Cost Share Adjustment Process for Public Goods: Exploring Alternative Institutions for Coordination under Heterogeneity

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Abstract

This paper reports experimental comparison of four institutions or mechanisms for group decision about cost-sharing for a public good when there is heterogeneity in endowments and rewards. The foundation for design of these institutions is an optimizing algorithm for finding group agreement.

Three of the institutions are based on price-taking behavior: each group member selects a quantity given a personalized cost schedule. The fourth mechanism is similar to a Voluntary Contribution Mechanism in its use of bids, but it includes optimizing features. Three of the four use some form of bidding.

To compare these institutions experimentally, each was embedded in a game of group decision through which a group could locate a unanimous agreement among proposals. Testing confirmed that the nature of institutional rules can greatly affect individual behavior and cooperation in groups.

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Experimental game prototypes may be viewed at
http//:www.agecon.purdue.edu/staff/loehman/costsharing

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1.0 Introduction

Public goods occur both in social contexts (more commonly known as public or club goods) and in business contexts. Group decisions involve determining the nature of the good to be provided and how it will be financed by cost-sharing among group members. A shared computer system is an example of a public good within a firm. A shared neighborhood recreational facility is an example in a social context.

For a group seeking to provide a public good, heterogeneity in incomes (ability to pay) and/or benefits (willingness to pay) is a very typical situation. Equal sharing of costs is a common solution even when there is heterogeneity, perhaps because no other solution can be identified (Young, 1994). Rules based on unequal sharing — e.g. sharing costs in proportion to endowments or to strength of preferences - may be difficult to implement because of lack of information.[1]

As an approach for addressing complex group decision problems, Reiter (1995) formulated the concept of a *coordination process.* A coordination process is an algorithmic, iterative procedure for group decision that directs group interactions toward optimality. To provide coordination for public goods decisions, this paper develops and demonstrates several methods of cost share adjustment. These methods that determine cost shares via a *tatonnement* process: cost shares are adjusted until there is a common demand for the public good. The methods differ in terms of the underlying algorithmic rules for cost sharing and the associated message space or "language" for the process".

Larrick and Blount (1995, p.283) have suggested that "...people's perceptions of relationships, and consequently their tendency to behave cooperatively, are highly labile....Social context can affect behavior through perceptions of relationships." Thus, because rules and information create social context, the selection of rules and information will affect cooperative behavior and hence social outcomes.

Experimental research about public goods has focused mainly on the linkage of behavior to the economic and social environment; for example, how free-riding relates to the level of cost to provide a public good. Smith (1991, 1980, 1979, 1978) expanded the horizons of experimental economics to consider also the interaction between behavior and institutional rules. Following Smith, this research concerns how institutional rules affect group outcomes.

Incentive problems arise when information about preferences and/or incomes must be obtained. Following Samuelson (1954), a maintained hypothesis of economics is that public goods will be under-provided by voluntary mechanisms because of free-riding.

1.1 Comparison of Smith's and Our Institutions

Smith (1978, 1979, 1980) experimentally tested alternative institutional rules for group decision about public goods, varying rules about cost sharing and message exchange. Smith's Auction Mechanism used bid and quantity messages. The bid message was the contribution per unit of public good, and the quantity message was the demand for the public good. The group quantity was the average of quantity proposals. The cost sharing rule used personalized prices for a public good, which for incentive reasons were not based on the individual's own bid; the price for each member was based on the unit cost minus the sum of bids of other members. Smith's Free-rider Mechanism relied only on bid messages, with no incentive for bidding and determined group quantity directly from the sum of bids.

The Free-rider institution is similar to the Voluntary Contribution Mechanism (VCM) with the addition of unanimity voting. VCM experiments (emphasizing testing of free-riding) have become a standard for public goods (Isaac, Walker, and Thomas, 1984; Isaac, McCue, and Plott, 1985; Isaac, Schmitz, and Walter, 1989). In VCM, bids determine cost shares and group quantity directly, hence "voluntary contribution". Although VCM experiments use repeated trials, an optimization principles are not used. Observed inefficiency of this mechanism may be attributed as much to difficulty in locating an optimum as to free-riding (Dasgupta, 1997).

To compare Auction and Free-rider mechanisms, each was embedded in a similar group voting game: the message process repeats until group members unanimously agree to their shares of cost and the group quantity. Voting occurred each round of the group process to check if the current combination of shares and level of the public good is the group choice. The environment consisted of heterogeneous preferences and endowments for a single good with a linear homogeneous cost function. Group size was six persons. Results in 1979 were based on eight to ten trials of each mechanism.

In Smith's results (1979) for the Auction Mechanism, the public good quantity was 73% of the theoretical optimum. Near optimal results were obtained for games with agreements, but 2/10 (20%) of the games ended in no agreement. The average number of rounds was 8.3. For the simpler, non-optimizing Free-rider Mechanism, public good level was also 73% of the optimum, with agreement in all games; it required 5.75 rounds on the average.

Our research agenda differs from Smith's in three ways. First, cost is nonlinear in our environment, whereas Smith used a linear homogeneous cost function. Therefore, the foundation for our allocation and adjustment rules is the *cost share equilibrium* with personalized cost shares (see below) instead of the Lindahl equilibrium with personalized prices.

Second, we investigate how the message space affects behavior. Tested mechanisms use both bid and quantity messages, only quantity messages, and only bid messages. (Smith compared only bids with bids and quantities.) The mechanism using only bid messages is similar to VCM, adding optimization rules and unanimity voting. Our hypothesis is that the nature of the message space may interact with strategic behavior possibilities.

Third, voting to select a group outcome is carried out differently. Our experimental game set-up is similar to a naturally-occurring group process in which proposal generation (the Proposal Phase) occurs prior to approval voting (the Approval Phase) Coordination algorithms operate during the Proposal Phase to guide group proposals toward efficiency. The group must vote unanimously to end the proposal process. In the Approval Phase, unanimity voting is used to make a group decision; any group choice will be individually rational[2] because it is voluntary.

Although others have devised elaborate incentive mechanisms for free-riding, here unanimity voting is the main incentive mechanism: any extreme proposal would not be a candidate for group selection under unanimity voting. Thus, group members should not bother to make extreme proposals, particularly since voting trials are limited in number. Unanimity voting in another setting has been found to greatly enhance the efficiency of group outcomes (Walker, Gardner, Herr, and Ostrom, 1997).

