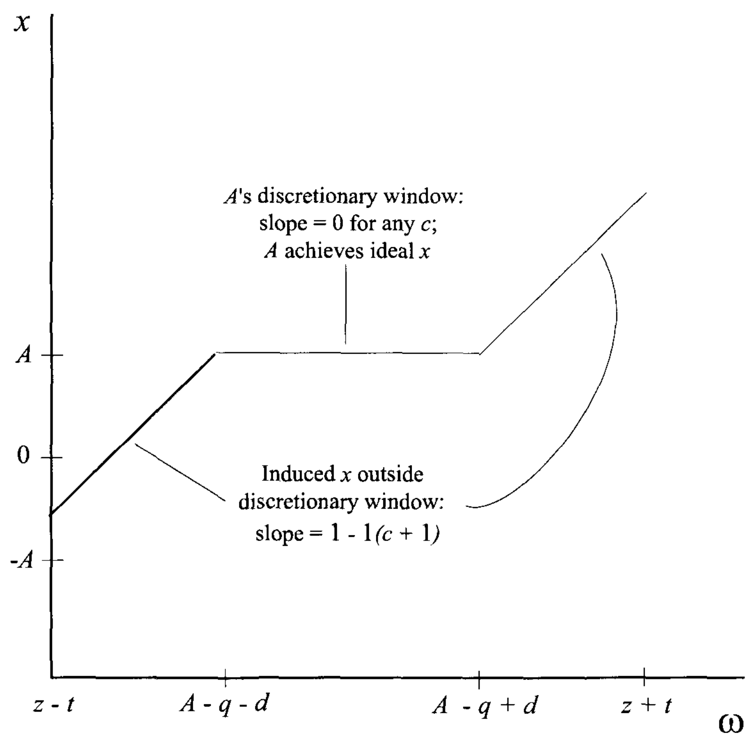

Figure 3.2: Agency policy choices and induced outcomes

3.3.2 Legislative Choice of Status Quo and Discretion

Working backwards up the tree, L's first problem is to find a status quo choice and a level of discretion that maximize its expected utility, given how the agent will respond later in the policy process. Simultaneous solution of first order conditions (see Appendix A) yields $d^* = \max\{t - A - \frac{A}{c}, 0\}$ and

$$q^* = \begin{cases} -z - \frac{A}{c} & \text{if } d > 0 \\ -z & \text{if } d = 0. \end{cases}$$

(Recall that z is the posterior mean and t is half the posterior range.) Notice that $\frac{\partial d^*}{\partial c} = \frac{A}{c^2}$, which is positive since $c > 0$. Thus, larger c implies more costly subversion implies more discretion. Moreover, choosing $\widehat{d} \pm \widehat{q}$ such that $\{\omega \in [z - t, z + t] : \omega \in [A - \widehat{q} + \widehat{d}, z + t]\}$ has positive measure is dominated for L. Suppose $A - \widehat{q} + \widehat{d} \neq z + t$ and let L increase $\widehat{d}$ by an appropriate $\Delta\widehat{d}$ and lower $\widehat{q}$ by the same amount, so that $\{\omega \in [A - \widehat{q} + \widehat{d}, z + t]\}$ has measure 0 and $A - \widehat{q} - \widehat{d}$ does not change. After this change, for $\omega > A - \widehat{q} + \widehat{d}$ the realized outcome x is constant at A, rather than variable in ω around points larger than A (see Figure 3.2); for $\omega \leqslant A - \widehat{q} + \widehat{d}$ the realized outcome is unaffected by the change.

Examining the limiting case of $c = \infty$ helps to reveal the effect of subversion at this stage. Simultaneous solution of first order conditions given posterior beliefs yields $d^* = \max\{t - A, 0\}$ and $q^* = -z = -E\omega$. Thus, the status quo choice is simply the one that in expectation leads to the legislature's ideal outcome (after the random shock). This is the case covered in Epstein and O'Halloran (1999), where $\frac{\partial d^*}{\partial A} = -1$ whenever $A \in (0, t)$. The more distant is A's ideal point from L's, the less authority L delegates.

The *optimal* choices of the legislature at this stage therefore contain an intuitive subversion correction, relative to the no subversion results. Again the status quo is based in part on the negative of the posterior mean, but now is even lower in inverse proportion to the subversion cost. As subversion cost falls, then provided some discretion is still granted, the status quo becomes more negative to account not only for L's information about ω, but also A's subversion ability.

Proposition 3.1 *If $c < \infty$ and $d > 0$, $q^* = -z - \frac{A}{c}$: L's policy choice is biased relative to that leading to L in without the possibility of subversion by the agent.*

That is, the legislature must bias *policy choices* away from those that lead to its ideal outcome without subversion, if it wants *outcomes* to be closer to its ideal. This is because the legislature must count on some possibility of subversion by the agent. Suppose in particular that the ideal outcome of the median member of the electorate is L. Then, in the presence of an agent who can subvert legislative dictates, policy bias (relative to the electorate) cannot be taken as evidence that the legislature is unrepresentative. Even if its ideal outcome was identical to the median voter's in the electorate, it would still need to bias its status quo policy choice to account for subversion.

Subversion not only causes bias in legislative policy choices, but in which agencies will exist as well.

Proposition 3.2 *Provided $t > A$, $\frac{\partial d^*}{\partial c} > 0$: as c falls L will reduce discretion d when it does give A some control. If $c \leqslant \frac{A}{t-A}$, $d^* = 0$: when subversion is easy enough, L* *will grant A no policy making authority.*

In other words, the possibility of subversion means that $d^* = 0$ for more A's, and that this effect is stronger the smaller is c. Thus, the model predicts a selection bias in the agencies that exist and/or receive any policy authority: those agencies in policy areas where subversion would be easy enough simply receive no delegated authority. This result may be considered a parallel to the one obtained in Banks (1989) and Banks and Weingast (1992), in a model of bureaucratic service production. Rather than taking policy out of its own hands and putting it in the hands of those who "know best," the legislature retains control over policy that it is not as well suited to make as some other actors. The reason is that in these cases, the control problem introduced by delegation is too costly relative to the expertise gains for the legislature to tolerate.

3.3.3 Legislative Investigations

Finally, L must decide whether to gather expertise of its own on the policy issue — i.e., whether to purchase the signal ($v = 1$) or not ($v = 0$). L's optimal choice of investigation depends on whether any discretion is granted later on, because this influences decisions later in the game for which L must now account.

First consider the case where $A \in (0, \frac{1}{4}(\frac{c}{c+1}))$. For these A values nonzero discretionary authority is granted whether the legislature investigates or not, which happens if and only if b is small enough relative to A and c: $b \leqslant \frac{4}{3}A^3(1 + \frac{1}{c}) = \underline{b}$.[10]

[10]The numerical values themselves are simply artifacts of the uniform-quadratic setup. The important part is the intuition arising from these results and the relationship between the numbers.

There is enough commonality of interest between the parties here that L always wants A to have some authority. This can be seen from the earlier result that $d^* = \max\{t - A - \frac{A}{c}, 0\}$. Since $t = \frac{1}{4}$ is the lowest t can be, and in this case $A - \frac{A}{c}$ is even lower, some discretion is always granted.

In the second case, where $A \in [\frac{1}{4}(\frac{c}{c+1}), \frac{1}{2}(\frac{c}{c+1}))$, nonzero discretion is granted only in case $v = 0$ and L is uncertain enough to tolerate A's preference difference and subversion capability. However, investigation can still be useful to L in setting policy itself when $d^* = 0$. The investigation is worth purchasing if and only if $b \leqslant A^2 - \frac{4}{3}A^3(1 + \frac{1}{c}) - \frac{1}{48} = \bar{b}$.

Finally, if $A \in [\frac{1}{2}(\frac{c}{c+1}), 1)$, no discretion is ever granted, regardless of the investigation decision. Policy is made outside the administrative realm. The investigation can again be purchased, however, and will be useful to L as it completely determines policy itself. L will investigate if and only if $b \leqslant \frac{1}{16}$. The investigation decision here is unrelated to A's ideal point.

Consider what happens to these cutoff b values as subversion cost decreases. In the second case, as subversion becomes more costly, L is actually willing to investigate for *more* possible b values—and by implication delegate less.

This seems like an unintuitive result — why investigate more and delegate less if subversion is more costly for the agent? — until one accounts for the fact that the set of A's for which each of these cases holds is itself influenced by c. Since $d^* = t - A - \frac{A}{c}$, as c falls and subversion becomes easier, the relevant range of A values shrinks and moves closer to 0. So in order for any delegation to occur, the agent must be closer to L as c falls. What is actually being picked up in the second case is that the legislature knows it might investigate into oblivion an agent whose ideal point is very close to its own, not the backward result that the legislature feels it must put tighter constraints on the agent as subversion becomes more difficult. As subversion becomes very easy, L knows that it will delegate only to agents who are so close to L, that investigation—which will cause discretion to fall to 0 by construction in that case—becomes less useful. Thus, as c falls, investigation has to actually become cheaper for the legislature to do it in this case.

In the first case, on the other hand, by construction L will delegate whether or not it investigates. Therefore, unlike the second case, it must focus on conflict of interest with A and possible agency losses. Thus as c falls the range of allowable values of investigation cost b that lead L to investigate is larger.

In spite of the complications on the above cases, the comparative static is that, for each given A value in this game, higher values of b make the condition leading to investigation harder to satisfy. The legislature will be less informed about the policy area, and will delegate more often to bureaucratic agents who are informed, the higher is the investigation cost b (for this last statement, of course, A must be sufficiently small, given c, for L to grant some discretion). This implies that toleration of agency losses (the concession to A implied by grants of wide latitude) from delegation will be higher the more costly it is to obtain information through other avenues.

Proposition 3.3 *For a given subversion cost c, a sufficiently large increase in investigation cost b results in (a) more delegation (change in $d^* = 0$ to $d^* > 0$)*

if $A \in [\frac{1}{4}(\frac{c}{c+1}), \frac{1}{2}(\frac{c}{c+1}))$*; and (b) more discretionary authority (increase in* d^**) if* $A \leqslant \frac{1}{4}(\frac{c}{c+1})$.

Thus, in policy areas with a high cost of creating expertise in the legislature, the legislature will rely more on delegation and discretion to make policy. In other words, when studying variation in delegation patterns by policy area, the cost of information acquisition in a policy area matters as well as divergence in ideal points.

Moreover, expertise of the agent is a substitute for expertise of the legislature: investigation both limits the set of A ideal points that will receive any discretion at all, and lessens the discretion granted in those cases where at least some is given. Thus, all else constant, the presence of an expert agency causes the legislature to investigate less, and to be less informed about policy, than it would without the expert. In case $A \in [\frac{1}{4}(\frac{c}{c+1}), \frac{1}{2}(\frac{c}{c+1}))$, this "substitution effect" is especially clear: the legislature *either* investigates *or* it delegates.[11]

A robust result in the legislative-bureaucratic interaction literature is that as preferences of the legislature and the agency diverge, the legislature will delegate less (at least weakly) (c.f. Bendor, Glazer, and Hammond 2001). When the extent of the agent's expertise is endogenous, there is another effect of preference divergence as well, based on the interaction of preference divergence, investigation, and discretion.

Proposition 3.4 $\frac{\partial b}{\partial A} > 0$ *for all* A *and* $\frac{\partial \bar{b}}{\partial A} > 0$ *for* $A \in [\frac{1}{4}(\frac{c}{c+1}), \frac{1}{2}(\frac{c}{c+1}))$*: as the agent's ideal outcome diverges from the legislature's, the legislature will investigate*

[11]Again the special case of $c = \infty$ is instructive. If $A \in (0, \frac{1}{4})$, discretion is always granted, and the legislature will investigate if and only if the signal cost $b \leqslant \frac{4}{3}A^3$. If $A \in [\frac{1}{4}, \frac{1}{2})$, nonzero discretion occurs only in case the signal is not purchased. The signal is worth purchasing if and only if $b \leqslant A^2 - \frac{4}{3}A^3 - \frac{1}{48}$. If $A \in [\frac{1}{2}, 1)$, no discretion is ever granted. L investigates if and only if $b \leqslant \frac{1}{16}$.

for (weakly) more possible b's.

Considering Propositions 3.3 and 3.4, then, an increase in A therefore has two effects on discretion. The first is the one well known in the literature: as the bureaucrat gets more extreme relative to the legislature, it receives less policy making authority. The second, indirect effect is that more extreme agents induce the legislature to investigate for more possible b values, which leads it to delegate less.

Figure 3.3 depicts the regions in b, c space where a general A receives nonzero discretionary authority. The shaded areas are ones where some discretion is granted. Since investigation and delegation are substitutes for each other, for any value of c, the area of the shaded region grows as b grows. Furthermore, there are b values such that as c increases, and subversion is more costly, L is actually less likely to delegate any authority.

3.4 Preferences Over Subversion Cost

Subversion cost c is exogenous in the previous sections because the institutional backdrop against which delegation decisions are made, which will affect the subversion cost, is in some sense more enduring than those decisions themselves. It is nevertheless interesting to examine the preferences the players have over c, a question that sheds some light on the prior issue of institutional design. For simplicity and to focus attention on subversion, in this section it is useful to examine the special case of $b = \infty$,[12] so $v = 0$ and investigation is not a concern.

[12] $b = \infty$ is much stronger than necessary. For any A and any strictly positive c, there will exist a finite b above which the legislature will not investigate, so that investigation can be ignored.

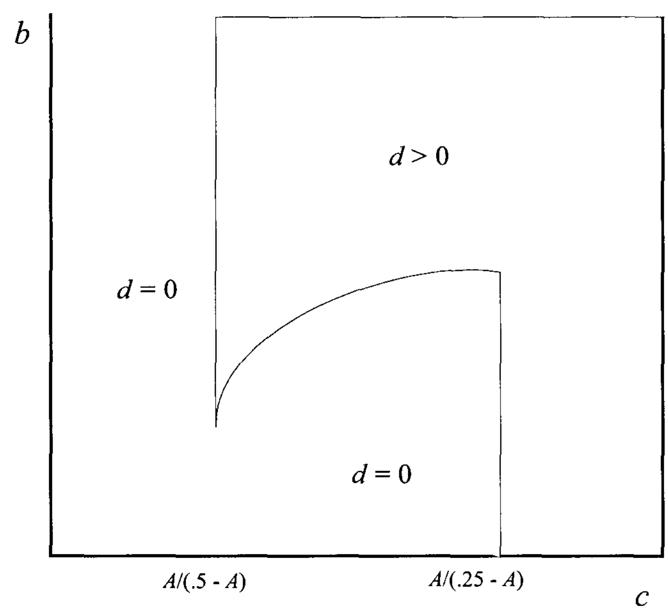

Figure 3.3: Delegation as a function of agent preferences, investigation cost, and subversion cost

Fixing some $A \in (0,1)$, one might expect that the legislature prefers subversion to be very costly, and the agency prefers it to be very cheap (at least conditional on it being expensive enough to induce $d^* > 0$). *Ceteris paribus* this is true, but in equilibrium it is not — because of the equilibrium response of q^* and d^* to changes in c.[13]

Proposition 3.5 *If $c > \frac{A}{.5-A}$ so that $d^* > 0$, L's equilibrium utility is decreasing in c. If $c \leqslant \frac{A}{.5-A}$ so that $d^* = 0$, L's equilibrium utility is constant in c. Further, L's equilibrium utility for any $c > \frac{A}{.5-A}$ is higher than for any $c \leqslant \frac{A}{.5-A}$.*

Moreover, as the agent becomes more extreme, L suffers greater utility loss from a given increase in c (see Appendix B). As c declines L responds by granting a smaller discretionary window and strategically adjusting its location. Given A's best response, the outcome x is closer to 0 in expectation as c declines. It is also more variable, but this second order cost to L is outweighed by the first order benefit of a better expected outcome.

Thus, not only does the legislature lack complete control over the agent in this model, it does not want complete control. When subversion is relatively cheap, the legislature knows that the bureaucrat is unable to attain its own ideal point as often as when subversion is costly (because discretion is smaller the smaller is c), but the bureaucrat will still put its superior information to use in deciding to subvert. On the other hand, L does not want subversion to be too easy, because then L best responds

[13]Thus L's ideal c is not well defined: L wants it as low as possible, as long as $c > \frac{A}{.5-A}$. This defines an open set, on which a monotonic function (which equilibrium utility is on $c \in (\frac{A}{.5-A}, \infty)$) cannot attain a maximum. Since c is not a choice variable in this model, and the purpose here is simply to examine the institutional pressures this model reveals, this is not a problem.

by bypassing the agency. This is L's best response when c is "too low," but L is better off when c is high enough to warrant some delegation.

Administrative scholars have long noted that political control of bureaucracy is imperfect (e.g., Goodnow 1900; Hill and Brazier 1991; Mashaw 1990; McNollgast 1987, 1989, 1999; Schick 1983) — even with conscious effort, American institutions allow some agency "slippage" or "wiggle room." Proposition 3.5 is suggestive in light of these observations. While legislatures obviously do not prefer all subversive decisions, in this model they are better off if subversion is relatively cheap. It would then be less surprising to see imperfect control as a necessary byproduct of administrative procedures designed by legislatures.

As for the agent's preferences, it is fairly intuitive that A does not want c to be too low. Low values of c may cause the legislature to bypass agency policy making altogether, and its perfect knowledge about the random shock may then never be used in policy making. If A could credibly commit to use its superior knowledge in certain ways beneficial to both parties, this problem would not arise. However, the possibility of subversion combined with the fact that A moves last in the game means that such commitment is not possible — by sequential rationality A will use any subversion ability to its own advantage (which will be to L's advantage too only for certain values of ω) — and Pareto inferior outcomes may result. Higher values of c mean that the agent is bypassed less often in policy making, and this Pareto inefficiency arises less often. In short, if c is such that $d^* = 0$, then A would prefer that its subversion ability be constrained.

Moreover, even conditional on $c > \frac{A}{.5-A}$, *A is always better off if subversion is more costly.* For a *given* d and q, A is obviously better off when subversion is cheaper. But this reasoning does not take into account the equilibrium effect of a lower c on d^* and q^*.

Proposition 3.6 *A's equilibrium utility is increasing in c.*

Again, given A's best response, higher c's moves x closer to 0 on average and increases its variance. Both of these effects make the agent worse off. The legislature makes up for more costly subversion by granting more discretion in equilibrium: the agent then gets wider latitude "for free," rather than having to "pay" for it. Nevertheless, faced with the possibility of subversion, A does best by engaging in it when its ideal outcome is not attained given d^* and q^*. The legislature, in turn, does best by so adjusting these variables for subversion, because the agent cannot commit to forego subversion if such adjustments are not made.

Proposition 3.6 implies there may be cases when agents resist expansion of their discretion. If subversion is easy enough, discretion will be so tightly constrained that the agent would be better off with no discretion at all. This is in contrast to the implication where subversion is infinitely costly — then agents are always better off when their discretion is expanded (c.f. Epstein and O'Halloran 1999).

Figures 3.4 and 3.5 illustrate these propositions. In Figure 3.4, a nonequilibrium figure, q and d are held constant and c declines. This clearly benefits A, as the expected outcome is closer to its ideal and the variance in outcomes decreases. While the lower variance in outcome benefits L, it is of second order, and is swamped by *the first order* effect of a less attractive expected outcome. In Figure 3.5, on the other hand, the equilibrium effect of lowering c is represented. Now A faces both higher variance and a less attractive expectation as c falls. L is worse off in the second order because of the higher variance, but is better off in the first order because of the more attractive mean.

Figure 3.5 shows that when subversion is possible, $q \pm d$ does double duty for L. For any c, it serves to rule out policy choices that could never benefit L in any state of the world; for finite c, it allows L to force A to "buy" what it used to get for free. This assures that A's policy choices are more in line with L's interests.

3.5 Empirical Implications

Proposition 3.1, on the bias in legislative policy under subversion, and the assumption that $c > 0$ imply that *ceteris paribus,* as a legislature grants less discretionary authority, the enacted policy is closer to the median ideal point in the legislature. Importantly, the converse is not true. When enacted policy is closer to the median of the legislature, it may be because for a given subversion cost less discretion has been granted, but it may also be that subversion cost is higher. The latter implies both more discretion for agents and enacted policy closer to the legislature's median.

Proposition 3.2 on selection bias in extant agencies may help illuminate phenomena such as the direction of environmental policy in the early 1970s. Before the EPA came into its own, there was some concern that delegating authority to agencies heavily influenced by anti-environmental constituencies would cause them to steer policy

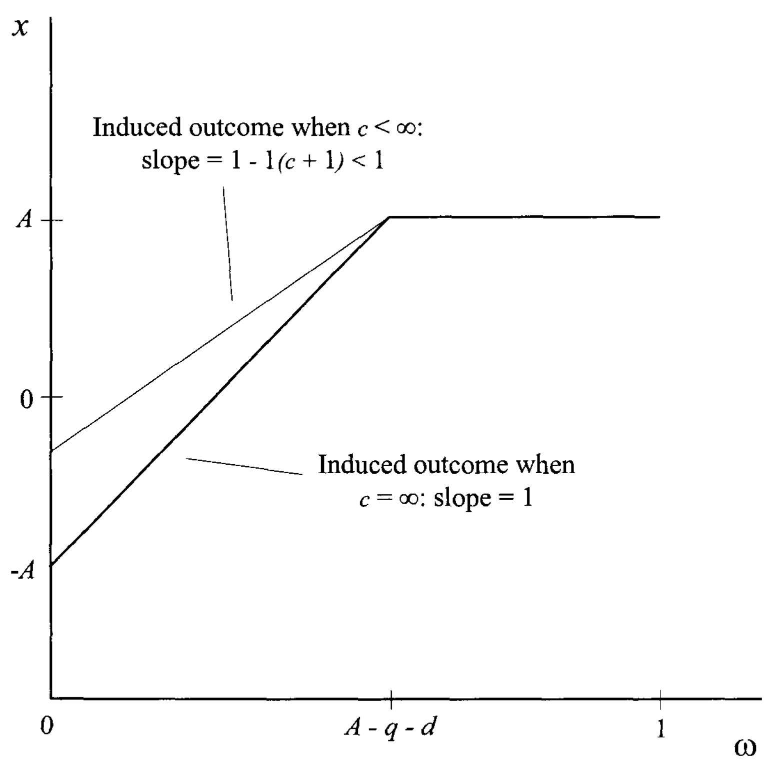

Figure 3.4: Nonequilibrium effect of change in subversion cost

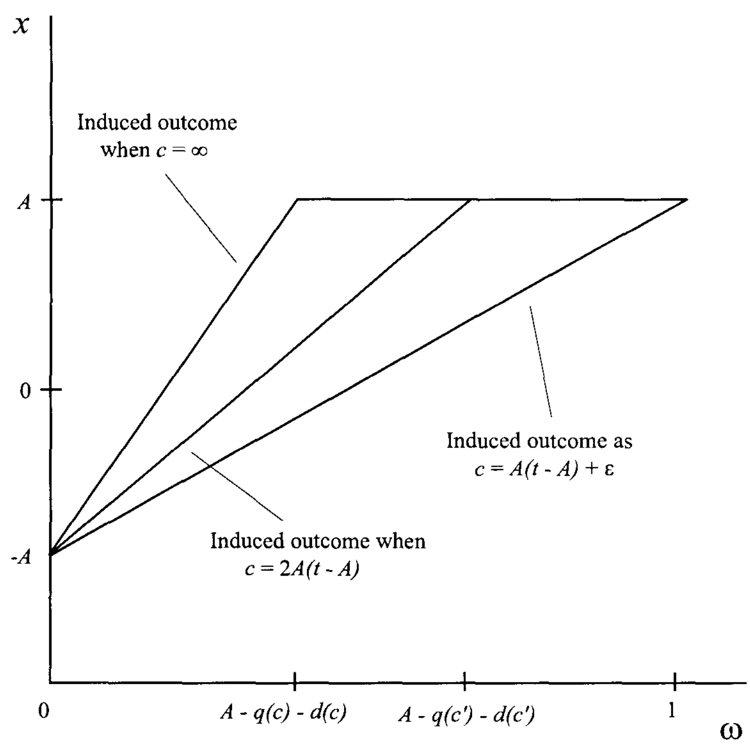

Figure 3.5: Equilibrium effect of change in subversion cost

outcomes in their own favor, despite congressional directives not to. A solution was to use citizen suits to enforce pollution standards, rather than use traditional bureaucratic channels. Judge Skelly Wright, involved in one such 1971 suit, had said that the goal of the new pollution suits was to assure that important congressional intentions to reduce pollution not be "lost or misdirected in the vast hallways of the federal bureaucracy" (Glaberson 1999). From the perspective of this model, in other words, subversion would have been too easy for existing agencies, so Congress opted not to entrust policy to them.

Subversion cost was motivated in part by the possibility of legal challenges to agency policy choices. If courts with jurisdiction over agency policy are closely aligned with them ideologically, it will be easier for agencies to legitimize their preferred policy choices. One direct implication of Proposition 3.2, then, is that as preferences of an agency and judges with jurisdiction over that agency diverge, discretion should increase. This is reminiscent of the McCubbins and Schwartz (1984) fire alarm oversight logic: legislatures economize on oversight by "farming it out" to third parties. Proposition 3.2 takes this logic to the issue of when delegation will occur.

Throughout careers on certain committees and work on certain issues, legislators themselves and their staffs, while they may not necessarily match executive branch experts, can acquire a considerable body of policy expertise. Therefore, under the ancillary hypothesis that this expertise tends to increase with a legislator's tenure on a given committee, one can operationalize the cost of expertise as the average number of years committee members have spent on the committee.[14] An implication

[14] An alternative measure would be the number of years the chair or longest serving member has

of Proposition 3.3 on the relationship between b and d^* therefore is that as committee tenure increases, less discretion is granted to agencies.[15]

Another implication of Proposition 3.3 comes from a different way of viewing the legislature's costs of expertise. *Ceteris paribus*, an increase in the technical education required in a field increases the amount of discretion to bureaucratic policy makers in that field. However, this must be separated from the hypothesis that Congress is fully in control of the bureaucracy, and thus gets more utility from delegating to these experts without any loss. A finer prediction that discriminates between these two hypotheses is that in areas where the education level of bureaucratic policy makers is very high, discretion is greater when the field of education is very different from the fields of most legislators. Thus, scientists, engineers, and possibly statisticians and economists should get more discretionary authority than lawyers and liberally educated policy makers, all else constant.

Propositions 3.3 and 3.4 (on the relationship between v and A) suggest that agency policy output should be less responsive to changes in congressional preferences the greater is the cost of expertise. This is an operationalization of the argument that greater agency losses are tolerated when expertise is more expensive. Thus, as the tenure of a committee chair or the average committee member increases, agency policy should be more responsive to changes in committee preferences.

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spent on the committee.

[15]It is important to control for selection bias here, so as not to pick up variation across policy areas in the ability of committee chairs and members to maintain their status. Controlling for committee type, or examining time series for a given committee, would help here.

3.6 Discussion and Conclusions

The product of this model is a simple theory of delegation, and why it varies by policy area. The theory points to three important parameters: the distance in ideal points between the agency and the legislature; the cost to the legislature of acquiring expertise through other means; and the cost to the agency of subverting the legislature's dictates.

The model highlights a new, indirect effect of a change in the agent's preferences on discretionary authority: its effect on the desire to investigate. It also implies that expertise in the bureaucracy is a substitute for expertise elsewhere, not a complement. Subversion introduces the intuition that there is selection bias in the agencies that receive policy making authority: they are the ones for which subverting legislative dictates is not "too easy." Subversion also implies that even a perfectly representative legislature will bias policy choices away from the median member of the electorate. The equilibrium effect on discretionary grants of lowering subversion cost implies that legislatures are actually better off when subversion is relatively (but not extremely) cheap. Subversion of a legislature's policy dictates is not the same as subversion of a legislature's interests, because even though those dictates are ex ante optimal, ex post they may be wrong (from the legislature's point of view), and the expert bureaucrat knows when they are. Agents, by contrast, are better off when subversion is more expensive, because the legislature accounts for easy subversion by tightly constraining discretion or not delegating at all.

There are several possible directions for future research. One direction to investigate is corruption. Delegation of decision making or administrative authority carries the danger that different decisions will be made, or will be made on different bases, than those desired by the delegator. The representation of subversion in this chapter is one way of capturing that.

Such a direction requires reckoning with other actors besides the legislature and the agent, which raises another point about this model. Other actors can at best be interpreted as represented through the preferences of L and A, or the parameters b and c. It would be interesting to include some of these other actors, like the president or courts, in a nontrivial way.

Since legislatures can take an active role in designing institutions, the problem is really one of mechanism design, and this may be a fruitful direction to take this research.[16] deFigueiredo, Spiller and Urbiztondo (1999) apply this approach in a model of bureaucratic service production. In informational environments like this one, identifying the agent's private knowledge of ω as the type would allow for analysis of optimal incentive schemes to extract that information, and how these schemes change with investigation and with the incentive instruments (like limited side payments) available to the principal.

[16]¿From this point of view this model is an optimal mechanisms model, where the set of mechanisms open to the principal is all compact, connected regions of the policy space.

Appendix A: Investigations and Subversion

Derivation of Agent's Optimal Policy. If A's ideal outcome can be obtained by choosing a policy within the discretionary bounds set by L, A will clearly not pay the cost to subvert. This is the case when $\omega \in [A-d-q, A-q+d]$. Otherwise its utility maximizing choice of policy p is equivalent to a choice of subversion level s. To see this, suppose that ω is relatively small, so that A wants to choose a policy larger than any in the discretionary bound set by L to get close to its ideal outcome. Then A will choose a policy $p = q + d + s$, where d and q are taken as given. So A's maximization problem in this case is

$$\max_s U_A(s) = -(q + d + s + \omega - A)^2 - cs^2.$$

The first order condition is

$$\frac{\partial U_A}{\partial s} = -2(q + d + s + \omega - A) - 2cs = 0$$

which implies that $s^* = \frac{A-d-q-\omega}{c+1}$; the second order condition is $c > -1$, true by assumption. A similar exercise can be performed when ω is very large, so that A wants to choose a relatively small policy: then $p = q - d - s$. This yields A's equilibrium policy with the possibility of subversion:

$$p^* = \begin{cases} q + d + (\frac{A-q-d-\omega}{c+1}) & \text{if } \omega < A - q - d \\ A - \omega & \text{if } A - d - q < \omega < A - q + d \\ q - d + (\frac{A-q+d-\omega}{c+1}) & \text{if } A - q + d < \omega. \end{cases}$$

As $c \to \infty$ these results collapse to the no-subversion case. ■

Derivation of Optimal Status Quo and Discretion. With subversion accounted for, L's problem with a given posterior $\omega \sim U[z-t, z+t]$ is

$$\begin{aligned}\max_{d,q} EU_L(d,q) &= \int_{z-t}^{A-q-d} -(\omega+q+d+(\frac{A-q-d-\omega}{c+1}))^2 dF(\omega) \\ &+ \int_{A-q+d}^{z+t} -(\omega+q-d-(\frac{A-q+d-\omega}{c+1}))^2 dF(\omega) \\ &+ \int_{A-q-d}^{A-q+d} -A^2 dF(\omega).\end{aligned}$$

Simultaneous solution of first order conditions[17] yields the following:

$$q^* = -\tfrac{1}{2c^2}\left(-2A+2tc-2cd+2c^2z-Ac^2+tc^3-c^3d+(-A+tc-cd)\,c^2\right)$$

$$\begin{aligned}d^* = \tfrac{1}{c}&\frac{-A+tc+2c^2q+2c^2z-Ac^2+tc^3+\left(-c^2z^2-2c^2zq-c^2q^2+A^2c^2+A^2\right)^{1/2}}{c^2+1} \\ &-\frac{\left(-c^2z^2-2c^2zq-c^2q^2+A^2c^2+A^2\right)^{1/2}c^2}{c^2+1}\end{aligned}$$

or

$$d^* = \max\{t-A-\tfrac{A}{c}, 0\}, \text{ and}$$
$$q^* = \begin{cases} -z-\frac{A}{c} & \text{if } d>0 \\ -z & \text{if } d=0. \end{cases}$$

The special case of $c=\infty$ can be obtained simply by taking the limits of the above expressions for d^* and q^* as $c \to \infty$, or by formally analyzing a model in which $p \in [q-d, q+d]$. This yields $d^* = \max\{t-A, 0\}$ and $q^* = -z = -E\omega$. ■

Proof of Proposition 3.1: This requires $q^* = -z - \frac{A}{c}$ if $d>0$, which follows from the above derivation. ■

[17] Second order conditions are also satisfied.

Proof of Proposition 3.2: Since $d^* = \max\{t - A - \frac{A}{c}, 0\}$, $\frac{\partial d^*}{\partial c} > 0$ provided $d^* > 0$. Further, $d^* > 0$ if and only if $c > \frac{A}{t-A}$. ∎

Derivation of Optimal Investigation. L must decide on a level of investigation v taking account of the optimal strategies later in the game. Recall that when $d = 0$, $x = q + \omega$ and the agent exerts no control over policy.

Assuming nonzero discretion, L's problem (this time suppressing dependence on d and q) is

$$\begin{aligned}\max_v EU_L(v) \;=\; & \int_{z(v)-t(v)}^{z(v)+2A+\frac{2A}{c}-t(v)} -(\omega + (-z(v) - \frac{A}{c}) + (t(v) - A - \frac{A}{c}) \\ & + (\frac{A - (-z(v) - \frac{A}{c}) - (t(v) - A - \frac{A}{c}) - \omega}{c+1}))^2 dF(\omega) \\ & + \int_{z(v)+2A+2A\frac{1}{c}-t(v)}^{z(v)+t(v)} -A^2 dF(\omega) - b(v).\end{aligned}$$

Let $b(v) = 0$ if $v = 0$ and $b(v) = b$ if $v = 1$ (i.e., L investigates). The probability of getting a particular posterior mean is exactly cancelled by the width of the support of the posterior (i.e., the inverse of the posterior density in the case of uniform distributions) given the posterior mean. Thus with $d > 0$ L's expected utility reduces to

$$\max_v EU_L = -\frac{1}{3}A^3 \frac{(c+1)}{t(v)c} - A^2 \frac{t(v)c - A - cA}{t(v)c} - b(v).$$

This is independent of z, the realized posterior mean. The reason is, whatever signal is observed, the status quo choice will adjust the location of A's discretionary window so that the actual posterior mean is not relevant. What matters for utility is the precision of the posterior belief.

If no discretion is granted, the expected utility is

$$EU_L = \frac{1}{2}\int_0^{\frac{1}{2}} -(\omega - \frac{1}{4})^2 dF(\omega) - \frac{1}{2}\int_{\frac{1}{2}}^1 -(\omega - \frac{3}{4})^2 dF(\omega) - b$$

or $-\frac{1}{48} - b$ if $v = 1$, and

$$EU_L = \int_0^1 -(\omega - \frac{1}{2})^2 dF(\omega)$$

$-\frac{1}{12}$ if $v = 0$.

Comparing these expected utilities in case $A \in (0, \frac{1}{4}(\frac{c}{c+1}))$, so that authority is always delegated regardless of v, $v = 1$ if and only if

$$-\frac{4A^3}{3}(1 + \frac{1}{c}) - 4A^2(\frac{1}{4} - A - \frac{A}{c}) - b \geqslant -\frac{2A^3}{3}(1 + \frac{1}{c}) - 2A^2(\frac{1}{2} - A - \frac{A}{c})$$

or $b \leqslant \frac{4}{3}A^3(1 + \frac{1}{c}) = \underline{b}$.