Our two-stage voting procedure may have better optimality properties than Smith's sequential voting when there is strategic behavior. When it is apparent that strategic behavior is occurring, group members may vote to stop the process and select cost shares and public good level corresponding to an earlier round.

1.2 Information Rules and Heterogeneity

To compare the efficiency effects of alternative information rules, especially when there is heterogeneity, we review treatments in VCM experiments. Heterogeneity may affect perceptions of fairness and hence affect the potential for success of group action. Information may affect how heterogeneity is perceived.

Coates and Gronberg (2001, 1996) tested the effects of sequential versus simultaneous bidding in VCM for groups of size four. Sequential bidding provides information about others' bids. Simultaneous bidding involves more risk since the level of others' contributions is not known at the time a bid is made. Measuring efficiency as the percent of maximum group surplus achieved, the sequential institution achieved 65-69% efficiency while the simultaneous institution achieved 44-50%, depending on the level of provision cost. Thus, more information improves efficiency.

Sell and Wilson (1991) tested how information about previous contributions affects current contributions for VCM. Alternatives were no information, information about average group contribution, and information about individual contributions. They found that information about individual contributions had the most positive effect on contributions, achieving at best around 70% of the optimum contribution after nine repetitions of VCM. Aggregate information achieved only about 50% of the optimum, with about the same result for no information.

2 Individual rationality means that each group member is better off in comparison to the status quo of no group provision.

Chan et al. (1999, 1996) tested the effects of heterogeneity on contributions in a VCM game with information and communication treatments. Three-person groups were used. In their design, in contrast to many VCM experiments, the optimum contribution is not the full endowment. In a no-communication environment, they found (contrary to Bergstrom, Blume, and Varian, 1986) that heterogeneity in endowment and reward increased contributions substantially. In a communication environment, the reverse result was obtained (communication was face-to-face with full disclosure possible). With heterogeneity in endowment and reward and communication, about 70% of the optimum contribution was made. About 60% of the optimum was obtained under no communication.

2.0 Allocation Rules and Social Desirability Criteria

Alternative mechanisms or rules can be compared based on the desirability of their outcomes. Below, we compare alternative institutions in terms of efficiency, number of iterative rounds, rate of group agreement, etc. The basis for these comparisons is mechanism design.

Hurwicz (1994, 1973) formalized description of an institution as a game-form with allocation rules and message space that map player strategies into outcomes. Voluntary Contribution mechanisms, Smith's Auction Mechanism, and our cost share adjustment processes each have different allocation rules that regulate how public good levels are determined from messages about bids and/or quantities.

Hurwicz defined a social desirability correspondence to identify the desirable subset of outcomes. Economic efficiency and fairness are examples of social desirability criteria. Another important design element is the environment, i.e. preferences, costs, resource endowments; heterogeneity is one type of environment. Early theoretical work showed that it is not always possible to attain a desirable outcome for any given environment.

Information cost is another important social criterion in the mechanism design literature. Early mechanism design literature was concerned with the size of the message space needed to operate a system (Reiter, 1974, Mount and Reiter, 1974). A smaller message space (e.g. quantity messages versus both bid and quantity messages) is less costly, hence more desirable. More recently, transactions cost (e.g. cost of operating a system) has been identified as an important social criterion (Williamson, 1989). The number of iterations or rounds needed to find a group decision is a measure of transactions cost.

3.0 Allocation Rules for Cost Sharing

The *cost share equilibrium* of Mas-Colell and Silvestre (1989, 1991) is the foundation for our cost share adjustment algorithms. The cost share equilibrium is consistent with heterogeneity in that it accommodates unequal cost-sharing rates for different types of group members. The theoretical concept is reviewed briefly below, together with details of alternative algorithms.

3.1 Cost Share Equilibrium: A basis for unanimity

Assume a group is engaged in making a decision about the level and cost-sharing for a public good. The environment consists of two goods (the public good and a private good representing all other goods), a preference ordering for each group member over the two goods, group member endowments, and a cost function for the public good relative to the other good. We assume there is no crowding. Pareto optimality for the public good Q is the solution of a vector optimization problem (Takayama, 1974):

$$\max_{Q,x_i} \; \Sigma \, \beta_i \, u_i(x_i, Q)$$
$$\text{s.t.} \quad \Sigma \, x_i + C(Q) \le M$$

where private consumption for each member is denoted by x_i, $C(Q)$ is the cost of the public good relative to the private good, individual incomes are M_i which sum to M, and β_i are Negishi weights on group members. Potentially, there is a Pareto optimum solution for each set of weights. At an interior solution, any Pareto optimum outcome will satisfy the Samuelson condition:

$$\sum_i \frac{u_Q^i}{u_x^i} = C'(Q).$$

The cost share equilibrium was proposed by Mas-Colell and Silvestre (1989, 1991) as a decentralized solution concept for a public good. Cost sharing is defined in terms of personalized charge functions $T_i(Q)$ for each group member, such that $T_i(0) = 0$ and $\Sigma \, T_i(Q) = C(Q)$ (feasibility) for any Q.

A cost share equilibrium is a feasible Q^* such that no group member would prefer a different public good level for the given charge functions:

$$u^i(x_i^*, Q^*) \ge u^i(M_i - T_i(Q), Q) \text{ for all members i and feasible Q.}$$

That is, at a cost share equilibrium, there is unanimity about the level of the public good for the given cost share functions.

The cost share equilibrium generalizes price-taking behavior. Taking the charge function as given, each person's quantity demand Q_i can be represented as satisfying:

$$\max_{x_i,Q_i} \; u^i(x_i, Q_i)$$
$$\text{s.t. } x_i + T_i(Q_i) < M_i.$$

An equilibrium public good level satisfies all individual maximization problems simultaneously.