If A is such that $A \in (\frac{1}{4}(\frac{c}{c+1}), \frac{1}{2}(\frac{c}{c+1}))$, or delegation occurs only in case $v = 0$, it will investigate if and only if

$$-\frac{1}{48} - b \geqslant -\frac{2A^3}{3}(1 + \frac{1}{c}) - 2A^2(\frac{1}{2} - A - \frac{A}{c})$$

or $b \leqslant A^2 - \frac{4}{3}A^3(1 + \frac{1}{c}) - \frac{1}{48} = \overline{b}$.

Finally, if $A \geqslant \frac{1}{2}(\frac{c}{c+1})$, L can again investigate but discretion is never granted. $v = 1$ if and only if $-\frac{1}{48} - b \geqslant -\frac{1}{12}$, or $b \leqslant \frac{1}{16}$.

The results for $c = \infty$ follow from $\lim_{c \to \infty} \frac{c}{c+1} = 1$. ■

Proof of Proposition 3.3: The result is immediate from a combination of the facts that $A \in (\frac{1}{4}(\frac{c}{c+1}), \frac{1}{2}(\frac{c}{c+1}))$ receive nonzero discretion if and only if $v = 0$, $A \in (0, \frac{1}{4}(\frac{c}{c+1}))$ receives more discretion when $v = 0$, and the comparative static that higher values of b result in less investigation. ∎

Proof of Proposition 3.4: $\frac{\partial b}{dA} = 4A^2(1 + \frac{1}{c}) > 0$. $\frac{\partial \bar{b}}{dA} = 2A - 4A^2(1 + \frac{1}{c}) > 0$ for $A \in (\frac{1}{4}(\frac{c}{c+1}), \frac{1}{2}(\frac{c}{c+1}))$. ∎

Appendix B: Preferences over Subversion Cost

For the results on preferences over c, fix $v = 0$ and $b = \infty$ and note that only when $c > \frac{A}{.5-A}$ does the agent get a chance to influence policy; if $c \leqslant \frac{A}{.5-A}$, $x = q + \omega$.

Proof of Proposition 3.5: Fix A and consider L's equilibrium utility. First note that when $c > \frac{A}{\frac{1}{2}-A}$, L is better off the smaller is c. In this case, L's expected utility is

$$EU_L = -\frac{2}{3}A^3\frac{(c+1)}{c} - 2A^2\frac{.5c - A - cA}{c}.$$

The first derivative of this expression in c is $-\frac{4A^3}{3c^2}$, which is always negative. Thus, as c gets larger, evidently L's utility gets smaller. Furthermore, $\frac{\partial^2 EU_L}{\partial c \partial A} < 0$ as well.

It must also be shown (because of the discontinuity in payoffs at $c = \frac{A}{.5-A}$) that L prefers $c > \frac{A}{.5-A}$ to $c \leqslant \frac{A}{.5-A}$. Again, expected utility when $v = 0$ and $c \leqslant \frac{A}{.5-A}$ is $\int_0^1 -(\omega - \frac{1}{2})^2 dF(\omega) = -\frac{1}{12}$. Then it remains to show $-\frac{2}{3}A^3\frac{(c+1)}{c} - 2A^2\frac{.5c-A-cA}{c} > -\frac{1}{12}$ whenever $c > \frac{A}{.5-A}$. But this is obvious because in such a case, it has been shown (Appendix A) that L's utility maximizing choice is to grant some discretion: if $-\frac{1}{12}$ were better for L, it would have taken it. ∎

Proof of Proposition 3.6: Consider A's preferences over c. When $c > \frac{A}{.5-A}$, A's expected utility in equilibrium is

$$\begin{aligned} EU_A \;=\; & \int_0^{2A+\frac{2A}{c}} \{-(\omega + (-\frac{1}{2} - \frac{A}{c}) + (\frac{1}{2} - A - \frac{A}{c}) + (\frac{A + \frac{A}{c} + A + \frac{A}{c} - \omega}{c+1}) - A)^2 \\ & -c(\frac{A + \frac{A}{c} + A + \frac{A}{c} - \omega}{c+1})^2\} d\omega, \end{aligned}$$

or $-\frac{8}{3}A^3\frac{c^2+2c+1}{c^2}$. Conditional on nonzero discretion being granted, the first derivative of A's equilibrium expected utility in c is $\frac{\partial EU_A}{\partial c} = \frac{16}{3}A^3\frac{c+1}{c^3} > 0$. Thus, as long as there is some discretion granted, A's utility is growing in c. Note also that $\frac{\partial^2 EU_A}{\partial c \partial A} > 0$.

It must also be the case that a given A is better off for some c that is sufficiently large to induce discretion. For purposes of this proof focus on $c \to \infty$, which is sufficient for the result. Now when $c \leqslant \frac{A}{.5-A}$ and no policy authority is granted, A's expected utility is

$$EU_A = \int_0^1 -(\omega - \frac{1}{2} - A)^2 d\omega,$$

or $-\frac{1}{12} - A^2$. Comparing this to the agent's utility with some discretion granted and $c = \infty$, first note that $\lim_{c\to\infty} -\frac{8}{3}A^3\frac{c^2+2c+1}{c^2} = -\frac{8}{3}A^3$. Then it remains to show that $-\frac{8}{3}A^3 > -\frac{1}{12} - A^2$, which is true as long as $A \in (0, \frac{1}{2})$, but any relevant A must be in this interval in the first place (A's outside it get no discretionary authority). ∎

Chapter 4 An Experimental Comparison of Mechanisms for the Provision of Excludable Public Goods

Abstract

This chapter compares three collective choice procedures for the provision of excludable public goods under incomplete information. One, serial cost sharing (SCS), is budget balanced, individually rational, anonymous, and strategy proof. The other two are "hybrid" procedures: voluntary cost sharing with proportional rebates (PCS) and with no rebates (NR). PCS satisfies all these properties except strategy proofness, and NR satisfies all the properties except for strategy proofness and budget balance. However, PCS and NR do not exclude any potential users, and they do not require equal cost shares, thereby overcoming the two main sources of inefficiency with SCS. I characterize the Bayesian Nash equilibria of the hybrid mechanisms and conduct laboratory experiments to compare the performance of the three mechanisms. I find that PCS produces significantly more efficient allocations than either SCS or NR.

4.1 Introduction

For the last several decades, economists have grappled with the question of how to design mechanisms for the efficient production and cost-sharing of public goods. Nearly all of the energy has been directed toward the case of pure, nonexcludable public goods. While the reasons for focusing on that kind of public good are historical and well rooted in the traditional literature following Samuelson (1954), it is not at all clear that this is the most typical case in practice. Many public goods are excludable. Even the classic examples like lighthouses, parks, and security can, in principle (and often do, in practice), exclude some users.

Recently there has been an upsurge of interest in the design of mechanisms for excludable public goods.[1] These mechanisms focus largely on cost-sharing schemes which divide the consumers into users and non-users, and then have a formula for dividing the costs among the users. In some cases, the extra degree of freedom to exclude can be efficiency enhancing since the threat of exclusion can relax incentive and/or participation constraints. But this comes with a cost. The very act of exclusion creates inefficiencies in a very direct way, which I call *exclusionary inefficiency.* Once a public good is provided, it is costless to allow extra users, so it is inefficient to exclude.[2] A subset of the mechanisms for production and cost sharing of excludable public goods are all those mechanisms that *exclude nobody.* In mechanisms of this sort, there is no exclusionary inefficiency.

[1]See, for example, Moulin (1994), Deb and Razzolini (1999), Chen and Khoroshilov (1999), Chen (2000), Dorsey and Razzolini (2000), and Norman (2000).

[2]This is true for nonrival public goods. In case of crowding or other sorts of user externalities, the inefficiencies created by exclusion are less severe, and exclusion can even be efficiency enhancing.

In this chapter I report on experiments for the provision of excludable threshold public goods, and compare a widely acclaimed exclusionary cost-sharing mechanism, serial cost-sharing, with two very simple nonexclusionary rules. I consider a public good technology where, if a certain threshold of contributions is met, the good is produced and may be consumed at no extra cost to any subset of the group; the good is not produced if the threshold is not met. Consumers have private valuations of the public good, and there is incomplete information about these preferences.

Serial cost sharing (SCS)[3] is now quite familiar in the literature on excludable public goods (Moulin 1994, Deb and Razzolini 1999), and is related to the serial cost sharing mechanism for private goods (Moulin and Shenker 1992). The mechanism is strategy proof, balanced, and individually rational. The two nonexclusionary mechanisms are voluntary cost sharing with proportional rebates (PCS) and with no rebates (NR) of any contributions beyond the threshold. These are "hybrid" mechanisms. NR can be viewed as an anonymous, individually rational base mechanism, to which PCS adds budget balance. None of the three mechanisms are fully efficient.

I characterize the set of Bayesian Nash equilibria in PCS and NR, and establish several properties, including monotonicity of the bidding functions. Both mechanisms typically have multiple equilibria, in contrast to many auction mechanisms for public goods with independent private valuations. Each set includes some equilibrium allocation rules that are more efficient (and some that are less efficient) than the strategy proof allocation rule under SCS. The laboratory experiments provide information

[3]More specifically, the Direct Serial Mechanism to represent the serial formula (see Moulin 1994). My terminology follows Moulin's.

about the ability of these procedures to select "desirable" equilibria, and about how resulting collective choices compare on welfare grounds with those under SCS.

The experiments find systematic differences between these procedures, in terms of both the individual and the collective behavior they induce. The dominant strategy equilibrium in SCS explains individual behavior very well. PCS induced significantly higher bidding than NR. Overbidding (i.e., bidding above value) was fairly common — more common than I anticipated — in PCS, but it was rarely observed in NR. Learning does not appear to have much effect on subject behavior within a given procedure, in the sense that there is only minimal evidence of trends in bidding behavior. An alternative hypothesis, risk aversion, is one possible explanation for the overbidding.

PCS extracts more consumer surplus than SCS and makes efficient decisions more often. Unlike SCS, PCS is not strategy proof, but it overcomes the two main sources of inefficiency in SCS: it never excludes any potential users of the public good, and it allows unequal cost shares so high value users can subsidize low value ones. Furthermore, NR, which is neither strategy proof nor budget balanced, also overcomes these difficulties. The comparison between NR and SCS is more subtle since NR is not balanced. SCS delivers more consumer surplus and leads to ex post efficient decisions more often than NR. However, NR does substantially better when total rather than gross surplus (i.e., including overcontributions) is the welfare criterion. In fact, if the unrebated overcontributions are not subtracted in the surplus calculation, NR is comparable to SCS in extracting available surplus. Both are outperformed by PCS.

There are three previous experimental studies of SCS. Chen and Khoroshilov (1999) and Chen (2000) report on some experiments with serial cost sharing. They focus on serial cost sharing and average cost pricing in complete information environments, and in environments with limited information (e.g., subjects observe their own action and payoff, but not the game form or other subjects' choices or payoffs). They emphasize learning in these mechanisms. Dorsey and Razzolini (2000) study SCS experimentally. In contrast to these results they find that SCS performs relatively well on efficiency grounds. One reason for this is that they use a continuous public good technology, whereas in these experiments it is discrete. Thus in applications of SCS a benevolent mechanism designer may want to pay attention to the public good technology, even though the incentive properties of SCS are the same in both cases. It would be interesting to know whether this effect of the technology on the efficiency of SCS is robust.

This chapter is also related to the interdisciplinary body of experimental work on threshold or step-level public goods, where the level of the public good consumed is positive if and only if contributions exceed some threshold (e.g., Bagnoli and McKee 1991; Isaac, Schmidtz, and Walker 1988; Marwell and Ames 1979, 1980; Palfrey and Rosenthal 1991; Rapoport 1985, 1987, 1988; Rapoport and Eshed-Levy 1989; Rapoport and Suleiman 1993). Unlike these experiments, however, these papers typically focus on variants of the Voluntary Contribution Mechanism under complete information, and often on all-or-nothing contributions. Suleiman and Rapoport (1992) study continuous contributions when return from public good is independent of total *contributions* (provided they exceed the threshold), an environment closely related to the present one for PCS and NR. They focus (like Isaac, Schmidtz, and Walker 1988) on the effect changes in the threshold have on contributions and the probability of public good provision. They find (again like Isaac, Schmidtz, and Walker 1988) that higher thresholds lead to higher contributions but lower probability of provision. Cadsby and Maynes (1998) study continuous contributions under complete information; in one treatment contributions may be refunded if the threshold is not met (similar to NR; see also the Provision Point Mechanism in Bagnoli and McKee 1991). This "money back guarantee" increases contributions relative to the case when contributions are lost even if the threshold is not met.

Dawes, Orbell, Simmons, and van de Kragt (1986) examine all-or-nothing contribution, and rebates. Consistent with some of my findings with finer grained contributions in PCS and NR, they find that rebates (their "no fear" condition) increase contributions. Marks and Croson (1998) study mechanisms like PCS and NR with continuous contributions under complete information, in addition to a mechanism where surplus contributions finance a continuous public good. They find that Nash outcomes are more common under the No Rebate procedure, and that rebates significantly affect the variance of contributions. Both of these mechanisms are analogous to auctions in private good environments. In fact, the public good environments in this chapter are isomorphic to private good environments with fixed costs, zero marginal costs, and no capacity constraint.

Auction-like procedures, similar to PCS and NR, have also been experimentally *examined by* Smith (1979a, 1979b, 1980); Ferejohn, Forsythe, and Noll (1979); and Ferejohn, Forsythe, Noll, and Palfrey (1982). Smith compares the performance of institutional rules that vary individual incentives. In these "auction mechanisms" agents submit bids for how much they want of one public good or a menu of public projects and cost shares they will accept. If all agents agree on a quantity and cost share, that is the outcome; otherwise the public good is not produced. In Ferejohn, Forsythe, and Noll and Ferejohn, Forsythe, Noll, and Palfrey, groups had to select several public projects to produce and decide how to split costs; different members had different values and budgets. The collective choice procedures involved features of voting rules, auctions, and rebates.

Van Dijk and Grodzka (1992) study threshold public good provision with limited information about asymmetric endowments. They focus on subject evaluations of the equity of contributions. They do not study the effects of incomplete information in the game theoretic sense or try to control beliefs about the information asymmetry. Croson and Marks (1999) study the PPM (examined in Bagnoli and McKee 1991 under complete information), an all-or-nothing contribution procedure, under incomplete information. They find no significant differences in the likelihood of successful provision under complete and incomplete information.

The rest of the chapter is organized as follows. Section 2 defines the environment, equilibrium, and some key properties of collective choice procedures. In Section 3 I develop and review some theoretical results on the mechanisms I test. In Section 4 I cover some properties of these mechanisms specific to the experimental parameters.

In Section 5 I describe the design of the experiments. Section 6 discusses results from the experiments. Section 7 concludes. Proofs are contained in Appendix A; *instructions from the experiment* are in Appendix B.

4.2 The Model

A group of individuals must decide whether to produce and how to share the cost of an excludable public good. There are n players, output of the public good, g, is either 0 or 1. The cost function is $C(1) = C > 0$ and $C(0) = 0$. The set of possible valuations for player i, denoted V, is a finite set of real numbers, and is the same for all players. I use v_i to denote i's valuation, and $v = (v_1, ..., v_n) \in V^n$ denotes a profile of valuations. Player i knows v_i, but does not know v_j for $j \neq i$. Values are independently and identically distributed across the players, according to the probability distribution function, p, which is common knowledge among the players. I assume that $\max\{V\} < C$, and that for some profile v, $\sum_i v_i \geqslant C$. The set of feasible outcomes is $A = \{g, s_1, ..., s_n, x_1, ..., x_n | g \in \{0,1\}, s_i \geqslant 0 \ \forall i, \sum_i s_i \geqslant C(g), 0 \leq x_i \leq g\}$ where s_i is i's share of $C(g)$. Player i's utility of an outcome $a = (g, s_1, ..., s_n, x_1, ..., x_n)$, is given by $U_i(a) = v_i x_i - s_i$. I call g the *public good decision*, s_i is i's *cost share*, and x_i is i's public good allocation.

A collective choice procedure is simply a mechanism or game form, (B, f), where $B = B_1 \times \cdots \times B_n$ is the message space and $f : B \to A$ is the outcome function. The outcome function f has three components, $f = (G, S, X)$.

Definition 4.1 *A* direct mechanism *is one where* $B \equiv V$.

Definition 4.2 *A* strategy *for player i is a function $b_i : V_i \longrightarrow B_i$. A strategy profile $b(v) = (b_1(v_1), ..., b_n(v_n))$ is one strategy for each player.*

Definition 4.3 *The real valued function $b_i(v_i)$ is* weakly monotone *if $v_i > v_i'$ implies $b_i(v_i) \geqslant b_i(v_i')$. It is strictly monotone if $v_i > v_i'$ implies $b_i(v_i) > b_i(v_i')$.*

When player i has valuation v_i his payoff function in the game induced by the mechanism is:

$$u_i(b(v), v) = v_i X_i(b(v)) - S_i(b(v))$$

Let v_{-i} be all elements of v besides v_i, and similarly for $b_{-i}(v_{-i})$.