A linear cost share equilibrium (LCSE) uses a particular form for $T_i(Q)$ with personalized prices p_i and shares s_i (Mas-Colell and Silvestre, 1991) as parameters. The form of the personalized charge function is:

$$T_i(Q) = s_i\, C(Q) + p_i\, Q$$

with personalized prices that sum to zero and shares that sum to one At an equilibrium Q*, first order conditions for each group member are

$$u_Q^i / u_x^i = s_i C'(Q^*) + p_i.$$

The ratio of marginal utilities is termed "marginal willingness to pay"($MWTP^i$). This condition says that at an equilibrium Q*, marginal willingness to pay is equal to the marginal charge:

$$MWTP^i(Q^*) = s_i C'(Q^*) + p_i.$$

Clearly, with personalized prices that sum to zero and shares that sum to one, both feasibility and Pareto optimality are satisfied at an equilibrium.

3.2 Alternative Algorithmic Rules for Locating a Cost Share Equilibrium

Mas-Collel and Silvestre did not address how to specify the parameters s_i and p_i of the charge function that correspond to an equilibrium. Each of the algorithms described below provides a method of determining these parameters and locating the corresponding equilibrium.

Four different cost share adjustment processes are described here. Three processes are based on price-taking behavior; each process can in theory produce a linear cost share equilibrium. The *Quantity Process* uses only quantity messages. The *Bid/Quantity Process* uses both bid and quantity messages. A generalization for nonlinear cost of a process proposed by Smith (1978) also uses both bid and quantity messages. The fourth process tested -- the *Optimal Bidding Process* -- uses two types of bid messages to search for an optimal outcome. For each process that uses some form of bidding (Bid/Quantity, Smith, and Optimal Bidding), following Bagnoli and McKee (1991), a provision point rule is added as an incentive.

Similar to an auctioneer in a tatonnement process, a coordinator executes message exchange. Message exchange is between the coordinator and each group member privately. Based on messages, the coordinator applies allocation rules to determine group outcomes.[3]

3.2.1 Overview of a Price-taking Process

With price-taking behavior, the general procedure is to locate a cost share equilibrium through adjustment of personalized prices p_i, starting from equal shares (zero prices with equal cost share parameters $s_i = 1/n$). Rule sets are described in more detail below. Alternative rules for price adjustment are based on message exchange.

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[3]The coordinator's role could be carried out by a computer network.

1. Given the charge schedule $T_i (Q_i;s_i,p_i)$, each person states their quantity proposal Q_i.

2. Individual proposals Q_i are averaged to obtain the group average Q_r.

3. The personalized price p_i for each member for each good is determined by a pricing rule.

Since any round could be selected in the approval voting, prices are normalized to sum to zero for feasibility. The process repeats until $Q_i = Q^*$ for all i (the cost share equilibrium) is obtained in step 1.[4]

3.2.2 Quantity Process

This process is a pure price-taking process in that prices are determined solely from quantity messages. The pricing rule is similar to *tatonnement* price adjustment. The computational rule for personalized price p_i^t for each member in round t is:

$$p_i^{t+1} = p_i^t + s_i [C'(Q_i^t) - C'(Q_r^t)]$$

Normalizing the resulting prices,

$$p_i^{t+1\prime} = p_i^{t+1} - \Sigma p_j^{t+1}/n \approx p_i^t + s_i C''(Q_i^t) [\Sigma (Q_i^t - Q_j^t)]/n.$$

Thus, with increasing marginal cost, if person i's quantity proposal is greater than others', the price will increase on the next round; conversely when a proposal is less than others'.

3.2.3 Bid/Quantity Process

Price is determined directly from the first order condition: price is equal to the difference between marginal willingness to pay and the share of marginal cost. For a discrete quantity change, incremental cost is used instead of marginal cost. The "incremental bid" b_i is the additional willingness to pay to increase quantity from the current quantity to the next level:

$$p_i^{t+1} = b_i^t - s_i [C(Q_r^t + \Delta Q) - C(Q_r^t)].$$

Normalizing prices:

$$p_i^{t+1\prime} = p_i^{t+1} - \Sigma p_j^{t+1}/n = b_i^t - \Sigma b_j^t/n.$$

Thus, a member with a bid greater than the average bid will receive a greater price.

The provision point rule is similar to Bagnoli and McKee (1991): the group quantity will only be allowed to increase if the sum of the incremental bids exceeds incremental cost.

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[4] See Loehman (2001) for simulation of these alternative algorithms for a common set of preference and cost parameters. The Quantity and Optimal Bidding processes may take longer to converge than the Bid/Quantity or Smith processes.

3.2.4 Smith Process

As in Smith's original rule, for incentive reasons, a group member's price is not determined from her own bid. The form of the charge function is:

$$T_i(Q) = s_i\, C(Q) + [(1 - s_i)\, C'(Q_{-i}) - \Sigma_{j\text{-}i}\, b_j]\, Q,$$

where the term $[\cdot]$ is the personalized price p_i. b_j represents marginal willingness to pay by member j to increase the current group quantity by one unit, $\Sigma_{j\text{-}i}$ denotes the sum of bids excluding member i, and Q_{-i} denotes the average group proposal excluding member i. At an equilibrium,

$$\Sigma_j\, b_j = C'(Q^*),\ Q_{-i} = Q^*.$$

Since personalized prices will not necessarily sum to zero out of equilibrium, normalization is needed out of equilibrium for feasibility. However, through normalization, the intended incentive effect is lost; particularly for a small group, both an individual's bid and quantity proposals will affect the price:

$$p_i' = p_i - \Sigma p_j/n = (n\text{-}1)/n\ [\Sigma_j\ (C'(Q_{-i})\text{-}C'(Q_{-j})/n] + (b_i - \Sigma b_j/n).$$

$$\approx (n\text{-}1)/n\ \ C''(Q_{-i})\ [\Sigma_j\, (Q_{-i} - Q_{-j})/n]\ \ + (b_i - \Sigma b_j/n)$$

$$= (n\text{-}1)/n\ \ C''(Q_{-i})\ [\Sigma_j\, (Q_j - Q_i)/n]\ \ + (b_i - \Sigma b_j/n)$$

For increasing marginal cost, this formula implies that a person will receive a reduced price if their quantity proposal exceeds others. Providing an incentive to free-ride, a bid greater than the average bid will increase the relative price. The provision point rule is the same as above.

3.2.5 Optimal Bidding Process

This process utilizes two types of bid messages -- "total" and "incremental" bids. Similar to the Voluntary Contribution Mechanism, the sum of the *"total" bids* determines a *feasible quantity* QF; QF is the maximum level such that the sum of "total" bids covers total cost. In contrast to the VCM method, there are suggestions based on optimization principles.

The *incremental bid* is the amount a group member would pay to obtain an increase to the next higher level from QF. The provision test indicates the direction of the optimum relative to the feasible quantity: the sum of incremental bids is compared to incremental cost to determine the *suggested quantity* (QS) in the direction of the group optimum. The incremental bids are also used to compute *suggested cost shares* for the next round. Cost shares are in proportion to bids, so that costs are exactly covered. However, the suggestions are just that; bidding is voluntary.

The provision test is similar to the rule used by Bagnoli et al. (1991, 1992) for a public good with discrete levels. In their case, the level of the good is increased one step at a time, starting from zero, as long as the sum of bids to increase the level covers incremental cost. Their process stops when a quantity is found such that incremental costs are no longer covered by the sum of bids over members. By individual rationality, utilities are improved as long as the process continues. If bids are truthful, their process can achieve an optimum.

The transaction cost (iterations) for our process may be less since it is not necessary to test each possible level. The Optimal Bidding Process starts at a feasible level as determined by initial bids. Similar to the MDP process (Dreze and de Valle Poussin, 1971), the process is utility-improving when quantity increases, but not necessarily when quantity decreases. However, unlike the MDP process, costs are exactly covered when cost is nonlinear. Similar to the method proposed by Tulkens (1978), quantity adjustment is discrete.

More formally, the Optimal Bidding Process is described as follows:

1. The initial *feasible quantity* QF^t:

Given "total" bids B_i^t, QF^t is the largest quantity that satisfies $\Sigma B_i^t \geq C(QF^t)$.

2. Cost shares for the feasible quantity are proportional to total bids:

$$T_i^t = T_i(QF^t) = \frac{B_i^t}{\Sigma B_i^t} C(QF^t).$$

3. *Suggested Quantity* (QS) and *Suggested Cost Shares* (ST_i) for the next round of bidding:

a) Given QF^t and the current cost share, each member proposes the incremental bid b_i^t to increase to the next level. The suggested quantity QS^t is determined from the incremental bids and incremental cost [5]:

$$\dot{QS} = 1, \text{ if } \Sigma b_i^t - C'(QF^t) > 0;$$
$$\dot{QS} = 0, \text{ if } \Sigma b_i^t - C'(QF^t) = 0;$$
$$\dot{QS} = -1, \text{ if } \Sigma b_i^t - C'(QF^t) < 0.$$

b) The *suggested share parameters* are as follows:

$$s_i^t = \frac{T_i^t + b_i^t}{\Sigma(T_i^t + b_i^t)} \text{ if } \dot{QS} > 0;$$
$$s_i^t = \frac{B_i^t}{\Sigma B_i^t} \text{ if } \dot{QS} \leq 0.$$

The *suggested cost share* ST_i^{t+1} is the suggested share times the cost of the suggested quantity:

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[5] Utility improvement occurs when QS increases:

$$u^i(M_i - ST_i, QS) \geq u(M_i - (T_i + b_i), QS) = u^i(M_i - T_i, QF) \geq u^i(M_i - B_i, QF).$$

$$ST_i^{t+1} = s_i^t C(QS^t)$$

The group members may choose to use suggested cost shares as their bids for the next round. The process repeats until QS and bids are no longer changing. Although the rules seem complicated compared to VCM, the process is easily computerized.

When "total" bids equal ST_i and $MWTP^i(QF) = s_i C'(QF)$[6], the sum of marginal bids is equal to marginal cost and QF=QS. This is a ratio equilibrium (Kaneko, 1977).

4.0 Experimental Game Setup

4.1 Description of Experimental Game Form

Each cost share adjustment mechanism is embedded in a common experimental game framework. For price-taking methods, the Proposal Phase starts from equal cost shares for each group member; each round produces a group quantity and cost shares. For each round of the Optimal Bidding Process, bids determine both a feasible group quantity and cost shares.

The Proposal Phase must end by unanimous group agreement to go on to the Approval Phase. The Approval Phase then allows groups to review and vote over the set of group proposals. If the group does not agree to stop the proposals within a certain number of rounds, then the proposal process has a randomized end (to simulate discussion breakdown in a natural process). In the trials reported below, subjects were told that the Proposal Phase would end with probability of 0.5 after five proposal rounds.

The idea behind the Approval Phase is similar to Hare voting: to reduce the number of plans given serious attention, plans that are nobody's favorites can be dropped from consideration. Each member first indicates the three most preferred proposals by rank. Each subject is then shown a screen with ranking information for all group members. (There is a danger that providing preference information could create potential disagreement.) In order for a proposal to be selected by the group, all members must approve it. In the case of no agreement, all group members receive their non-cooperative allocations. Three chances at approval voting were given. Multiple "yes" votes were permissible. With ties: for price-taking, the proposal with minimum variance in quantity is selected; for Optimal Bidding, the largest feasible quantity is selected.

At the beginning of each game session, each member is shown their non-cooperative best individual outcome. For each non-cooperative quantity level, the subject reward is the same as for group participation, but the full cost must be paid, thus reducing net reward compared to a group solution. However, the group may choose a higher quantity than a member would desire individually. On all information screens, the individual's best net reward level outside the group is shown as a reminder of the benefits of cooperation and as a check on individual rationality.

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[6]The ratio equilibrium is a special case of LCSE with zero personalized prices: $T_i(Q) = s_i C(Q)$.

4.2 Environment and Information

The environment for this game is described by parameters (group size, endowment, reward schedules for each member, and the cost function) and information. Group size was three members, with heterogeneity in rewards and endowments. Following Smith (1976), members' rewards are based on specified cost and utility functions and given endowments.

Parameters. The costs and payoffs were as follows. The cost function is nonlinear with a fixed cost f: $C(Q) = 1/s[\ f + 10\ (sQ) - 5\ (sQ^{2)} + 5\ (sQ)^3]$. Each of three members has a quasi-linear utility function of the form: $u_i(x_i, Q) = x_i + \gamma_i /s \log(1 + sQ)$. The fixed cost and the scaling factor s were varied in the different games played to obtain different optimal Q levels and status quo for individual members. (E.g., a high fixed cost and low endowment would mean that a person could not afford the good alone.) For the quasi-linear utility functions, there is a theoretical efficient public good level that is independent of the distribution of income (Bergstrom and Cornes, 1983); the efficient solution maximizes the sum of utilities.