Definition 4.4 *A pure strategy* Bayesian Nash equilibrium *(BNE) is a strategy profile $b(\cdot)$ such that $b_i(\cdot) \in \arg\max_{b_i' \in B_i} \sum_{v_{-i}} p(v_{-i}|v_i) u_i((b_i', b_{-i}(v_{-i})), v)$ $\forall i$.*

Definition 4.5 *An equilibrium, b, is* symmetric *if for every $v' \in V$, $b_i(v') = b_j(v') = b(v')$, $\forall i, j$.*

Definition 4.6 *An equilibrium, b, is* trivial *if $G(b(v)) = 0$ for all v.*

Definition 4.7 *A strategy b_i for player i is* ex post weakly dominated *if there exists a b_i' such that for all value profiles v, $u_i((b_i', b_{-i}(v_{-i})), v) \geqslant u_i((b_i, b_{-i}(v_{-i})), v)$ for all $b_{-i}(v_{-i})$ with strict inequality for some $b_{-i}(v_{-i})$ and some v.*

Thus when i knows all other values, b_i is never better than, and sometimes strictly worse than, b_i', no matter what players other than i do. Ex post weak domination *implies weak* domination at the interim stage, when i knows v_i but not v_{-i} (as in the experiments), and at the ex ante stage, when i knows neither her own value nor those of any other players, but only the prior on v.

Let z^T be the components of a vector belonging to a set T.

Definition 4.8 *A direct mechanism is* ex post coalition strategy proof *if for any* $M \subseteq N$, *any value profile* $v \in \prod_{i=1}^{n} V$, *and any profile of messages* $(\hat{v}^M, \hat{v}^{M\backslash N}) \in \prod_{i=1}^{n} V$, $\#\{u_i((\hat{v}^M, \hat{v}^{M\backslash N}), v) > u_i((v^M, \hat{v}^{M\backslash N}), v)$ *for some* $i \in M\} < \#\{u_j((\hat{v}^M, \hat{v}^{M\backslash N}), v) < u_j((v^M, \hat{v}^{M\backslash N}), v)$ *for some* $j \in M\}$.

Thus if any subset M of N (including the singleton i) could coordinate a deviation from the truth, more members of M are worse off than better off, regardless of what $k \in M\backslash N$ does.

Definition 4.9 *A mechanism is* ex post individually rational *if* $u_i(b(v), v) \geqslant 0\ \forall v \in V,\ \forall i$.

Definition 4.10 *A mechanism is* anonymous *if at any value profile* v *such that* $v_i = v_j$ *and* $v_{-i} = v_{-j}$, $u_i((b_i(v_i), b_{-i}(v_{-i})), (v_i, v_{-i})) = u_j((b(v_j), b_{-j}(v_{-j})), (v_j, v_{-j}))\ \forall i, j$.

Definition 4.11 *A mechanism is* budget balanced *if* $\sum_i S_i(b_i) = C,\ \forall b_i$.

One of my purposes is to compare the welfare properties of the various mechanisms. I define two measures here.

Definition 4.12 *The* consumer surplus *of an outcome for the group* N *is* $(\sum_i v_i x_i - \sum_i s_i)$.

***Definition* 4.13** *The* total surplus *of an outcome for the group* N *is* $(\sum_i v_i x_i - gC)$.

4.3 Properties of SCS, PCS, and NR

In this section I review some properties of SCS. I also present some results on PCS and NR, and in particular properties of their sets of equilibria.

4.3.1 Serial Cost Sharing

With excludable public goods there are several ways to express the serial cost sharing formula (Moulin 1994). I focus on the direct serial mechanism associated with SCS. Represented in this way SCS has the attractive features of coalition strategy proofness, a strengthening of individual rationality, anonymity, and budget balance.

Each agent is asked to report an element of V. Without loss of generality, suppose $\hat{v}_1 \geqslant \hat{v}_2 \geqslant ... \geqslant \hat{v}_n$ are the declared valuations. If $\sum_i \hat{v}_i < C$, the public good is not produced and all agents $i \in N$ pay $S_i(\hat{v}) = 0$. If $\sum_i \hat{v}_i \geqslant C$, and there is an integer k such that $\hat{v}_k \geqslant \frac{C}{k}$, then the public good is produced. Furthermore, if k^* is the largest integer such that $\hat{v}_k \geqslant \frac{C}{k}$, then agents $j \in \{1, 2, ..., k^*\}$ each consume the public good and all pay $S_j(\hat{v}) = \frac{C}{k^*}$, while other agents $i \in \{k^* + 1, ..., n\}$ do not consume the good and pay $S_i(\hat{v}) = 0$. If $\sum_i \hat{v}_i \geqslant C$ but there is not an integer k such that $\hat{v}_k \geqslant \frac{C}{k}$, the good is not produced and all agents $i \in N$ pay $S_i(\hat{v}) = 0$. Note that an individual's payment is not affected by declarations of valuation higher than her own. This is an important component of the incentive scheme generated by this mechanism. Some important properties of SCS are listed in the following theorem.

***Proposition* 4.1 (Moulin 1994, Theorem 2)** *SCS is ex post coalition strategy proof, ex post individually rational, budget balanced, and anonymous.*

This mechanism achieves budget balance in dominant strategies, so obviously it must not be efficient (c.f. Green and Laffont 1977) except in special uninteresting cases. In particular, to achieve incentive compatibility it exploits excludability of the public good: some agents are excluded from consumption of the public good in equilibrium. That is, for some agents and some profiles of reports, $X_i(b) < G(b)$. When $v_i > 0$ this is ex post inefficient. A feature that leads indirectly to ex post inefficiency is that among the group members who consume the same amount of the public good, costs for that quantity of the good are shared equally. With a binary public good, then, all consumers must share costs equally. Thus the mechanism cannot take advantage of a relatively high valuation to balance a relatively low one. For example, in a three person group, if the sum of all three valuations is higher than the cost, but none is higher than half the cost and one is less than a third of the cost, the SCS mechanism will not produce the good, even though by construction it would be efficient to do so.

4.3.2 Proportional Cost Sharing (PCS)

In PCS, agents submit bids and share the cost of the public good only if the sum of all bids is greater than the cost of the good. This mechanism, like SCS, is individually rational, anonymous, and balances the budget. However, it is not strategy proof. Nevertheless, it has two potential advantages over SCS. First, it never excludes anyone from consuming the public good, even though exclusion is feasible. Second, it allows for different agents to have different cost shares. This permits high valuation consumers to subsidize the consumption of low valuation consumers.

Agents submit real number bids from 0 to C.[4] If $\sum_j b_j \geqslant C$ the good is consumed by all agents, and consumed by no agents otherwise. Agent i's cost share is

$$s_i = \begin{cases} \frac{Cb_i}{\sum_j b_j} & \text{if } \sum_j b_j \geqslant C \\ 0 & \text{if } \sum_j b_j < C \end{cases}$$

Notice, therefore, that by construction, $\sum_i s_i = C$ if the good is produced, so PCS is budget balanced. Individual rationality and anonymity are similarly obvious.

There can be multiple Bayesian equilibria, and the set depends on the distribution of values and the production cost. The first result is that none of the involve overbidding (bidding above valuation), and indeed this is dominated.

Proposition 4.2 (No overbidding) *Any strategy in which $b_i(v_i) > v_i$ for some v_i is ex post weakly dominated in the PCS mechanism.*

Let $P_i(b_i) = \Pr(\sum_{j \neq i} b_j(v_j) \geqslant C - b_i)$ denote the probability that when player i bids b_i the good is produced, given the bid functions of the other players. Let $S_i(b_i) = E_{v_{-i}}(s_i(b(v))|b_i)$ denote i's expected cost share given a bid of b_i. I will use the following lemma. Note that since valuations are strictly bounded above by C, the proposition above implies that $b_i < C$ for all i in any BNE.

[4] In the experiments agents submit integer bids from 0 to C. This does not affect the theoretical results.

Lemma 4.1 (Cost Share Monotonicity) *If $P_i(b_i) > 0$ and $b_i < C$, $S_i(b_i)$ is strictly increasing at b_i.*

Proposition 4.3 (Bid Monotonicity)*Let $b^*(v)$ be a Bayesian Nash equilibrium bidding function in PCS. If $P_i(b^*(v)) > 0$ for all $v > \min\{V\}$, then, for all v_i, v_j, $v_i > v_j \Rightarrow b^*(v_i) \geq b^*(v_j)$.*

4.3.3 Cost Sharing with No Rebates (NR)

Cost Sharing with No Rebates is the same as Proportional Cost Sharing except excess contributions are not rebated. If the good is produced, then everyone simply pays their bid. Therefore it is individually rational and anonymous. Like PCS, it never excludes anyone, and it allows unequal cost shares, so high value users can subsidize low value users.

Formally, each agent i submits a real number bid, b_i, from 0 to C. If $\sum_j b_j \geqslant C$ the good is consumed by all agents, and consumed by no agents otherwise. Agent i's cost share is

$$s_i = \begin{cases} b_i & \text{if } \sum_j b_j \geqslant C \\ 0 & \text{if } \sum_j b_j < C \end{cases}$$

.

Therefore, if the good is produced, each agent simply pays its bid.

The equilibrium set for NR bears some similarities to that of PCS.

Proposition 4.4 (No overbidding) *Any strategy in which* $b_i(v_i) > v_i$ *for some* v_i *is ex post weakly dominated in the NR mechanism.*

Proposition 4.5 (Bid Monotonicity)*Let* $b^*(v)$ *be a Bayesian Nash equilibrium bidding function in NR. If* $P_i(b^*(v)) > 0$ *for all* $v > \min\{V\}$*, then, for all* v_i*,* v_j*,* $v_i > v_j \Rightarrow b^*(v_i) \geq b^*(v_j)$.

The proofs of these two propositions are the same as for the analogous propositions in the previous section. Ex post weak dominance only required a $s_i(b_i)$ such that $\frac{\partial s_i}{\partial b_i} > 0$ when $\sum_j b_j \geqslant C$ and $\sum_{j \neq i} b_j > 0$, and Lemma 1 required for weak monotonicity is also true for NR.

4.4 Experimental Parameters

In the laboratory experiments, I use 3 person groups, with cost $C = 102$ and each v_i is independently drawn from a uniform distribution over a set of three possible values, $V_i = \{29, 45, 90\}$, $i = 1, 2, 3$. The valuations were chosen in a way that allows the possibility of systematically different equilibrium behavior across the three mechanisms I wish to compare. Additional details of the experimental design are given in the next section. Let $< A, B, C >$ denote the profile of values A, B, C and all its permutations.

4.4.1 Equilibria in SCS

SCS has multiple equilibria under the parameters in this chapter. All but one of these are trivial and the one remaining is in weakly dominant strategies. For example, if all agents but one always claim to have $v = 29$, the remaining agent cannot gain by claiming otherwise. The unique nontrivial SCS equilibrium entails truthful revelation by each bidder. It will produce the public good for at least some group members in the profiles $< 90, 90, 90 >$, $< 90, 90, 45 >$, $< 90, 45, 45 >$, $< 45, 45, 45 >$, and $< 90, 90, 29 >$. Only the last of these involves exclusion, and hence fails to realize all available surplus in the profile. The unique SCS equilibrium makes the efficient decision (in the sense of producing when the sum of values is at least 102) in 12 of 27 equally likely value profiles. Three of these 12 involve exclusion, so in nine of 27 profiles, the weakly dominant SCS equilibrium is fully efficient.

If $v_1 \in [\frac{2C}{3}, C]$, $v_2 \in [\frac{C}{3}, \frac{C}{2}]$, and $v_3 \in [0, \frac{C}{3}]$ where v_i is the *ith* highest value, the good is never produced even though it is always efficient to do so. Only one person is willing to share up to $\frac{1}{2}$ the cost, and only two people are willing to share up to $\frac{1}{3}$. In the experiment all three group members have an equal chance of drawing a value from one of these three regions. All three possible values used in the experiment are near the upper bound of their respective intervals, making the size of the lost surplus relatively large, in the probability $\frac{2}{9}$ event that each one of these regions is represented in a given group.

4.4.2 Equilibria in PCS and NR

Consider a symmetric bid function $b = \{b^L, b^M, b^H\}$ where $v = 29$ bids b^L, $v = 45$ bids b^M, and $v = 90$ bids b^H. The following propositions ensure that weak monotonicity of bids applies in symmetric equilibria for both PCS and NR in this environment.[5]

Proposition 4.6 *In PCS, $P(b^L)$, $P(b^M)$, and $P(b^H)$ are strictly positive in any nontrivial symmetric equilibrium.*

Proposition 4.7 *In NR, $P(b^M)$ and $P(b^H)$ are strictly positive in any nontrivial symmetric equilibrium.*

The proof is the first paragraph of that for the PCS analogue. Unlike for PCS, $P(b^L) = 0$ is possible in a nontrivial symmetric equilibrium in NR: $\{0, 34, 34\}$ is an example.

No player will overbid in equilibrium in a profile that leads to production with positive probability. This fact, weak monotonicity, and the following proposition greatly aided the search for Bayesian Nash equilibria.

Proposition 4.8 *Consider a symmetric profile of bid functions $b = \{b^L, b^M, b^H\}$ in PCS or NR. If player i with value v_i has any interim profitable deviation from b^v, then one of the following deviations is profitable: $d = 0$ or $d = 102 - x - y$ for some $x, y \in b$.*

[5] I only consider symmetric equilibria.

Given the experimental treatment, I limited attention in PCS and NR to integer valued bid functions. I further restricted attention to pure strategy (and symmetric) equilibria.[6] Given the restriction to integer-valued bid functions, a numerical search for equilibria was most efficient. For each weakly monotone, integer valued, pure bid function with no overbidding, I checked each possible test deviations identified in Proposition 4.8.

A family of trivial symmetric pure strategy BNE under the experimental parameters exists with the bid function

$$b_i = \begin{cases} l & \text{if } v_i = 29 \\ m & \text{if } v_i = 45 \\ h & \text{if } v_i = 90 \end{cases}$$

where $0 \leqslant l \leqslant 6$, $0 \leqslant m \leqslant 6$, and $0 \leqslant h \leqslant 6$.

Under PCS, there are four categories of equilibria. These four categories can be ranked by efficiency, as measured by total surplus. Within each category, the set of profiles at which the good is produced is the same. The most efficient group contains four equilibria,[7] all of which involve some pooling. 17 BNE fall into the second most efficient class; the remaining 40 fall into the third most efficient group. The multiplicity of equilibria in a given category simply corresponds to different equilibrium cost shares for the same allocations. The fourth category produces

[6]This only restricts the class of equilibria I consider. All equilibria I find are equilibria with respect to the set of all integer valued bid functions.

Focusing on symmetric equilibria for experimental purposes is not limiting, since subject matching precluded coordination on asymmetric equilibria.

[7]$\{21, 21, 60\}, \{22, 22, 58\}, \{23, 23, 56\}$, and $\{24, 24, 54\}$, where $\{X, Y, Z\}$ denotes the bid of type 29, 45, and 90 respectively.

for exactly the same set of profiles as in SCS, and includes the least efficient PCS equilibria. The set of all symmetric PCS equilibria is graphed in Figure 4.1.

For NR (Figure 4.2), 35 equilibria are nontrivial; only four of these[8] are more efficient than the undominated SCS equilibrium.[9] Table 4.1 shows production decisions by profile for SCS, the three better categories of PCS equilibria, and the best NR equilibria.

			Equilibrium		
Profile	PCS 1	PCS 2	PCS 3	NR	SCS
$< L, L, L >$					
$< L, L, M >$					
$< L, M, M >$					
$< M, M, M >$		X		X	X
$< L, L, H >$	X				
$< L, M, H >$	X	X	X	X	
$< M, M, H >$	X	X	X	X	X
$< L, H, H >$	X	X	X	X	X*
$< M, H, H >$	X	X	X	X	X
$< H, H, H >$	X	X	X	X	X

Table 4.1: Production decisions at each profile, by equilibrium class

4.4.3 Ex Post Efficiency of equilibria in SCS, PCS, and NR

From the derivation above, with these parameters the most efficient NR equilibrium is as efficient as the second most efficient PCS equilibrium. The most efficient and second most efficient equilibrium under PCS produces higher expected surplus than the SCS dominant strategy equilibrium. The remaining 31 nontrivial, integer valued, symmetric, pure BNE in NR are strictly less efficient than the SCS equilibrium.

[8] $\{23, 34, 45\}$, $\{24, 34, 44\}$, $\{25, 35, 42\}$, and $\{26, 35, 41\}$.

[9] Equilibrium sets in PCS and NR are strictly non-nested.

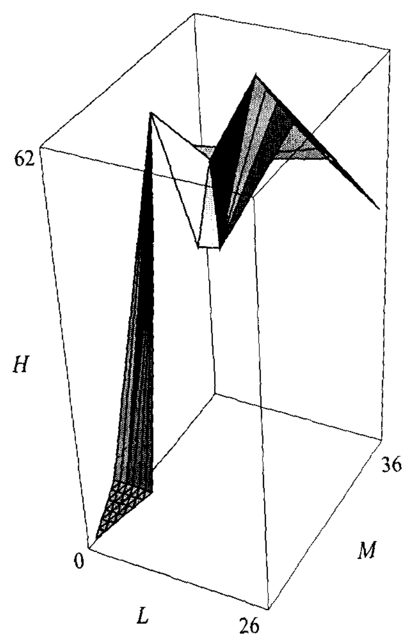

Figure 4.1: Equilibrium set, PCS

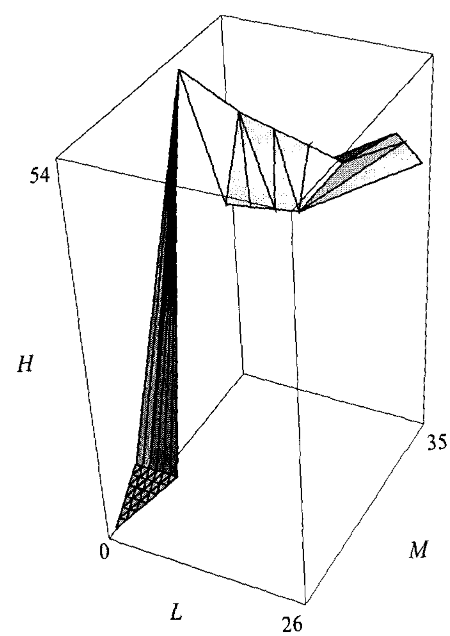

Figure 4.2: Equilibrium set, NR

4.4.4 *Ex Ante* Efficiency of equilibria in SCS, PCS, and NR

An allocation rule is ex ante efficient and individually rational if there does not exist another individually rational and feasible allocation rule that is a Bayesian equilibrium of some mechanism that ex ante Pareto dominates it. From results in Ledyard and Palfrey (1999a) ex ante efficiency implies no exclusion in this experimental environment. Full characterization of interim efficient allocation rules, of which ex ante efficient allocation rules are a special case, can be found in Ledyard and Palfrey (1999a).