Heterogeneous Member types. There were three types of members in each game: A = (High Reward, Low Endowment); B= (High Reward, High Endowment); C=(Low Reward, Low Endowment). In each game, two of the members could not afford to provide the good individually. The type of each subject was varied over the course of three games.

Information. There is no direct communication among group members. Historical information about others' contributions/cost shares is provided, but endowments and rewards are not revealed. For all processes with bidding, bids and quantity proposals are simultaneous. The information format for the Optimal Bidding Process is based on a matrix of outcomes for "your bid" and "others' bids". The price-taking processes use reward and cost schedules.

Groups. Each group had three members. Each participated in a practice game with no payoff, followed by three real games with real rewards. All groups played simultaneously. To avoid strategic behavior from learning about group members, following Andreoni (1988), group members were mixed randomly after the first game for each succeeding game. Experimental cost for each session was about $300 based on an average of about $15 per subject plus a $5 show up fee. Each session took about two hours each for a practice game and three real games.

5.0 Representative Game Outcomes

Table 1 contains data from a representative game session for the Quantity Process and shows the information available to group members regarding quantity proposals and cost shares. Payoff information was private. The third member (C) starts out with a lower than average quantity proposal and continues this for four rounds; consequently this member receives much lower cost shares. The cost share equilibrium was located and approved. (Other outcomes were also approved as indicated by unanimous "yes" votes.) For this outcome, all three group members are better off compared to their best individual outcomes. The advantaged (B) member receives the largest cost share while the disadvantaged (C) member has the lowest share.

Table 2 shows data for a representative Bid/Quantity game session. Bids and payoffs were private. In this session, the third group member (C) starts out by proposing a quantity much less than the other members' proposals. This person also has some negative incremental bids, indicating desire for a subsidy relative to the proposed cost share for the indicated group plan. Consequently, this person receives a cost share of less than 1/3 on subsequent rounds. Group member (A) puts in larger quantity proposals than the others and also puts in larger incremental bids for most rounds; consequently, this person gets the largest cost share at the equilibrium. All group members agree to a group quantity of Q=6 for the indicated cost shares; all three group members are better off compared to their best individual outcomes. Because of the bidding pattern, the advantaged (B) type member does not pay the largest cost share in the equilibrium solution. The (C) type member has the lowest share due to having the lowest bids. (Because of misrepresentation, the outcome is not the actual theoretical equilibrium of Q=7.)

Table 3 shows data from a representative Optimal Bid game session. Note the decay in bidding until round 6 when two members dramatically increase their bids, and then decay sets in. again followed by another round of decay/recovery. The algorithm indicates repeatedly that the optimum is in the direction greater than Q=3, but not greater than Q=4. For the final rounds, group members do not adopt the suggested contributions that would lead to the suggested plan. However, voting over all the rounds does result in acceptance of the optimal level (Q=4) and also the sub-optimal level Q=3. Again, the (C) member makes lower total and incremental bids and so has the lowest cost shares, while the advantaged (B) type member has the largest shares.

6.0 Comparative Experimental Results for Alternative Cost Share Adjustment Processes

Each rule set was tested in one game session. Since the number of games is relatively small, no formal hypothesis testing was performed (the number of games is similar in magnitude to the number of games for Smith's 1979 comparisons. Table 4 shows the number of games for each rule set and comparative results.

The efficiency of each process is measured by the ratio of the selected public good level to the theoretical optimum. (When there was no agreement, a quantity level of zero was taken to be the group outcome.) Average efficiency for bidding institutions ranged from 62% to 69%. These results are of comparable magnitude to Smith's results (1979). The Quantity Process achieved 94% efficiency over nine games; see more extensive testing below.

The number of proposal rounds can be associated with transactions costs in a natural group setting: a coordination process would not be satisfactory if it required a large number of iterations to reach a good outcome. The number of proposal rounds was similar for each process; the average number of rounds was in the range from four to six.

Among the three processes that used bidding, the Optimal Bidding Process was best in terms of efficiency (69%), finding agreement, satisfying the provision point test, and lowest percent of negative or zero bids. For all methods with bidding, there appears to be an increase in strategic behavior over games: more proposal rounds and more zero or negative incremental bids for the last two games than for the first game.

Quantity Process. The Quantity Process was very successful in finding a group solution. As explanation, since it does not employ bid messages, it provides less possibility for strategic behavior. However, the outcome was not necessarily a cost share equilibrium. See more extensive testing below.

Bid/Quantity Rule (Provision Point test at Qr-l). A cost share equilibrium was found only once in the **twelve** games. Because the Provision Point test was met only about half the time, the group outcome was less than the efficient outcome. Although bids were usually insufficient to meet the provision test, bids were positive most of the time.

Smith Ride (Provision Point test at Q_r). The least satisfactory results were obtained with this rule. This may be attributable to the nature of the Provision Point rule: contributions were required to cover the incremental cost to go from the group average to the next higher level. At least one member (the low/endowment/low reward member) would not want this increase with the given cost shares! Consequently, negative bids were often submitted — probably as protest bids to send the message that an increase in quantity was not desirable. Negative bidding by one member seemed to generate more of this behavior in other members — even those who would be advantaged by an increase in the good — probably because of the share rule that charges higher bidders more. Voting then seemed to suffer as well, with some members holding out for group outcomes giving them higher reward levels. The result was no agreement in 1/3 of the games!

Because of the greater occurrence of no agreement, efficiency of this rule was lower than for the other processes. There were also more low quantity proposals with this rule, in spite of the indicated reward for making high proposals.

Optimal Bidding Process. This method had the highest efficiency (69%) among the three bidding mechanisms. To correlate, its rate of satisfying the provision test is also best. As a measure of free-riding, negative or zero bids were about the same as for the Bid/Quantity Process. It was better than the Bid/Quantity process in terms of the rate of finding agreement.

This mechanism improves on V C M because it provides information about optimal direction for the public good level, and it also includes unanimity voting. Its efficiency is better than the 50% efficiency for a V C M game with simultaneous messages (Coates and Gronberg, 1996). It is better than the 60% efficiency of the V C M game of Chan (1999, 1996) with no communication. It is about the same as the 70% efficiency of the V C M game with individual information (Sell and Wilson, 1991). It is close to Smith's Free-rider Mechanism result of 73% (recall both use unanimity voting).

7.0 Extensive Testing of the Quantity Process and the Effect of Information about Others

In more extensive testing (144 games), the Quantity Process was examined in terms of efficiency, proposal rounds to find group agreement, and success rates for locating and accepting a cost share equilibrium. Table 5 shows the relative efficiency of game outcomes; an average efficiency of 77% was obtained. Efficiency was 83% on the third game; the increase in third game compared to the second game was statistically significant, indicating learning effects.

We also tested the effect of information about others' types. In about half the games, group members had no knowledge about others except that they were heterogeneous in terms of rewards and endowments. For the other treatment, group members were told their own type (high/low endowment and high/low reward) and the types of others, but responses were not identified by type. There is no significant difference in efficiency by information treatment.

Table 6 shows the number of rounds for termination of the Proposal Phase. Each game equilibrium could be found theoretically in three proposal rounds, if proposals were truthful, whereas strategic behavior would be expected to increase the number of rounds to find an agreement. The Quantity process required an average of five proposal rounds. Although there were more rounds overall with heterogeneity information, the average number of rounds for each game is not statistically different for the two information treatments. Pooling the information treatments, the number of rounds for the second and third games is significantly greater than for the first game, indicating that members were exploring more strategies.

Table 7 shows the approval rate for the equal shares solution. Overall the approval rate is 31%. Thus, even when there is heterogeneity, equal shares is a robust sharing rule. A reasonable hypothesis is that equal sharing is more attractive when an alternative rule is not transparent. Correspondingly, the highest approval rate for equal shares is found for the first game. There are significant game effects between the first and second games and between the second and third games, evidently indicating learning about the cost share equilibrium. The overall approval of the equal shares solution is less when information about player types is provided, but the difference is not significant.

Table 8 shows the proportion of "successes" in finding the cost share equilibrium (CSE). Overall, a CSE was found in 46% of the games. The greatest success rate is on the last game. There is evidently a learning process: the overall percent of successes for the second game was significantly greater than for the first game, while the third game had about the same success rate as the second game. The difference by information treatment is not significant.

Table 9 examines the approval rate for the cost share equilibrium. Overall, the approval rate for the cost share equilibrium is 21%. The lowest approval rate is on the first game (with the highest approval rate for equal shares). The second game had the highest approval rate (also the lowest approval rate for the equal shares). On the third game, there is movement away from approval of the CSE. One problem may be the underlying algorithm for the given parameterization: it can produce negative cost shares (subsidies) which may not be agreeable to non-subsidized group members. The information treatment did not cause a significant difference. A reasonable hypothesis when there is more attention on heterogeneity is that a CSE allowing unequal shares should be more attractive; the approval rate is lower for all games for the "informed" treatment but not significantly.

Because equal shares is a more transparent solution concept than the cost share equilibrium, the conditional probability of CSE approval (the rate of approval given that the CSE is found) is appropriate to compare their relative attractiveness. Conditional probabilities in Table 10 give more positive support for the CSE as a solution concept. The conditional approval rate overall is 45%, higher than the overall rate of 31% for equal shares. The second game has the highest approval rate game; overall, the conditional probability of approving the CSE for the second game is 58%.

About a third of the group agreements were neither the equal shares solution nor the cost share equilibrium. Failure to reach a group agreement occurred in 12/69 (17.3%) games with no heterogeneity information and in 9/75 (12%) of the "informed" games, averaging 14.5%. Nearly half of the "disagreement" cases were associated with a subsidy for one group member, due to the nature of the underlying algorithm. The other disagreements were due voting methods: either a non-compromising member held out for her most preferred outcomes in the allotted vote trials, or there was an indicated lack of understanding of the voting process.

8.0 Conclusions

Smith (1997) suggested that self-interest and reciprocity are behaviors present in any individual, and that institutional rules can call forth either behavior. Our results comparing alternative cost share adjustment rules demonstrate that institutional rules do affect behavior: University of Arizona Business School students who tested each institution were similar, but outcomes for four different rule sets were quite different!

Overall, a process of cost share adjustment with simultaneous messages seems promising in terms of the efficiency that can be achieved with relatively few rounds. Algorithmic rules for determining a group public good level, coupled with unanimity voting over proposals, can lead to a near-efficient group outcome. Apparently, a process with proposals and unanimity voting can be beneficial for locating a group decision even when a Cost Share Equilibrium is not found. When there is heterogeneity, detailed information about group members is not necessary for a process to work well.

Comparing the four processes, the Quantity Process gave the best results in terms of efficiency. From 144 experimental games for the Quantity Process, an average efficiency of 77% was obtained in 4 to 5 proposal rounds. Failure to reach a decision occurred in about 14% of the games, either due to the nature of the underlying algorithm or to voting rules. Rules for the Quantity Process are simple, but the underlying algorithm may produce undesirable subsidies that then lead to disagreement.

Because processes with bidding evoked more strategic behavior, they achieved lower efficiencies (62-69%) with more proposal rounds (5 to 6), and there is evidence that strategic behavior led to breakdown in group agreement. Apparently, there is interaction between allocation rules and voting rules!

Evidently, improvement over VCM results is possible at the cost of more complex allocation rules. Efficiency for the Optimal Bid Process shows improvement over Voluntary Contribution experiments under conditions of simultaneous bidding, no communication, and limited information about others' contributions. Improved methods include providing information (similar to the gradient method of optimization) each round about the direction for the optimal public good level coupled with unanimity voting for the group decision among proposals.

Probably there is no perfect mechanism for group decision about public goods. More extensive comparative testing could help determine the relative desirability of alternative institutions for cost share adjustment, including alternative voting methods. Since approval voting with student subjects often exhibited inconsistencies, further trials should include more training in the rules of the games.