In these environments ex ante efficiency entails production at all profiles except $< 29, 29, 29 >$. I show that none of the three rules I study here are ex ante efficient. However, the departure from first best efficiency is quite small in the second best mechanism. Further, the best equilibria of PCS are 95.02% ex ante efficient; the best equilibria from NR are 88.79% ex ante efficient; and the dominant strategy SCS equilibrium is 61.57% ex ante efficient.

Proposition 4.9 *No allocation rule is ex ante efficient.*

Under these parameters, the best a welfare maximizing principal can do subject to incentive compatibility, individual rationality, and feasibility is produce at all profiles except $< 29, 29, 29 >$ and $< 29, 29, 45 >$. This is implementable according to the profile-contingent payments in Table 4.2.

A principal could present the agents with this table, and they would willingly report their valuations. The expected taxes satisfy incentive compatibility and individual

Payments			
	Own type		
Other types	29	45	90
29, 29	0	0.0	44.0
29, 45	0	36.5	41.6
29, 90	29	31.4	36.5
45, 29	0	36.5	41.6
45, 45	29	34.0	39.9
45, 90	29	31.4	39.9
90, 29	29	31.4	36.5
90, 45	29	31.4	39.9
90, 90	29	31.4	34

Table 4.2: Profile contingent payments in the second-best allocation rule

rationality: $t_{29} = \frac{2}{3}(29)$, $t_{45} = 29.333$, and $t_{90} = 39.333$. They also satisfy feasibility: $t_{29} + t_{45} + t_{90} \geqslant \frac{23}{27}(102)$.

4.4.5 Hypotheses

Based on the previous equilibrium results, I formulated the hypotheses in Tables 4.3 and 4.4. The first three deal with individual-level behavior; the second three cover collective welfare properties. All are based on the assumption of equilibrium behavior.

H1	Subjects will reveal their types truthfully in SCS
H2	Bids in PCS will be higher than bids in NR
H3	Bidding above value will not occur in PCS or NR

Table 4.3: Hypotheses about individual behavior

H4a	PCS will extract more available consumer surplus than SCS
H4b	PCS will make efficient decisions more often than SCS
H5a	NR will extract more available consumer surplus than SCS
H5b	NR will make efficient decisions more often than SCS
H6a	PCS will extract more available surplus than NR
H6b	PCS will make efficient decisions more often than NR

Table 4.4: Hypotheses about collective behavior

Hypothesis 2 seemed reasonable because relative to NR, PCS lowers the cost of high bids. NR has equilibria where subjects bid more than PCS, but we had no reason to believe such equilibria would be selected.

In view of the multiple equilibria in PCS, **Hypothesis 4** and the assumption of equilibrium behavior imply a statement about equilibrium selection. Given the large number to choose from, I believed subjects would be able to coordinate on PCS equilibria more efficient than the undominated SCS equilibrium. I wish to avoid Pareto efficiency as a precise equilibrium selection device, while still maintaining that higher surplus equilibria should be "focal."

Given the equilibrium sets for these parameters, I conjectured that NR may not outperform SCS on efficiency grounds, since NR has fewer equilibria that are more efficienct than the SCS equilibrium. Therefore I view **Hypothesis 5** as less likely to be borne out in the data, compared to Hypothesis 4.

NR's most efficient equilibria are as efficient, in terms of likelihood of production and surplus extraction, as PCS's second-most efficient equilibria. **Hypothesis 6** implies that I did not expect NR to be systematically better than PCS at inducing coordination on its most efficient equilibria.

4.5 Experimental Design

To test the hypotheses, I conducted seven sessions of the experiment in the Social Science Experimental Laboratory at Caltech. Each session had two parts, with the two parts using different mechanisms, and each part repeated over 10 rounds. Subjects for most sessions were students at Pasadena City College (PCC), but for one session, the first SCS-PCS session, they were undergraduates at Caltech. All PCC sessions had nine subjects. The Caltech session had 12 subjects. Subjects participated in each mechanism for 10 rounds, where a round consisted of one decision by each subject and a resulting collective decision on public good consumption for the group. This information is summarized in Table 4.5.

Session No.	1st Trtmnt.	2nd Trtmnt.	# subjects	Subj. pool
1	SCS	PCS	12	CIT
2	SCS	PCS	9	PCC
3	SCS	PCS	9	PCC
4	PCS	NR	9	PCC
5	NR	PCS	9	PCC
6	PCS	NR	9	PCC
7	NR	PCS	9	PCC

Table 4.5: Experiment design

Instructions were read aloud to the subjects at the beginning of the experiment to ensure public knowledge of the procedures. In addition, for each mechanism there were two practice rounds[10] to familiarize subjects with the procedures. At the beginning of each round, subjects were randomly matched into groups of three as follows: numbered ping pong balls were placed in a box and shuffled in plain sight of the subjects. Three ping pong balls were drawn from the box, and the subjects whose numbers were on the balls constituted group 1. This process was repeated (without replacement) to draw the remaining groups in each round. Subjects did not know the other members of their group in any round; they only knew that they were randomly re-matched after every decision.

[10]Except for the two sessions with NR run second, where one practice round with that mechanism was sufficient for subjects to understand it.

An experimenter then went from subject to subject to have each one independently throw a six sided die to determine his or her valuation for the round.[11] A roll of 1 or 2 meant $v_i = 29$; a roll of 3 or 4 meant $v_i = 45$; and 5 or 6 meant $v_i = 90$. Subjects each then decided what to bid for the round and recorded the decision on the decision/record sheet. In SCS, subjects could bid either Low, Medium, or High, meaning a willingness to share none, $\frac{1}{3}$, or $\frac{1}{2}$ of the cost $C = 102$, respectively. In PCS and NR, subjects could bid any integer between 0 and the cost $C = 102$. When all decisions were made an experimenter collected the sheets. For each group, decisions on whether the public good was produced and who consumed it were made according to the rules of the mechanism being played. For the SCS experiments, these were as in Table 4.6.

# H msgs.	# M msgs.	# L msgs.	Produce?	# Users	Cost share
3	0	0	YES	3	34
2	1	0	YES	3	34
1	2	0	YES	3	34
0	3	0	YES	3	34
2	0	1	YES	2	51
1	1	1	NO	0	–
1	0	2	NO	0	–
0	2	1	NO	0	–
0	1	2	NO	0	–
0	0	3	NO	0	–

Table 4.6: Messages, collective decisions, and cost shares: SCS

For PCS and NR, the rules were the ones described in Section 2 above. The experimenter returned the sheets to the subjects, and the next round proceeded in this same way. More details are available in the instructions (see Appendix B).

[11]The subjects were separated by privacy partitions, so that the outcome of their roll of the die was not observable to any other subject.

4.6 Results

In this section I discuss the results of the experiments, both in terms of the decision making behavior within each mechanism, and in terms of the performance of each mechanism on welfare grounds.

4.6.1 Individuals: Bidding Behavior

Figures 4.3, 4.4, and 4.5 display the CDFs of bids under each mechanism for $v = 29$, 45, and 90 respectively. The CDFs for SCS were computed by mapping a message of L, M, or H in that mechanism to a bid of 0, 34, and 51 respectively. Since these are the implied cost sharing offers for each message in that mechanism, this is the most straightforward way to compare SCS directly with NR and PCS.[12]

These CDFs reveal important differences in behavior in these procedures. For $v = 29$, both NR and PCS induce higher bidding than SCS. Over 85% of bidders in SCS were willing to share none of the cost (rather than $\frac{1}{2}$ or $\frac{1}{3}$), while in PCS and NR virtually all bidders were willing to share some of the cost. In PCS approximately 80% of bidders, and in NR 70% of bidders, were willing to share 20 units or more of the cost when $v = 29$. For $v = 45$, only about 15% of bidders in SCS are willing to share more than $\frac{1}{3}$ of the cost or 34 units; in PCS about 65% and in NR about 35% were willing to share more than $\frac{1}{3}$ (though for NR only about 15% were willing to share more than 35 units). In SCS no bidder can share more than $\frac{1}{2}$ of the cost, and for $v = 90$ in SCS 86% of bidders are willing to share this much. About 50% of

[12]Because any 1 to 1 correspondence from messages to bids can be used, it also makes sense to speak of "truthful" bids in SCS.

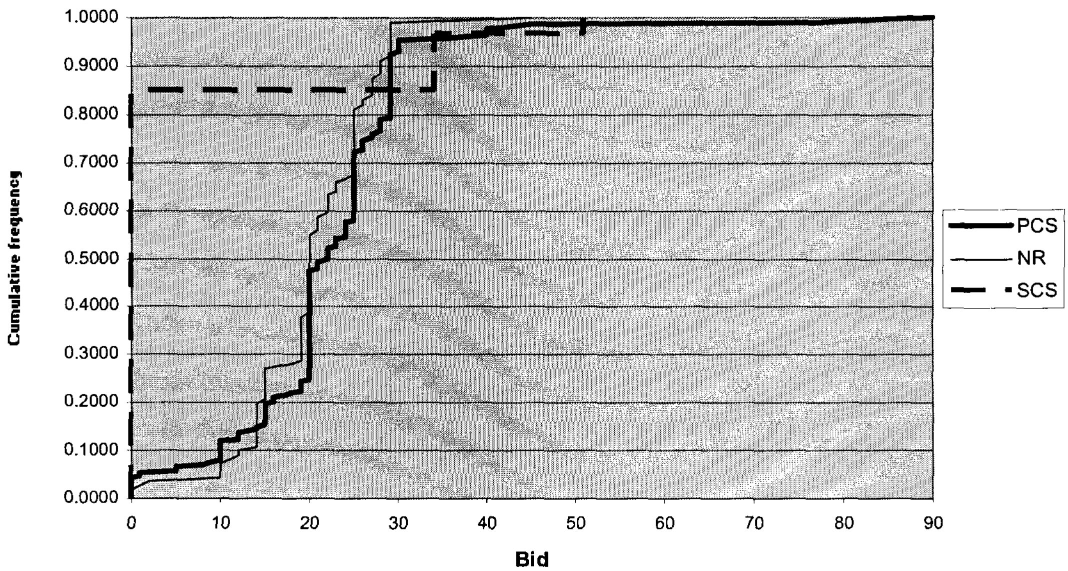

Figure 4.3: Bid CDFs by mechanism, value = 29

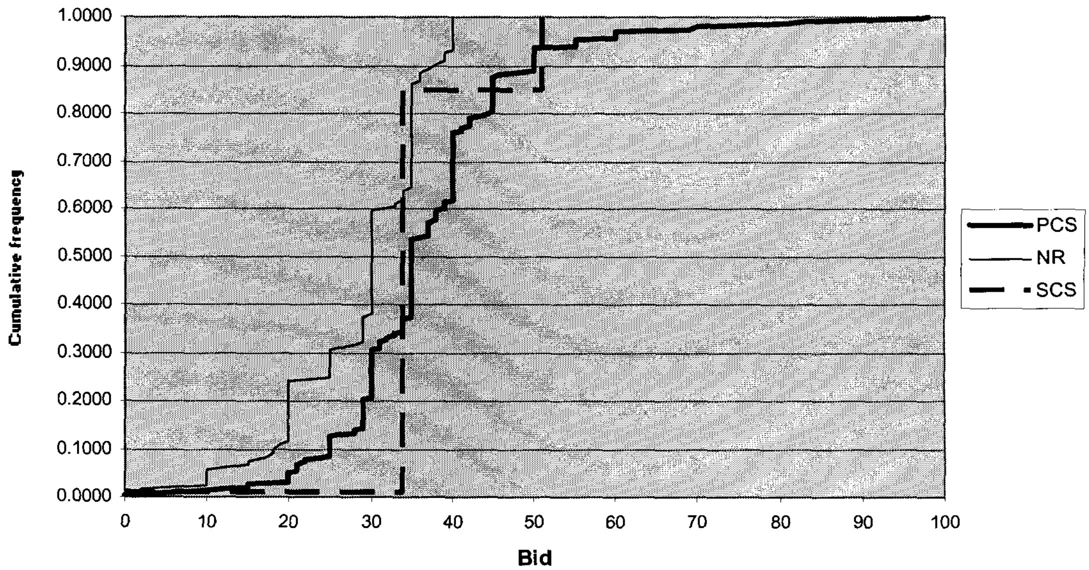

Figure 4.4: Bid CDFs by mechanism, value = 45

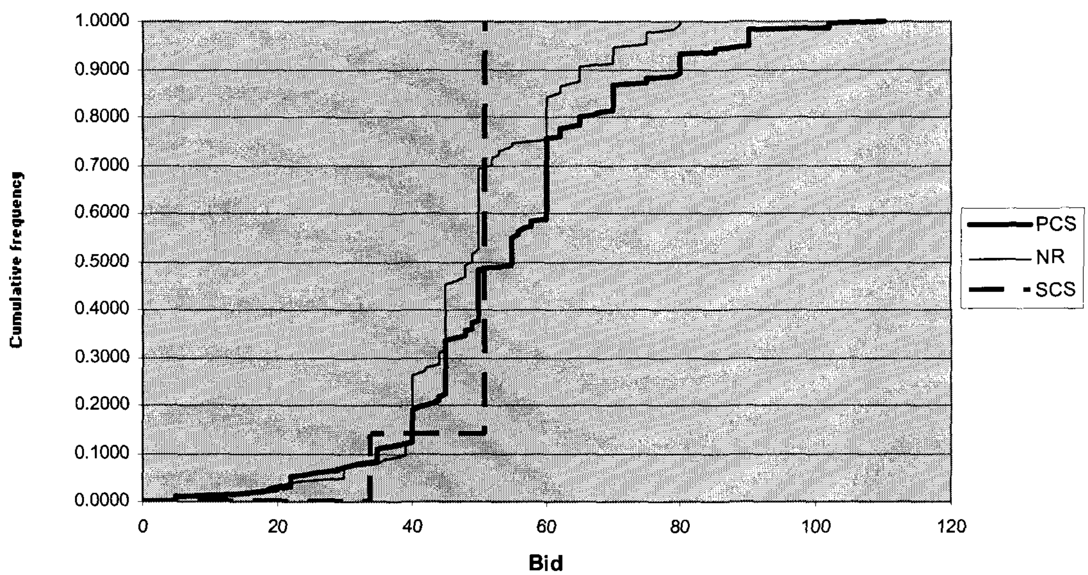

Figure 4.5: Bid CDFs by mechanism, value = 90

bidders in PCS and about 30% in NR are willing to share more than $\frac{1}{2}$ the cost.

Bidding behavior in SCS: A quantal response explanation for disequilibrium bids

The weakly dominant equilibrium in SCS does a good job of explaining subject behavior, in accordance with Hypothesis 1. Table 4.7 presents the empirical proportions of time a subject made each bid, conditional on value. The figures are aggregated over all three sessions of SCS. Thus, conditional on $v = 29$, 85.1% of bids were truthful.

bid/value	29	45	90
L	.851	.010	.000
M	.117	.837	.139
H	.032	.153	.861

Table 4.7: Empirical SCS bids, proportions

Nevertheless, Nash equilibrium (weakly dominant or otherwise) does leave some behavior unexplained in SCS. A model of equilibrium errors may add some explanatory power. Quantal response equilibrium (McKelvey and Palfrey 1995, 1996, 1998) is a statistical version of Nash equilibrium, in which players sometimes choose suboptimal strategies. The likelihood of choosing a strategy is monotonic and continuous in the expected utility of the strategy. Therefore, the theory predicts that low-cost errors are more likely to occur than high-cost errors. Table 4.8 lists cost of deviating from the dominant Nash equilibrium (i.e., larger positive numbers imply more costly behavior), given the empirical bidding frequencies from Table 4.7.

Thus, for 29 bidders in the SCS mechanism, the optimal strategy is to announce L, while announcing M is a low cost error and H is a high cost error. For the 45

bid/value	29	45	90
L	−0.52	5.35	31.83
M	2.02	−0.24	3.36
H	6.43	0.96	−0.54

Table 4.8: Expected cost of deviating from expected bid function, based on empirical bid frequencies

bidders, announcing L is the low cost error, and for 90 bidders, announcing M is the low cost error. This is consistent with the data, except for the 45 bidders, where the cost of L and H deviations are nearly the same.

Comparing bids under PCS and NR

It is evident from Figures 4.3, 4.4, and 4.5 that for each value, NR tends to lower bids relative to PCS, though this effect looks weaker for $v = 29$. Kolmogorov-Smirnov tests (2 tailed) for difference in distribution support these interpretations and, generally, Hypothesis 2. For $v = 45$ and 90, the differences due to the mechanism are large and significant. For $v = 29$, the difference is insignificant at the $\alpha = .10$ level. Table 4.9 displays the observed $\max |F_{PCS}(b) - F_{NR}(b)|$ for each value (where $F_A(b)$ is the CDF for the given value of mechanism A) and the critical values for $\alpha = .10$ and .001 (see Siegel 1956, Table M).