Table 1. Example of Quantity Process, Game 1

Round	Group Plan	Member Proposals			% Cost Shares			Member Payoffs			Approval Votes		
		A	B	C	A	B	C	A	B	C	A	B	C
1	7	8	9	6	33	33	33	5857	9437	2697	Yes	Yes	No
2	7	8	8	7	36	46	18	5790	9090	3110	Yes	Yes	No
3	7	8	8	7	39	50	11	5699	8999	3288	Yes	Yes	Yes
4	7	8	8	7	43	53	4	5612	8912	3470	Yes	Yes	Yes
5	8	8	8	8	45	54	1	5579	8949	3661	Yes	Yes	Yes
							non-coop	4220	7710	2000			

Table 2. Example of Bid/Quantity Process, Game 2

Round	Group Plan	Member Proposals			Member Incremental Bids			Exceeds Incr. Cost	% Cost Shares			Member Payoffs			Approval Votes		
		A	B	C	A	B	C		A	B	C	A	B	C	A	B	C
1	4	7	6	1	130	75	44	Yes	33	33	33	4833	7923	2633	No	No	No
2	5	8	6	5	200	150	57	No	40	32	28	5069	8457	2774	No	Yes	Yes
3	5	7	6	6	200	155	-11	No	43	35	22	5027	8402	2874	No	No	No
4	5	6	7	5	280	150	-23	No	46	39	15	4974	8337	2992	No	No	No
5	5	7	5	6	100	165	-63	No	54	35	10	4827	8402	3074	No	No	No
6	5	5	6	6	220	130	17	Yes	38	48	14	5104	8192	3002	Yes	Yes	Yes
7	6	6	6	6	280	175	34	Yes	47	34	19	5133	8793	2972	Yes	Yes	Yes
											non-coop	4040	7350	2000			

Table 3. Example of Optimal Bid Process, Game 3

Round	Feasible Plan	Suggested Plan	"Total" Bids			Incremental Bids			Exceeds Incr. Cost	% Cost Shares			Member Payoffs			Approval Votes		
			A	B	C	A	B	C		A	B	C	A	B	C	A	B	C
1	4	5	1500	2000	600	250	1000	300	Yes	37	49	15	3170	5560	2307	Yes	Yes	Yes
2	4	4	450	2500	766	250	800	300	Equal	12	67	21	4002	4932	2104	Yes	No	No
3	2	3	350	1200	701	400	250	150	Yes	16	53	31	3306	5024	1864	Yes	No	No
4	2	3	250	1300	724	400	300	150	Yes	11	57	32	3406	4939	1849	Yes	No	No
5	0	1	150	750	725	850	1300	0	Yes	9	46	45	2000	4000	2000	No	No	No
6	5	4	1500	3500	0	200	675	150	No	30	70	0	3263	4259	2896	Yes	No	Yes
7	4	5	550	4000	100	250	1075	100	Yes	12	86	2	4012	4294	2732	Yes	No	Yes
8	0	0	350	1050	200	1000	1050	0	Equal	22	66	13	2000	4000	2000	No	No	No
9	3	4	1500	1400	200	300	600	300	Yes	49	45	6	2821	5599	2525	No	Yes	Yes
10	3	4	550	2200	425	300	500	250	Yes	17	69	13	3629	4971	2345	Yes	Yes	Yes
11	3	4	500	2000	560	300	550	250	Yes	16	65	18	3654	5074	2217	Yes	Yes	Yes
												non-coop.	2000	4173	2000			

Table 4. Experimental Comparison of Alternative Cost Share Adjustment Processes

	Game I	II	III	Overall	
Efficient Q	8	7	4		
Quantity Process					
%Efficiency	0.83	1.0	1.0	0.94	
Avg. # Rounds	3.33	5.0	5.05	4.44	
# Games	3	3	3	9	
# No Agreement				0/9	=0.0
Bid/Quantity Process					
%Efficiency	0.50	0.80	0.65	0.65	
Avg. # Rounds	5.40	5.00	6.40	5.4	
# Games	5	5	5	15	
# Rounds Provision Met				39/84	= 0.46
# Negative or Zero Bids				63/(3x84)	= 0.25
# No Agreement				2/15	= 0.13
Smith Process					
%Efficiency	0.41	0.96	0.50	0.62	
Avg. # Rounds	4.75	6.25	6.5`	5.8	
# Games	4	4	4	12	
# Rounds Provision Met				10/70	= 0.14
# Negative or Zero Bids				125/(3x70)	= 0.60
# No Agreement				4/12	= 0.33
Optimal Bidding Process					
%Efficiency	0.75	0.64	0.68	0.69	
Avg. # Rounds	4.50	5.25	5.25	5.0	
# Games	4	4	4	12	
# Rounds Provision Met				32/60	= 0.53
# Negative or Zero Bids				43/(3x60)	= 0.24
# No Agreement				2/12	= 0.17

Table 5. Extensive Testing of Quantity Process: Efficiency

	Game			
	I	**II**	**III**	
Efficient Q	7	4	8	
				Overall
No Info:	0.76	0.71	0.83	0.77
#Games	23	23	23	69
Info:	0.77	0.71	0.83	0.77
#Games	25	25	25	75
Overall	0.77	0.71^{G*}	0.83	0.77
#Games	48	48	48	144

Table 6. Extensive Testing of Quantity Process: Number of Proposal Rounds

	Game			
	I	**II**	**III**	
Truthful	3	3	3	
				Overall
No Info:	3.61	5.00	4.43	4.35
Info:	3.60	4.56	5.12	4.42
Overall	3.60^{G**}	4.79	4.79	4.39

I - Information Effect
G - Game Effect
* - 95% t - test
** - 99% t - test

Table 7. Extensive Testing of Quantity Process: Equal Shares Approved

	Game			Overall
	I	II	III	
No Info:				
Number	13	2	9	24
Games	23	23	23	69
Percent	0.56	0.09	0.39	0.35
Info:				
Number	11	5	5	21
Games	25	25	25	75
Percent	0.44	0.20	0.20	0.28
Overall:				
Number	24	7	14	45
Games	48	48	48	144
Percent	0.50^{G**}	0.14^{G**}	0.29	0.31