Value	29	45	90
$\max \lvert F_{PCS}(b) - F_{NR}(b) \rvert$	0.1301	0.3438	0.2404
Critical, $\alpha = .10$	0.1435	0.1360	0.1363
Critical, $\alpha = .001$	0.2294	0.2174	0.2179
n's, PCS	207	236	217
n's, NR	111	122	127

Table 4.9: Kolmogorov-Smirnov test statistics and critical values

Higher bidding in PCS than NR is also reflected in overbidding as a proportion of all bids, conditional on value, where overbidding refers to bidding above value, a dominated action. While it is dominated, it is a less costly mistake under PCS than under NR. Empirically overbidding was much more common under PCS: in NR it happened only 2 times in 360 decisions, supporting Hypothesis 3 for NR. In PCS it happened 52 times in 660 decisions. This is common enough to lead to rejection of Hypothesis 3 for PCS. Table 4.10 displays results on bids above value (aggregated over all sessions for each mechanism).

	PCS			NR		
Value	29	45	90	29	45	90
Rds. 1-5	.076	.128	.025	.038	.000	.000
Rds. 6-10	.088	.126	.021	.000	.000	.000
All rds.	.082	.127	.023	.018	.000	.000

Table 4.10: Proportions of bids above value

Table 4.11 displays the median bids by value in each mechanism (aggregated over all sessions for each mechanism), for a given group of rounds.

	PCS			NR		
Value	29	45	90	29	45	90
Rds. 1-5	22	35	55	21	30	50
Rds. 6-10	23	37	55	20	30	48
All rds.	22	35	55	20	30	49

Table 4.11: Empirical median bid functions

For all three values, and in both early and later rounds, the median bid under PCS exceeds that under NR.

Bidding behavior in NR and PCS and equilibrium predictions

If all subjects used these median bids for each mechanism, PCS would produce the public good for profiles $< 90, 90, 90 >$, $< 90, 90, 45 >$, $< 90, 90, 29 >$, $< 90, 45, 45 >$, $< 90, 45, 29 >$, and $< 45, 45, 45 >$. NR would produce for $< 90, 90, 90 >$, $< 90, 90, 45 >$, $< 90, 90, 29 >$, and $< 90, 45, 45 >$.

The median bids suggest that in aggregate, subjects in PCS are not playing the most efficient symmetric, pure BNE. Since there are so many equilibria, it is difficult to rule out equilibrium as an explanation for aggregate bidding behavior. By a least squares criterion, the symmetric, pure BNE that best matches the empirical medians is $\{19, 31, 52\}$, but this exhibits different production behavior: it produces for all the same profiles as the median except $< 45, 45, 45 >$. In the set of symmetric, pure BNE that produce for the same profiles as the median bids, $\{19, 34, 49\}$ has the best fit by least squares.

For NR, the symmetric, pure BNE that best matched the aggregate empirical behavior by least squares is $\{23, 34, 45\}$, which is one of the most efficient for that mechanism. Yet under the median bids for NR, aggregate outcomes in that mechanism are not as efficient as in this equilibrium. Among the symmetric, pure BNE where production behavior matched that under the medians, $\{18, 30, 42\}$ has the best fit by least squares.

In neither mechanism do subjects converge to trivial equilibria. Subjects rarely submit 0 bids. Table 4.12 shows the proportion of 0 bids.

More fundamental than equilibrium behavior is individually optimal behavior.

	PCS			NR		
Value	29	45	90	29	45	90
Rds. 1-5	.038	.000	.000	.038	.000	.000
Rds. 6-10	.049	.009	.000	.000	.000	.000
All rds.	.043	.004	.000	.018	.000	.000

Table 4.12: Zero bids as proportion of all bids

Thus it is also interesting to examine the expected payoffs from a given bid in PCS and NR, given the distribution of bids in the population. Figures 4.6 and 4.7 illustrate these expected payoffs. These figures were constrcuted by taking the empirical distribution of bids over all sessions in each mechanism, irrespective of type, and convoluting it with itself. This gives a distribution over sums of bids for any two group members. Then (extending the notation for utility functions), for any given bid b_i, $\sum_{-i} b_{-i}[Prob[\sum_j b_j \geqslant 102|b_i] \times U[b_i, \sum_{-i} b_{-i}| \sum_j b_j \geqslant 102]]$ yields the desired expected payoff.

Visual inspection shows that for each type and mechanism, the median and mode (across all sessions) is relatively close to the expected payoff maximizing choice. For type 90 in NR, the median bid is exactly the one that maximizes the payoff, given the distribution of other bids. Especially for types 29 and 45 in each mechanism, the curves are relatively flat in the neighborhood of the expected payoff maximizing choice. This suggests that adaptive behavior processes would update slowly in these cases, for bids near the median.

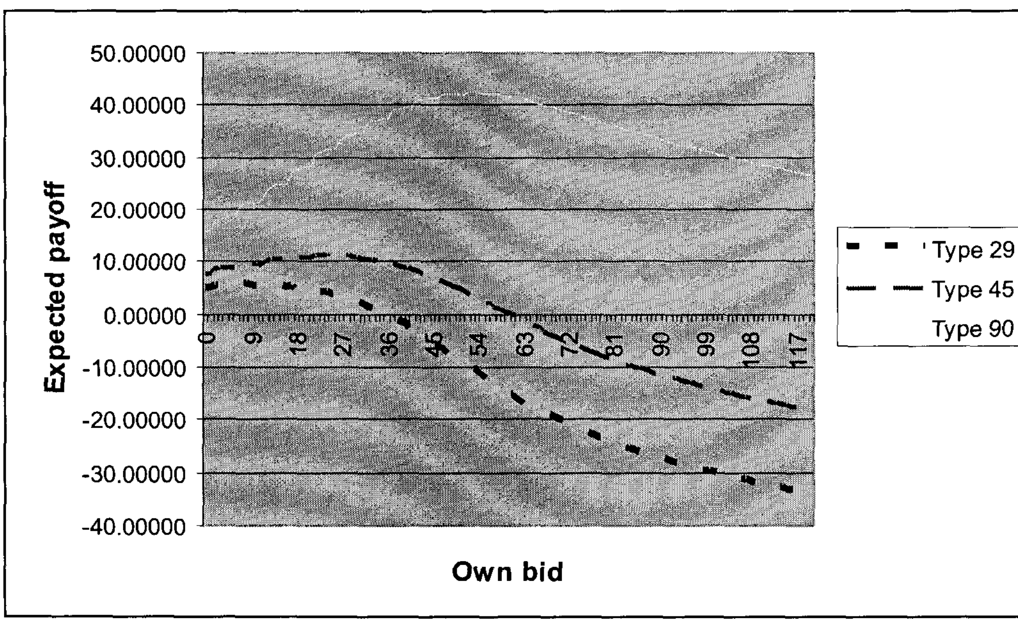

Figure 4.6: Expected payoff as a function of own bid, given other bids: PCS

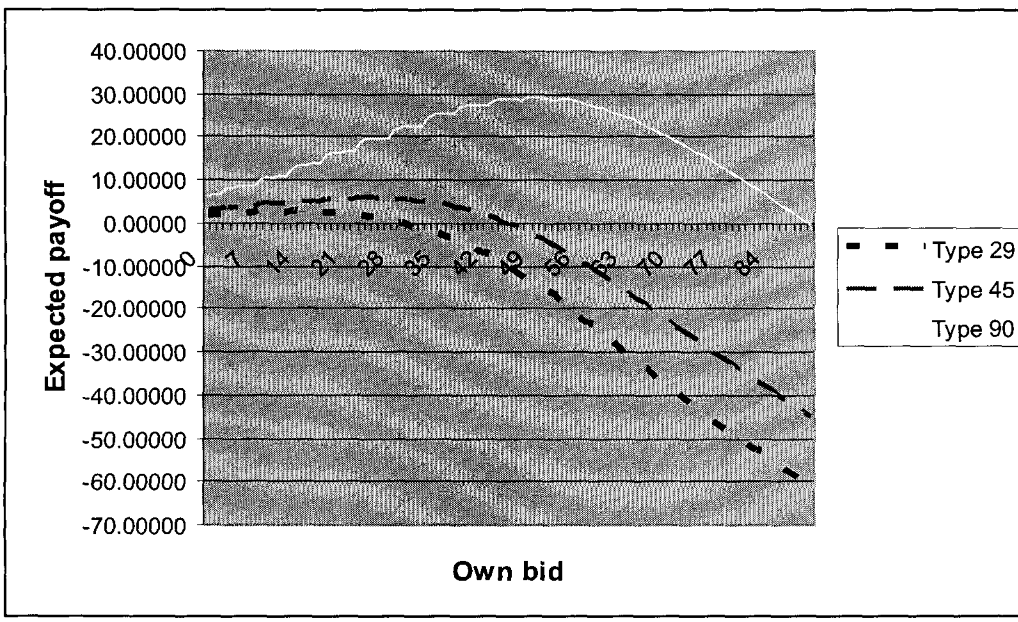

Figure 4.7: Expected payoff as a function of own bid, given other bids: NR

Risk aversion as a possible explanation of overbidding

At the same time, the risk neutral equilibrium is less successful in explaining individual behavior. One reason for this is bidding higher than that prescribed in any risk neutral equilibrium.[13] However, risk aversion may explain some of the overbidding in these public good auctions. There is evidence from other private goods auction experiments, and from field data, that subjects may be risk averse.[14]

To look at risk aversion as a possible explanation, I recalculate the equilibrium sets for the three rules if the players have a utility function given by $U_i(a) = (v_i x_i - s_i)^r$, $r = \frac{3}{4}, \frac{1}{2}$, and $\frac{1}{4}$. For SCS, there is no effect at all because truthful reporting is a dominant strategy equilibrium. However, risk aversion has a non-neutral effect for both PCS and NR. Intuitively, the effect of risk aversion should be to increase bids, for exactly the same reason as in private value auctions (Goeree, Holt, and Palfrey, 2000). Increasing one's bid increases the probability of providing the public good, but increases the expected payment, too. At the margin, a risk averse player will pay more than a risk neutral player to reduce downside risk (i.e. the risk of non-provision), so they are willing to bid higher. Thus, risk aversion creates upward pressure on bids, leading to more frequent provision, and more frequent overpayment, relative to the predictions based on risk neutrality. Figures 4.8 and 4.9 give a three dimensional graph of the equilibrium sets for PCS and NR, respectively, for $r = \frac{1}{2}$.

[13]In the experiment, subject payoffs are in dollars, so all of the above results are subject to the caveat that I assumed subjects were risk neutral.

[14]See Rabin (2000) for a critique of these finding about risk aversion in experimental and field data. That note argues that the levels of risk aversion estimated from experimental data are implausible because it implies far too much curvature, if one calibrates utility functions in terms of an individual's expected lifetime earnings. This reinforces the widely held belief that individuals do use expected lifetime income to frame most decision problems they face, but have a tendency to

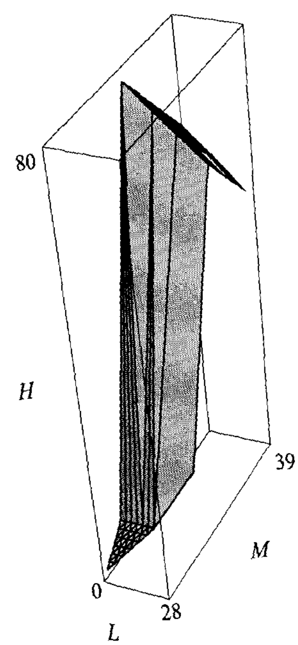

Figure 4.8: Equilibrium set, PCS, square root utility

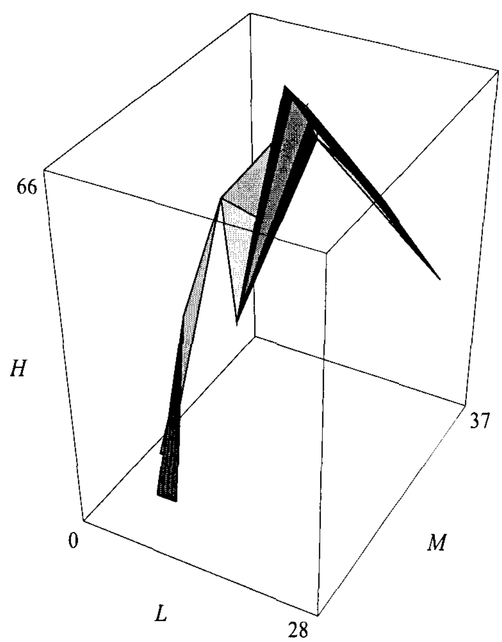

Figure 4.9: Equilibrium set, NR, square root utility

As Tables 4.13, 4.14, and 4.15 show, risk aversion tends to expand the range of bids part of some equilibrium, and weakly increases the upper bound of that range. As Tables 4.14 and 4.15 indicate, it improves the ability of some equilibrium to account for observed behavior (for example, for square root utility functions in PCS for $v = 45$, 70% of empirical bids were in the equilibrium range of bids over the first five rounds, 54% over the second five rounds, and 62% over all rounds).

	PCS			NR		
Value	29	45	90	29	45	90
Risk neutral	0 - 26	0 - 36	40 - 62	0 - 26	0 - 35	34 - 54
$r = \frac{3}{4}$	0 - 27	0 - 37	46 - 72	0 - 28	0 - 37	37 - 58
$r = \frac{1}{2}$	0 - 28	0 - 39	46 - 80	0 - 28	0 - 37	46 - 66
$r = \frac{1}{4}$	0 - 28	0 - 40	46 - 88	0 - 28	0 - 40	46 - 76

Table 4.13: Equilibrium bid range by selected utility function exponents

	PCS		
Value	29	45	90
Risk neutral	.74, .75, .74	.59, .49, .54	.63, .68, .65
$r = \frac{3}{4}$	.76, .76, .76	.63, .52, .57	.50, .56, .53
$r = \frac{1}{2}$	.78, .79, .79	.70, .54, .62	.57, .62, .59
$r = \frac{1}{4}$	.78, .79, .79	.77, .74, .76	.59, .63, .60

Table 4.14: Empirical proportion of bids in equilibrium bid range, PCS

	NR		
Value	29	45	90
Risk neutral	.78, .86, .82	.85, .85, .85	.64, .67, .65
$r = \frac{3}{4}$	.85, .95, .90	.89, .89, .89	.64, .67, .65
$r = \frac{1}{2}$	.85, .95, .90	.89, .89, .89	.47, .43, .45
$r = \frac{1}{4}$	.85, .95, .90	.98, 1.00, .99	.70, .49, .60

Table 4.15: Empirical proportion of bids in equilibrium bid range, NR

consider such problems in isolation. This is consistent with a prospect theoretic approach.

Risk aversion has a noticeable effect on the empirical proportion of bids falling in the equilibrium range, increasing it by 5 to 27 percentage points. Except for the values 29 and 45 in PCS, this proportion is quite high for $r = \frac{1}{4}$. These two exceptions are due to the relatively high proportion of bids above value in these cases (see Table 9). Of the bids that a rationality-based theory could explain (i.e., bids no greater than value), for $v = 29$ the proportion increases from .81 under risk neutrality to .86 under $r = \frac{1}{4}$. For $v = 45$ it increases from .61 under risk neutrality to .87 under $r = \frac{1}{4}$.

Learning

The results show little evidence of learning in any procedure at the individual level. I tested for learning for each value in PCS and NR by regressing bid on round. If there are no learning effects within a mechanism, each of these six lines plotting the bid as a function of round should have slope = 0. In all six cases OLS regressions cannot reject this null hypothesis at the 5% level and rejection occurs for only one in six at the 10% level. The coefficients and standard errors are listed in Table 4.16; * denotes significance at $\alpha = .10$.[15] Learning also does not appear to explain either change in overbidding, or in behavior consistent with equilibrium.[16] There is also very little evidence of learning in the SCS data.

However, there is some evidence of a different kind of learning effect in the data, which is a sequencing effect. Recall that two mechanisms were run, in sequence, in each session. Behavior in PCS, for $v = 29$ and $v = 45$, is mildly sensitive to which

[15] Statistical significance is probably overstated because the observations are not truly independent.

[16] One possible exception is bidding above value in NR with $v = 29$, but this was so rare in the first place (2 observations in 111) that generalization is difficult.

Value	PCS (OLS)	NR (OLS)
29	.000 (.311)	−.481* (.254)
45	−.257 (.301)	.125 (.257)
90	−.329 (.401)	−.252 (.408)
	$n = 660$	$n = 360$

Table 4.16: Results, Learning regressions

mechanism was run first in the experimental sessions. The sequence effect on NR appears weaker. This is reflected in Figures 4.10 and 4.11. Bids in PCS are less variable when it is run second than when it is run first. For $v = 45$ the CDF for PCS second is nearly first order stochastically dominated by that for PCS first. Also, there is no overbidding in PCS when it was run second, while it is somewhat common in sessions when it is run first. This is consistent with a more general finding that ovebidding declines with experience. For NR generalization seems more difficult. For $v = 29$ the CDF for NR second is first order stochastically dominated by that for NR first. For $v = 45$ in NR there is no clear effect.

4.6.2 Groups: Efficiency Comparisons

A major purpose of these experiments was to compare these mechanisms on efficiency grounds. The SCS mechanism has been argued for because of its attractive incentive properties, but ultimately its value depends on how efficiently it performs in comparison to other simple mechanisms. The PCS and NR mechanisms are indeed very simple, and shares with SCS the attractive feature of individual rationality.

There are several ways in which efficiency comparisons can be made. I focus on two: (a) the proportion of available total surplus extracted by each mechanism;

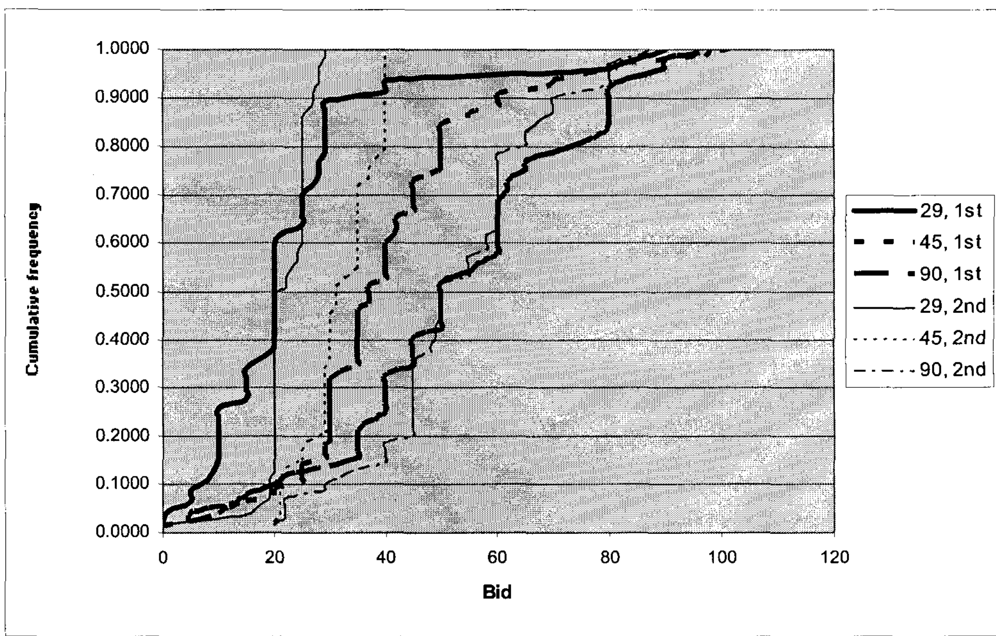

Figure 4.10: Sequence effects, PCS

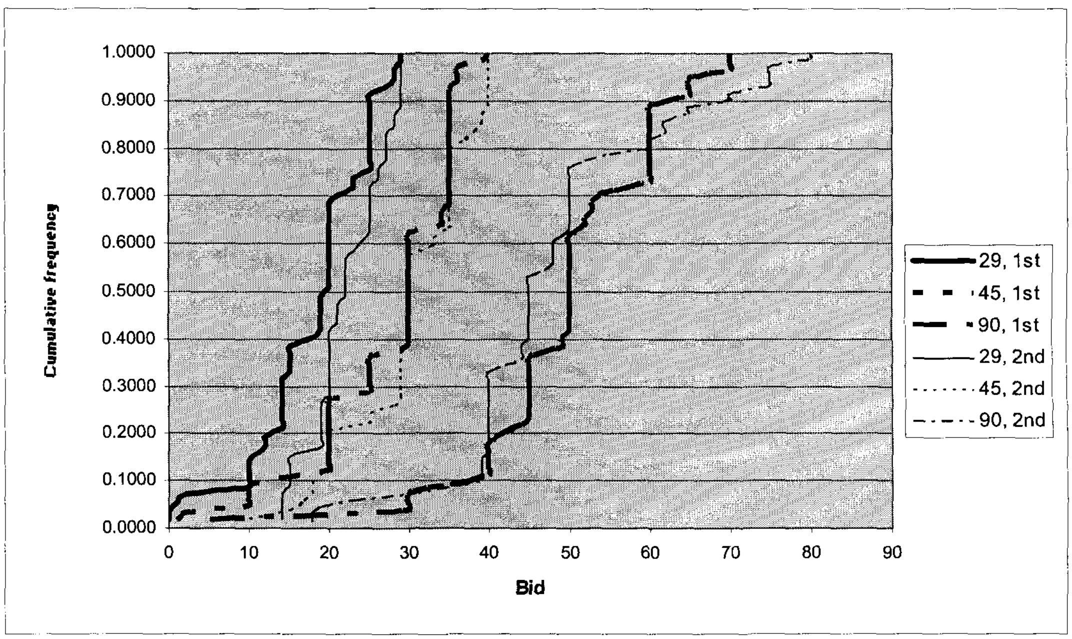

Figure 4.11: Sequence effects, NR

and (b) the proportion of times each mechanism makes the efficient decision. Both comparisons lead to the same conclusion. PCS significantly outperforms SCS and NR, with the latter two leading to approximately the same efficiency levels.

Surplus extraction

With total surplus extraction as the criterion, the PCS mechanism was clearly the best performing of the three mechanisms. As Table 14 shows, for almost all value profiles, PCS performs at least as well as, and sometimes much better (up to 50 percentage points) than SCS. The main exception is the profile $< 45, 45, 45 >$, which is the only one where SCS outperforms PCS, and this differernce is based on a very small number of observations. Interestingly, SCS and PCS surplus extractions move in similar ways as the type profile varies, but SCS changes much more sharply with profiles. This gives it a "hit or miss" character: it typically either does very well at extracting surplus or it does very poorly. This is due to the relatively low variance in the underlying bids. PCS outperforms NR, for all profiles, a difference that is attributable to the consistently higher bids under PCS than NR. The SCS and NR mechanisms perform almost identically, although there is some minor profile-specific differences. These conclusions are also supported by a comparison of surplus over all profiles, given in the last row of Table 4.17. Entries in columns 2-4 are proportions of possible surplus extracted. Column 6 lists total available surplus for each profile. The number of observations of each profile is in parentheses.

	Surplus	Extracton		
Profile	PCS	SCS	NR	Available surplus
$< 29, 29, 45 >$	.067 (30)	-2.30 (12)	.083 (12)	1
$< 29, 45, 45 >$	.379 (29)	.111 (9)	0.00 (16)	17
$< 45, 45, 45 >$	.692 (13)	1.00 (6)	0.00 (7)	33
$< 29, 29, 90 >$	.500 (9)	0.00 (11)	.111 (9)	46
$< 29, 45, 90 >$	.595 (42)	.191 (22)	.400 (25)	62
$< 45, 45, 90 >$	.905 (22)	1.00 (8)	.857 (7)	78
$< 29, 90, 90 >$	.917 (24)	.729 (11)	.813 (16)	107
$< 45, 90, 90 >$	.968 (32)	1.00 (12)	.889 (18)	123
$< 90, 90, 90 >$	1.00 (11)	1.00 (7)	1.00 (6)	168
Overall	.836	.684	.691	

Table 4.17: Surplus extraction at each profile, by mechanism

Proportion of Efficient Decisions

A somewhat coarser view of efficiency is the proportion of successful decisions under each mechanism. For each group-round, I recorded a 1 if the group made the efficient production decision, and 0 otherwise. For SCS, exclusion of the $v = 29$ member in a $< 90, 90, 29 >$ profile did not result in a 0, to make it harder for other mechanisms to outperform it. Otherwise, the results mirror the findings of Table 4.17. The results are presented in Table 4.18; standard errors are in parentheses.

PCS	NR	SCS
.650 (.032)	0.475 (.046)	0.520 (.050)

Table 4.18: Average success rate, by mechanism

This table reinforces the conclusions based on surplus extraction. PCS outperforms SCS (supporting Hypothesis 4b), which outperforms NR (rejecting Hypothesis 5b, supporting Hypothesis 6b). However, this "hit rate" analysis doesn't capture the fine details of mechanism performance. For example, as noted earlier, most of the difference between NR and SCS hit rates is due to the $< 29, 29, 45 >$ profile where a hit generates almost zero surplus.

Robustness of Efficiency Results to Other Environments

These efficiency results are for the specific parameters in the experiment, which leaves open the question of robustness across arbitrary environments. Recall that the distribution of valuations was chosen so that the amount of surplus varied a lot across different profiles. Thus, there is a lot of uncertainty in the environment. It is possible that in an environment with less uncertainty, for example if the likelihood of a 45 valuation was very high, SCS may have performed better because it was more successful at $< 45, 45, 45 >$ than the auction mechanisms. However, at profiles other than this one, the relative ranking of PCS and SCS on efficiency grounds was very consistent, suggesting that the ranking is fairly robust. Compared to NR, SCS does well in high-surplus profiles, while NR does better in low-surplus profiles. This suggests that in environments with sufficient heterogeneity of valuations, auction mechanisms, such as PCS, could be expected to perform better than SCS.

Another aspect of the environment is the number of agents in the model. This experiment considered a small group, and leaves open the question of performance in larger groups. The incentive problems of PCS will become worse as group size increases. The exclusion inefficiencies also become worse for SCS, so the question is which effect dominates. I conjecture that the group size effect will tend to favor SCS over PCS, so that for sufficiently large groups, PCS will not perform as well as SCS. In fact, replicating the economy used in these experiments many times will send the production probability to zero in PCS and NR (c.f. Al-Najjar and Smorodinsky

2000; Mailath and Postlewaite 1990), but not in SCS. The hybrid mechanisms work by inducing agents to "buy" pivot probability with their contributions, and as cost grows with group size this becomes less beneficial for any one agent. However, a version of PCS that allows for exclusion may do better than SCS. An example would be an auction mechanism where bidders are excluded if their bids fall below a reserve bid. In the limit, as the number of bidders goes to infinity, incentive compatibility will eventually imply equal cost shares (e.g. Ledyard and Palfrey 1999a, 1999b, 2002), so that optimal auction mechanisms for public goods will look similar to SCS.

In addition to varying group size, allowing random exclusion in SCS would improve its efficiency somewhat in this environment without compromising the incentive properties.[17] Random exclusion could add up to 7.0889 ($= 29p$) units to the surplus extraction, conditional on the $< 29, 90, 90 >$ profile occurring (a probability .1111 event). This by itself would not overturn efficiency comparisons in these experiments.

4.7 Conclusions

This chapter reports the results from a laboratory experiment designed to compare the performance of the Serial Cost Sharing mechanism to two public good auction mechanisms that are not incentive compatible. These alternative mechanisms are both simple to understand and to implement, they are individually rational, and one of them is budget balancing. I fully characterize the set of Bayesian Nash equilibria

[17]With two H messages and one L message, the player reporting L can consume with probability $p = \frac{11}{45} = .2444$ without comprising any incentive constraints. Under this exclusion rule, type 45 earns $45p = 11$ by reporting L, and $45 - 34 = 11$ by reporting M. Types 29 and 90 are still strictly better off reporting truthfully.

under the auction mechanisms, for this experimental environment, and establish some general properties of the equilibrium sets. The three mechanisms have systematic *theoretical* differences both in terms of the individual and collective behavior they induce. These theoretical properties are reflected in the data.

The dominant strategy equilibrium in SCS explained subject behavior fairly well. Deviations from dominant strategy can be accounted for by Quantal Response Equilibrium. PCS induced significantly higher bidding than NR, and bidding above value was quite rare in NR. The relatively high bidding behavior parallels a well-documented phenomena in private good auctions (Goeree, Holt, and Palfrey 2002). Risk aversion is one possible explanation for overbidding. All these findings, with the exception of systematic overbidding, supported the main hypotheses. There little evidence of learning, with the one exception that bids in PCS are lower among subjects who have previously participated in the NR mechanism.

As hypothesized, SCS was outperformed on welfare grounds — both the surplus extracted and the likelihood of an efficient decision — by PCS, in spite of the fact that PCS is not incentive compatible and is plagued with multiple equilibria. I find this result surprising, because of the combination of incentive problems and coordination problems in PCS, and it suggests that more research on auction-like public goods mechanisms is warranted. The key advantage of PCS is that it never inefficiently excludes any users of the public good, and it allows unequal cost shares, so high value users can subsidize low value ones. Thus it overcomes the primary two sources of inefficiency in SCS applied to public goods. Another auction mechanism, NR, which *is neither strategy proof* nor budget balanced, also overcomes these difficulties, but did not perform as well. The NR mechanism produced efficiency levels about the same as SCS. This indicates that the fine details of the auction mechanism can have important consequences. These findings echo similar results about the role of rebates for non-excludable public goods, reported in Ferejohn, Forsythe, Noll, and Palfrey (1982).

These results suggest several directions for further work, both experimentally and theoretically. Experimentally, it would be instructive to compare the performance of PCS and SCS in other environments and to other mechanisms that have interesting theoretical properties. One important example is the pivot mechanism. The standard pivot mechanism is not individually rational and does not balance the budget, but hybrid mechanisms that retain some features of the pivot mechanism, while allowing for exclusion or an opt-out stage, might be interesting to study. Auction procedures that allow for exclusion also warrant consideration. Such mechanisms could offer probabilities of public good consumption; agents would be excluded probabilistically. This could make each agent pivotal more often, and enhance efficiency as a result. A plurality voting scheme, in which agents vote over quantities and share $\frac{1}{n}$ of the cost of the plurality winner, is another interesting and practically relevant procedure.

Finally, the evidence I find indicating risk aversion suggests that the Bayesian mechanism design approach to public good provision should be extended to allow for environments with risk averse players. One would conjecture that the optimal mechanisms may differ significantly in small groups. This contrasts with the case of very large groups, where the convergence results in Ledyard and Palfrey (2001) indicate that risk aversion will not affect the form of the optimal mechanism.

Appendix A: Proofs

Proof of Proposition 4.2: Consider player i, suppose $b_i > v_i$, let $b_i' = v_i$, and fix $b_{-i}(v_{-i})$. First, if $\sum_{j \neq i} b_j(v_j) + b_i \geqslant C$ and $\sum_{j \neq i} b_j(v_j) + v_i < C$ at any value profile v, i suffers a loss at that profile under b_i: $b_i = C - \sum_{j \neq i} b_j(v_j)$ implies $s_i(b) = b_i > v_i$, and when $\sum_{j=1}^{n} b_j(v_j) > C$, $\frac{\partial s_i}{\partial b_i} = \frac{C(\sum_{j \neq i} b_j(v_j))}{(\sum_{j=1}^{n} b_j(v_j))^2}$, which is strictly positive if $\sum_{j \neq i} b_j(v_j) > 0$. If $\sum_{j \neq i} b_j(v_j) = 0$, then $s_i = C > v_i$. But i earns 0 payoff at such a profile with b_i'. Second, if $\sum_{j \neq i} b_j(v_j) + b_i \geqslant C$ and $\sum_{j \neq i} b_j(v_j) + v_i \geqslant C$ at any value profile v, a bid of b_i' costs less than b_i, but does not affect the collective decision. Third, if $\sum_{j \neq i} b_j(v_j) + b_i < C$ at any value profile v, i earns 0 payoff with both b_i' and b_i. ∎

Proof of Lemma 4.1: $P_i(b_i) > 0$ implies that the good is produced for at least some profiles. At all such profiles $\frac{\partial s_i}{\partial b_i} > 0$. At any profiles where the good is not produced, $\frac{\partial s_i}{\partial b_i} = 0$. ∎

Proof of Proposition 4.3: Consider two values v_i and v_i' for player i, and some bid function such that $b_i(v_i) = b$ and $b_i(v_i') = b'$. For i to optimize, the following inequalities must hold:

$$v_i P_i(b) - S_i(b) \geqslant v_i P_i(b') - S_i(b')$$

$$v_i' P_i(b') - S_i(b') \geqslant v_i' P_i(b) - S_i(b)$$

Subtracting RHS of the second from LHS of the first, and LHS of the second from RHS of the first yields

$$(v_i - v_i')(P_i(b) - P_i(b')) \geqslant 0$$

Then there are two cases to consider. First, $P_i(b) > P_i(b')$. Then if $v_i > v_i'$, $b > b'$ follows from the definition of a CDF. Second, $P_i(b) = P_i(b') > 0$. Then suppose that $v_i > v_i'$ but $b_i' > b$; by Lemma 1 this implies $S_i(b') > S_i(b)$, which implies $v_i'P_i(b') - S_i(b') < v_i'P_i(b) - S_i(b)$, which contradicts the assumption that i optimizes.

∎

Proof of Proposition 4.6: Focus on $P(b^M)$, as $P(b^H)$ must be strictly positive if $P(b^M)$ is. If $P(b^M) = 0$, then only at the profile $< 90, 90, 90 >$ is the public good produced (or else the equilibrium is trivial). Then the equilibrium bid b^H can only be 34. But $v = 45$ has a profitable deviation to $b' = 34$ in that case, which contradicts the assumption of equilibrium.

If $P(b^L) = 0$ in a nontrivial symmetric equilibrium, then $b^H < 51$. In any such strategy profile, some type has a profitable deviation. Consider two cases. First, if $b^H \in [37, 51]$, then $v = 29$ has a profitable deviation to $102 - 2b^H$, contradicting the assumption of equilibrium. Second, if $b^H < 37$, then $b^M \geqslant 30$, since $< 45, 90, 90 >$ produces in any equilibrium where $< 90, 90, 90 >$ produces. Further, $b^H \geqslant 34$ or else $< 90, 90, 90 >$ does not produce. But for a bid function $\{l, m, h\}$, $h \in [34, 36]$, $m \in [30, h]$, $l \in [0, 102 - 2h)$, $v_i = 90$ has a profitable deviation to $102 - m - l$. With this deviation, at $v_{-i} = (90, 90), (90, 45), (45, 90)$, and $(45, 45)$, $v_i = 90$'s payoff goes from 56 to 39, but at profiles $v_{-i} = (45, 29), (29, 45), (90, 29)$, and $(29, 90)$, $v_i = 90$'s payoff goes from 0 to 22. This contradicts the assumption of equilibrium. ∎

Proof of Proposition 4.8: I prove this by recursively considering all possible deviations. The order of the recursion is determined by $2b^M \lesseqgtr b^L + b^H$.