I - Information Effect
G - Game Effect
* - 95% t - test
** - 99% t - test

Table 8. Extensive Testing of Quantity Process: Cost Share Equilibrium Found

	Game I	II	III	Overall
No Info:				
Number	8	11	15	34
Games	23	23	23	69
Percent	0.35	0.48	0.65	0.49
Info:				
Number	6	15	12	33
Games	25	25	25	75
Percent	0.24	0.60	0.48	0.44
Overall:				
Number	14	26	27	67
Games	48	48	48	144
Percent	0.29^{G**}	0.54	0.56	0.46

I - Information Effect
G - Game Effect
* - 95% t - test
** - 99% t - test

Table 9. Extensive Testing of Quantity Process: Cost Share Equilibrium Approved

	Game I	II	III	Overall
No Info:				
Number	3	8	5	16
Games	23	23	23	69
Percent	0.13	0.35	0.22	0.23
Info:				
Number	2	7	5	14
Games	25	25	25	75
Percent	0.08	0.28	0.20	0.19
Overall:				
Number	5	15	10	30
Games	48	48	48	144
Percent	0.10^{G**}	0.31^{G**}	0.20	0.21

Table 10. Extensive Testing of Quantity Process:
Conditional Probability of Accepting Cost Share Equilibrium

	Game I	II	III	Overall
No Info:				
Number	3	8	5	16
Games	23	23	23	69
Percent	0.37	0.73	0.33	0.47
Info:				
Number	2	7	5	14
Games	25	25	25	75
Percent	0.33	0.47	0.42	0.43
Overall:				
Number	5	15	10	30
Games	48	48	48	144
Percent	0.36^{G**}	0.58^{G**}	0.37	0.45

I - Information Effect
G - Game Effect
* - 95% t - test
** - 99% t - test

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Appendix: Rule Descriptions

In the instructions for each game form, each rule was described in terms of its general properties (computational details were a "black box."). For price-taking processes, the initial charge schedule has equal shares (s_i = 1/n and zero personalized prices). After each subject makes a quantity proposal, a new charge schedule is displayed on the next round, with corresponding net payoffs.

Price-taking processes with price adjustment had a similar information format: charge, benefit, and net reward schedules were presented for a range of ten quantity levels. After seeing the information screen, each subject responded with a message about the desired public good quantity. Summaries of proposals and resulting shares of cost for all group members by round were available as public information on history and voting screens.

Instructions for the Proposal Phase were as follows:

Quantity Process. "The computer will determine the group plan based on the average of members' quantity proposals. Overall, a larger quantity means that both benefits and cost shares will increase for all group members.

Cost shares are equal in the first round. Your cost share for subsequent rounds will be calculated by the computer based on your quantity proposals relative to others' proposals. If your quantity proposal is greater than the average proposal, your cost share will increase on the next round. Conversely, your cost share will decrease if your proposal is less than the average."

Clearly, this rule has incentives for revealing a low demand, since a person's cost share depends on the public good demand proposal relative to others' proposals.

Bid/Quantity Process. "The computer will determine the group plan based on the average of members' quantity proposals. Overall, a larger quantity means that both benefits and cost shares will increase for all group members.

Each round, the group plan begins at the average of group members' quantity proposals minus one. Given the newly calculated group plan, you will be asked to bid to increase the group plan to the next higher level. To make the increase to the next higher level, the total of bids must be enough to cover the extra cost for that plan.

Cost shares are equal on the first round. Your cost share for subsequent rounds will be calculated by the computer based on your bids relative to others' bids. If your bid is greater than the average, your cost share will increase on the next round. Conversely, your cost share will decrease on the next round if your bid is less than the average."

Smith Rule. "The computer will determine the group plan based on the average of members' quantity proposals. Overall, a larger quantity means that both benefits and cost shares will increase for all group members.

Given the newly calculated group plan, you will be asked to propose your bid to increase the group plan to the next higher level. To make the increase, the total of bids proposed by the group must be enough to cover the increased cost for that plan.

Cost shares are equal in the first round. Your cost share for subsequent rounds will be calculated by the computer based on both your bid and your quantity proposals relative to others' proposals.
If your bid is greater than the average bid, your cost share will increase. Conversely, if your bid is less than the average, your cost share will decrease.

You can also receive a bonus -- a reduced cost share -- if your quantity proposal is greater than the average quantity proposal. Conversely, a quantity proposal less than the average can mean a penalty in term of increasing your share."

For games using the Smith process, the provision test was set at Q_r*, so that bids had to cover the incremental cost $C(Q_r*+1) - C(Q_r*)$. This greater provision point was tried (unsuccessfully) in an attempt to improve the efficiency of the process.

Optimal Bidding Process. Although the overall form of this game followed the proposal and approval phase format, the information display is different from the price-adjustment processes. The information display uses a payoff matrix, similar to a VCM game, to show net rewards. The same information matrix format displays the quantities that different bid combinations could "buy". The rules of the process were described as follows:

"Each round you will:

1) Make a Bid, to determine a feasible commodity plan and cost shares.

The sum of your bid and others' bids will result in a Feasible Group Plan. The computer will determine this plan from the highest level that can be afforded given the total bids and the cost for each plan level.

Your cost share will never be more than your bid on any round.

Since the sum of bids may be greater than the required cost for the feasible plan, bids are adjusted so that excess revenue is not collected. The percent share of group cost that you will pay is the relative proportion of your bid to the sum of bids.

Your net reward for each round will be based on the feasible commodity plan and your cost share.

2) Make an Incremental Bid, to suggest a new plan and cost share for the next round
Your benefit would increase if the group plan level were to increase. Your Incremental Bid represents an extra contribution over your current cost share toward an increase in the plan level.

The Suggested Group Plan is determined by the computer in the direction of maximal group net returns.

- If the sum of incremental bids exceeds the extra cost to increase the plan, then the Suggested Group Plan is one level higher than the current feasible plan.
- If the sum of incremental bids is less than required, then the Suggested Group Plan is one level less than the current feasible plan.
- If the sum of incremental bids exactly equals the extra cost, the Suggested Group plan is the same as the current feasible plan.

Your Suggested Cost Share for the next round will be in proportion to the sum of your original cost share and your incremental bid, if the plan level increases. The suggested cost shares will exactly cover the cost of the Suggested Group Plan."