First consider the case where $2b^M > b^L + b^H$. Focus on player i. Consider a deviation from b^v to $d_1 \in [0, \max[102 - 2b^H, 0]]$. All bids in this interval result in the same production decision as $d_1' = 0$, and $d_1' = 0$ never costs more than any of them. Consider next a deviation to $d_2 \in (\max[102 - 2b^H, 0], \max[102 - b^H - b^M, 0]]$. Such a deviation produces at the same profiles as $d_2' = \max[102 - 2b^H, 0]$ and costs more than d_2'. Consider a deviation to $d_3 \in (\max[102 - b^H - b^M, 0], 102 - 2b^M)$. This produces at the same profiles as $d_3' = \max[102 - b^H - b^M, 0]$ and costs more than d_3'. Consider a deviation to $d_4 \in (102 - 2b^M, 102 - b^L - b^H)$. This produces at the same profiles as $d_4' = 102 - 2b^M$ and costs more than d_4'. Consider a deviation to $d_5 \in (102 - b^L - b^H, 102 - b^L - b^M)$. This produces at the same profiles as $d_5' = 102 - b^L - b^H$ and costs more than d_5'. Consider a deviation to $d_6 \in (102 - b^L - b^M, 102 - 2b^L)$. This produces at the same profiles as $d_6' = 102 - b^L - b^M$ and costs more than d_6'. Finally, consider a deviation to $d_7 \in (102 - 2b^L, 102)$. This produces at the same profiles as $d_7' = 102 - 2b^L$ and costs more than d_7'.

Second, if $2b^M < b^L + b^H$, consider $d_3 \in (\max[102 - b^H - b^M, 0], \max[102 - b^H - b^L, 0])$ and $d_3 \in (\max[102 - b^H - b^L, 0], 102 - 2b^M)$, rather than $d_3 \in (\max[102 - b^H - b^M, 0], 102 - 2b^M)$ and $d_4 \in (102 - 2b^M, 102 - b^L - b^H)$. ∎

Proof of Proposition 4.9: The proof relies on no distortion at the top and binding adjacent incentive constraints. Let t_v be the expected payment of type v. Conditional on reporting $v = 29$, the probability of consumption is $\frac{8}{9}$, so $v = 45$'s incentive *constraint* is $(45 - 29)\frac{8}{9} \leqslant 45 - t_{45}$, or $t_{45} \leqslant 30.7778$. Then $v = 90$'s incentive constraint is $90 - 30.7778 \leqslant 90 - t_{90}$ or $t_{90} \leqslant 30.7778$. But feasibility requires $\frac{8}{9}(29) + 30.7778 + t_{90} \geqslant \frac{26}{27}(102)$ or $t_{90} \geqslant 41.6667$. Thus feasibility and incentive compatibility cannot both be satisfied. ∎

Appendix B: Instructions

Decision making experiment

This is an experiment in group decision making. You will be paid for your participation in cash, at the end of the experiment. Your payment depends partly on your decisions, partly on the decisions of others, and partly on chance. No other participant will be told how much you earn in the experiment, and you are not obligated to tell anyone else how much you earn. To keep track of your earnings during the experiment, we use an experimental currency, which we call francs. Francs are then redeemed for cash at the end of the experiment. Each franc is worth (exchange rate) dollars.

We will start with a brief instruction period, during which the experiment, the decisions you are to make, and how you earn money will be explained to you. Please listen carefully and raise your hand if you have a question. DO NOT write anything down yet, and do not pick up the die. After the instructions, we will have two practice rounds to familiarize you with the decision making procedure.

All interaction between you will take place via your decision sheets. Please do not try to communicate with each other in any other way; if you do, you will be asked to leave the experiment and will not be paid.

We will now pass out your decision and record sheets. The first of these sheets is for the first part of the experiment, on which you will record your decisions and payoffs for each round. We will collect these after the first part of the experiment is over. The second is a record sheet for the whole experiment, which you will use keep track of your earnings throughout the entire experiment.

We will also assign subject numbers, starting in the front on your right with #1, to help keep track of which decision sheet belongs to which participant. Please write your subject number in the space provided on both of your record sheets.

Serial Cost Sharing

The experiment consists of a sequence of rounds, and in each round you will be anonymously grouped with two other participants. To determine the groupings in the first round, numbered ping pong balls will be drawn out of a box, three at a time. The subjects with the first three numbers drawn will in the group 1, subjects with the next three numbers drawn will be in group 2, and so forth. You will NOT see the numbers on the balls that are drawn; therefore, you will not know who is in your group. Thus, decisions in the experiment are anonymous in the sense that no other participant will know what group you are in or what decisions you make. DEMONSTRATE.

In the second round and in each subsequent round, we will again draw the ping pong balls three at a time to determine new group assignments.

Therefore, in each round each of you are assigned to exactly one group. What happens in the groups you do not belong to has no effect on your payoff. In this sense, groups are completely independent of each other.

In each round, your group of three participants must decide whether or not to purchase a fictitious good called a gadget, and exactly which members of your group are allowed to use the gadget. For your group to purchase a gadget, your group must pay a *total* of 102 francs. It is possible that not everyone in your group is allowed to use the gadget. Those members of your group who are allowed to use the gadget are called "users" and pay an equal share of the cost. Those members of your group who are not allowed to use the gadget are called "nonusers" and do not pay any share of the cost. Therefore, if all members are users, the cost is split three ways, so each member pays 34 francs. If only two members are users, the cost is split two ways, and each of the two users pays 51 francs, and if only one member is a user, then this user pays the entire 102 francs.

If you are a user in a round, you earn for that round an amount called YOUR USER VALUE. Your user value is determined at the beginning of each round in the following way. At the beginning of each round, we will come to you privately one at a time and let you throw a fair six-sided die. If you roll a 1 or 2, your user value will be 29 francs. If you roll a 3 or 4, your user value will be 45 francs. If you roll a 5 or 6, your user value will be 90 francs. [write on board] Your user value determines how much you earn in francs if your group buys the gadget and you are a user. Record this user value in the space of your record sheet labeled YOUR USER VALUE, on the line corresponding to the round. Notice that no one else in your group knows your user value, and you do not know the user value of anyone else in your group. You only know your own user value. If you are a non-user in a round, you earn zero in that round, regardless of what your user value is.

To determine whether your group buys the gadget in a round, every member of the group will simultaneously submit a message. Every participant must choose one of three messages: high, medium, or low. WRITE ON BOARD: ALLOWABLE MESSAGES: “HIGH”, “MEDIUM”, “LOW”. You are free to submit any of these three messages in any round. To submit your message, record it on your record sheet in the column labeled YOUR MESSAGE, and we will collect all the sheets.

The messages are used to determine whether your group buys the gadget, and which members are users. If you submit “Low” then you are a non-user and your earnings for that round are zero, regardless of the messages other members send. If you send “Middle” that means that you are willing to be a user only if the cost is split three ways. “High” means that you are willing to be a user if the cost is split either two ways or three ways. The table on the board summarizes how messages are converted into purchase decisions.

Thus, if you announce low in a round, you will not have to pay anything, but you will not earn anything even if your group purchases the gadget. If you announce medium, you will pay 34 francs of the cost - a three-way split - and receive your user value, only if the group purchases the gadget. This purchase will occur as long as the other two member of your group both announce either medium or high. Similarly, if you announce high and no member announces low, you will pay 34 francs - a three-way split - and receive your user value. However, if you announce high and exactly one other member announces high and one other member announces low, your group will purchase the gadget. In this one case, you will pay 51 francs - a two-way split - and receive your user value. This information is summarized in the table on the board.

To help you understand this table, we will now go through each line of it. Every possible set of three messages is depicted on the table. Therefore, the table shows every possible combination of group decisions, number of users, and the share of the cost users must pay. The first line shows the outcome if all three messages in a group are HIGH. In that case, everyone claims to be willing to share up to half the cost of the gadget; therefore, all 3 members have an equal 1/3 share of the cost, 34 francs. The second line shows the case where the messages are 2 HIGH and 1 MEDIUM. The high messages imply a willingness to share at least 1/3 of the cost and up to 1/2 if necessary; the medium messages implies a willingness to share no more than 1/3 of the cost. Therefore, all 3 members are users and have an equal share of the cost, 34 francs. If the messages are as in the third and fourth lines - 1 HIGH and 2 MEDIUM, or 3 MEDIUM - again all group members claim to be willing to share no less than 1/3 the cost of the good. Again this means that all 3 members are users, and all have an equal 34 franc share of the cost. In the fifth line, there are 2 HIGH messages and 1 LOW. 2 members are willing to share up to 1/2 the cost of the gadget, while one member is not willing to share any of the cost. This member is therefore not a user and does not share any of the cost. The two members who send HIGH messages, however, are users, and they will split the cost equally between the two of them - 51 francs each. These five lines reflect ever possible way the group can purchase the good. In the next line there is one message of each type, high, medium and low. Therefore 1 member is willing to share up to 1/2 the cost if necessary; 1 member is willing to share 1/3 the cost but no more; and one member is willing to share none of the cost. This is not enough to cover the whole cost, so the group does not purchase the gadget. Therefore, no one is a user, and there is no cost to share. The next line is similar: one member is willing to share up to 1/2 the cost, but the other two claim to be willing to share none of it. This is not enough to cover the whole cost, so the group does not purchase, no one is a user, and there is no cost to share. In the next 3 lines, no member is willing to share up to 1/2 the cost. In line 7, 2 are willing to share 1/3 and 1 is willing to share none. In line 8, 1 is willing to share 1/3 and 2 are willing to share none. In both cases, there is not enough to cover the cost, so the group does not purchase the gadget, no one is a user, and there is no cost to share. Finally, in line 9, no member is willing to share any of the cost - therefore the group does not purchase the gadget, no one is a user, and there is again no cost to share. These five lines exhaust all the possible ways a group can decide not to purchase the gadget.

(Go through overhead of Part I record sheet.)

Your decision and record sheet is now displayed on the overhead. The first column lists the round. The next column is where you will record YOUR USER VALUE for a round, which you will determine by the throw of a die at the start of each round. After you learn your value, you will decide on a message, and in each round write it in the third column. We will then collect the decision sheets and fill in for you the messages of your other group members, which will be listed in the next two columns. The decisions sheets will then be returned, so that YOU can calculate your cost share, whether you are a user, and your payoff. When this is complete we will go on to the next round.

I will now explain how to calculate whether your are a user and your cost share in any round. Please listen carefully, as if you record your cost share incorrectly, you may shortchange yourself. In every round, to calculate your cost share, find the one of the following cases that applies to you, and record the information on your record sheet:

1. If YOUR MESSAGE is LOW, your cost share is ZERO and you are not a user. This is true no matter what the other messages are in your group.

2. If YOUR MESSAGE is MEDIUM and the neither of the other two messages in your group is LOW, then you are a user. Your cost share is 34.

3. If YOUR MESSAGE is MEDIUM and at least one of the other two messages in your group is LOW, you are not a user. Your cost share is ZERO.

4. If YOUR MESSAGE is HIGH and neither of the other two messages is low, you are a user. Your cost share is 34.

5. If YOUR MESSAGE is HIGH and one of the other two messages is LOW and the other is HIGH, you are a user. Your cost share is 51.

6. If YOUR MESSAGE is HIGH and at least one of the other messages is LOW, and neither of the other messages is HIGH, then you are not a user. Your cost share is ZERO.

In each round you will fall into exactly one of these cases. We will leave this up for the duration of the experiment so you can determine your cost share easily. (Solicit questions.)

We will now go through two practice matches, to help make the procedures more concrete. Please note that you are not paid for the practice matches. When you have written down your decision in each round, place your decision sheet UPSIDE DOWN on top of your monitor so we can come pick it up.

DO PRACTICE ROUND P1; solicit questions.

We will now proceed to practice round P2. This practice round is exactly like practice round P1. New groups will be formed using the ping pong balls, each of your new values will be randomly assigned by rolling a die in private, and you will be asked to decide which message to send.

DO PRACTICE ROUND P2 AND RETURN DECISION SHEETS.

We will now proceed to the first actual round. There will be 10 rounds. Each round will be conducted exactly like the two practice rounds.

BEGIN FIRST PAID ROUND.

AFTER LAST ROUND IN PART I:

The first part of the experiment is now over. Please add your payoffs in francs from each round and write the total in the space on the Part I record sheet. Then multiply this total in francs by the exchange rate to get your dollar earnings from Part I. Write down your dollar earnings in the space provided both on your Part I record sheet and the whole experiment record sheet. We will then collect the Part I record sheets and distribute record sheets for Part II.

Proportional Cost Sharing

In this part of the experiment, the determination of your group and your user value are the same as before, but the decision making and cost sharing procedures are different.

As before, you will be assigned a new value at the beginning of each round by rolling a die. The cost for your group to purchase the gadget is still 102 francs. Now, however, instead of having only three messages, high, medium or low, your message will be an integer from 0 to 102, which we will call YOUR BID. In any round, you may submit any integer you like in this range. If the sum of the bids in your group is at least 102, your group purchases the gadget and everyone is a user, regardless of what bid they submit. If the sum of bids in your group is less than the cost of the gadget, your group does not purchase the gadget.

If your group purchases the gadget in a round, you will be paid your user value for that round. However, you will also have to pay a share of the cost. Specifically, your share of the cost will be the ratio of your bid to the sum of all three bids in your group, times 102 francs. See formula on board. In other words, you will share a fraction of the 102 franc cost that is proportional to your bid. If the sum of the bids is 102, you pay your bid. If the sum is greater than 102, you pay less than your bid. Note, therefore, that you will never have to pay more than your bid.

If your group does not purchase the gadget in a round, there is no cost to share and you do not get your USER VALUE of the gadget; therefore you are *paid 0 Francs*.

Therefore, your payment in every round will be OVERHEAD:

· 0 Francs if your group does not purchase the gadget, i.e., (YOUR BID + OTHER 2 BIDS) < 102

· YOUR VALUE - 102*(YOUR BID)/(YOUR BID + OTHER 2 BIDS) if your group does purchase the gadget, i.e., if (YOUR BID + OTHER 2 BIDS) $\geq$ 102.

To sum up, there are three specific differences from the first part:

1. Your bid is any number between 0 and 102, rather than just a message High, Medium or Low.

2. Different people in the group may have different shares of the cost - the cost is not automatically split equally among users.

3. There is no difference between users and non-users. If your group purchases the gadget, you automatically use it, and therefore you get your value for the gadget, no matter what your bid was for that round.

Your decision and record sheet for Part II is displayed on the overhead. PLEASE WRITE YOUR SUBJECT NUMBER IN THE SPACE AT THE TOP. Again in each round you will record your value in the second column, and then your bid in the third. When all bids have been recorded, we will collect the decision sheets and fill in the columns with the bids of your group members, as well as the sum of ALL THREE BIDS in your group, including yours. Decision sheets will then be returned so that YOU can calculate your cost share and your payoff. Note that you will not calculate whether you are a user or not, because if the sum of the bids is greater than 102, you are automatically a user. In making all calculations, round to the nearest whole number.

To help you calculate your cost share in any round, always follow the following steps. It is important that you listen carefully so that you are paid what you truly earn in the experiment.

1. If the sum of the bids is LESS THAN 102, your cost share is ZERO and you do not use the gadget.

2. If the sum of the bids is AT LEAST 102, then to calculate your cost share you:

   A. enter YOUR BID in your calculator

   B. press * or × on the calculator

   C. press 102

   D. press =

   E. press / or ÷ on your calculator

   F. enter the sum of bids in your group

   G. press =.

The number that appears next is your cost share. If this cost share is not a whole number, round it to the nearest whole number. Write the result on your record sheet. In other words: to find your cost share, multiply your bid by 102, and divide the result by the sum of bids in your group. If your answer is ever greater than your bid, you made a mistake. To make this part more concrete, we will have two practice matches. The practice matches do not count toward your earnings.

No Rebates

In this part of the experiment, everything is as before except the rule for calculating your cost. The determination of your group and your user value are the same as before, as are the bids you can make and the rule to determine whether you are a user. Only the cost sharing procedure is different.

If the sum of bids is at least 102 so your group does purchase the gadget, your cost is simply YOUR BID. In every round where your group purchases the gadget, you are paid your USER VALUE for that round minus YOUR BID for that round. NOTE that if your bid in any round is larger than your user value for that round AND your group purchases the gadget, you will LOSE MONEY in that round. If your group does not purchase the gadget in a round, that is, the sum of bids in your group in that round is less than 102, there is no cost to share and you do not get your USER VALUE of the gadget; therefore you are paid 0 Francs.

In other words: if the sum of the bids in your group is at least 102, you are paid your user value AND you will have to pay your bid. This is true regardless of how much you bid. If the sum of bids in your group is less than 102, you are paid 0 and you don't have to pay anything. Thus, the bids are used to determine both whether your group purchases the gadget and what your cost will be.

Therefore, your payment in every round will be:

· 0 Francs if your group does not purchase the gadget, i.e., (YOUR BID + OTHER 2 BIDS) $<$ 102

· YOUR VALUE - YOUR BID if your group does purchase the gadget, i.e., if (YOUR BID + OTHER 2 BIDS) $\geq$ 102.

(Put these on overhead. Go through overhead of Part I record sheet.)

Your decision and record sheet is now displayed on the overhead and I will now explain how to fill it out. The first column lists the round of the experiment. The *next column* is where you will record YOUR USER VALUE for a round, which you will determine by the throw of a die at the start of each round. After you learn your value, you will decide on a bid, and in each round write it in the third column. When all bids have been recorded, we will collect the decision sheets and fill in the columns with the bids of your group members, as well as the sum of ALL THREE BIDS in your group, including yours. Decision sheets will then be returned so that YOU can calculate your cost share and your payoff. When you have calculated your cost share and payoff, write them in the spaces provided for that round. In making all calculations, round to the nearest whole number.

DO PRACTICE ROUND P1.

We will now go through two practice matches, to help make the procedures more concrete. Please note that you are not paid for the practice matches. When you have written down your decision in each round, place your decision sheet UPSIDE DOWN on top of your monitor so we can come pick it up. (Solicit questions.)

We will now proceed to practice round P2. This practice round is exactly like practice round P1. New groups will be formed using the ping pong balls, each of your new values will be randomly assigned by rolling a die in private, and you will be asked to decide which message to send.

DO PRACTICE ROUND P2 AND RETURN DECISION SHEETS; Solicit questions.

We will now proceed to the first actual round. There will be 10 rounds. Each round will be conducted exactly like the two practice rounds.

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