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BEHAVIORAL EXPLANATIONS OF EFFICIENT  
PUBLIC GOOD ALLOCATIONS

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Section 1: Introduction

For years, the free-rider problem was accepted as an insurmountable barrier to the Pareto-efficient provision of public goods via voluntary, decentralized decisionmaking.<sup>1</sup> Public goods for which the utility value to any one consumer does not diminish as additional consumers utilize them are in general characterized by lack of a low-cost exclusionary device. In many cases, exclusion of non-contributors is technologically impossible. Decentralized decision procedures depend upon being able to infer an individual's marginal evaluation<sup>2</sup> of the public good from his announced per unit voluntary cost share. When announced voluntary cost shares are collected as a means of obtaining resources for public good production, the individual faces a conflict between correctly revealing his marginal evaluation and enjoying a low share of the cost of public good production. A rational individual who believes that his consumption level of the public good will not significantly vary, with respect to his announced cost share, will volunteer to contribute a cost share which understates his marginal evaluation. If many individuals so understate, the level of the public good provided by the procedure is less than a Pareto-efficient level.<sup>3</sup>

Recent positive developments concerning the free-rider problem can be explained in terms of a simple model. Let  $i = 1, 2, \dots, I$  represent a typical agent, an allocation be  $y \in Y$ , a feasible set, where  $y = (y_0, y_1, \dots, y_I)$ .  $y_0$  is the quantity of a single pure public good, and  $y_i$  is agent  $i$ 's consumption of a single private good. Each agent  $i$  has a utility function  $U_i(y_0, y_i)$  and an initial endowment of the private good  $w_i$ .

The allocation achieved cannot directly depend upon  $(U_1, \dots, U_I)$ , which are unobservable. So agent  $i$  is modeled as selecting a message  $m_i$  in  $M$ , a set of feasible messages, with  $m = (m_1, \dots, m_I)$  in  $M^I$ , a set of message profiles.  $m_i$  is selected with knowledge of the outcome function  $f(m)$ , which chooses an element of  $Y$  given the message profile. Let  $(y_o, y_i) = f_i(m)$  denote a component function of  $f$ . The theoretical literature (see Groves, 1979, for a comparison of major results) labels the pair  $(M^I, f)$  an allocation mechanism.

The solution concepts that are generally employed with allocation mechanisms are Cournot-Nash equilibrium and dominant-strategy equilibrium. Let  $m_{)i}(\cdot)$  denote the message profile absent the  $i^{\text{th}}$  component. Cournot behavior is the choice of  $m_i^*$  given  $\hat{m}_{)i}(\cdot)$  which maximizes  $U_i[f(m)]$  subject to  $m_{)i}(\cdot) = \hat{m}_{)i}(\cdot)$  and  $m_i \in M$ . A Cournot-Nash equilibrium for  $(M^I, f)$  is a message profile  $m^*$  such that no agent  $i$  can gain utility by changing unilaterally from  $m_i^*$  to any other message in  $M$ . That is,  $U_i[f_i(m^*)] \geq U_i[f_i(m)]$  for  $m_{)i}(\cdot) = m_{)i}^*(\cdot)$  and  $m_i \in M$ .

When the message  $m_i^*$  is the Cournot choice for every  $m_{)i}(\cdot)$ , then  $m_i^*$  is called a dominant strategy. A dominant strategy equilibrium is a message profile  $m^*$  for which  $m_i^*$  is a dominant strategy for agent  $i$ ,  $i = 1, \dots, I$ . A dominant-strategy equilibrium does not require coordination to the extent a Cournot-Nash equilibrium does, since each agent's equilibrium message is an optimal response to any message profile.

Hurwicz (1972) and Green and Laffont (1977) demonstrated the nonexistence of any mechanism yielding Pareto-efficient allocations as dominant-strategy equilibria. Both papers analyzed a model where agents derive utility solely from the final or solution allocation, and where the demand information announced by agents is in the form of willingness-to-pay functions. These results suggest

that an agent may gain a more favorable final allocation by using a sophisticated strategy which takes into account the reaction functions of the other agents, than by reporting his "true" marginal willingness-to-pay.

Groves and Ledyard (1977) "solved" the free-rider problem by constructing a mechanism (without dominant strategies) for which the set of Cournot-Nash equilibria coincide with the Pareto frontier, a feature called "incentive compatibility." They actually presented a set of mechanisms, where an agent's public production cost share is a pro rata plus a fee for deviation from the average of the other agents' messages, the latter multiplied by a "strength of incentives" parameter.<sup>4</sup> Since their work, Cournot-Nash equilibrium has been the primary solution concept for general equilibrium analysis of allocation mechanisms.

For how wide a class of decisionmaking environments is this solution concept appropriate? There are experimental situations in which violations of Cournot behavior are widespread. Brubaker (1979) received substantial voluntary contributions from subjects who were clearly told that neither the collective nor any individual would be excluded from consumption of a discrete public good because contributions were too low. Subjects making these contributions did not adopt the dominant strategy of contributing zero. Marwell and Ames (1979) asked subjects to divide endowments of tokens between private and public exchanges. The private exchange yielded a fixed dollar rate of return on any subject's investment. In addition, each subject received a prespecified fraction of the total return on all subjects' investment in the public exchange. The public exchange offered a dollar rate of return increasing in the total amount contributed (over a relevant range, then eventually decreasing, to provide an optimum distribution), but not yielding a better return than the private exchange until well past the largest individual endowment. A significant fraction

of token endowments was provided to the public exchange though any subject choosing unilaterally should have preferred to switch all his tokens to the private exchange -- this would have been Cournot behavior.

The Brubaker and Marwell-Ames results do not imply that subjects whose choices deviate from Cournot choices would maintain their behavior as they became familiar with the situation. A variety of studies has replicated the experimental economy to determine whether subject behavior alters with experience. Coppinger, Smith and Titus (1978) reported on second-price auctions where bidding one's resale value is a dominant strategy, a fact which took most subjects several iterations to discover. While the theoretical literature does not address the question, it would seem that a sensible test of the appropriateness of Cournot-Nash equilibrium would be in an iterative procedure. Subjects would be able to send messages in every iteration, with the only allocation being determined when subjects unanimously accept a message profile.

Smith (1979) conducted six experiments with an iterative procedure incorporating an incentive-compatible allocation mechanism; all experiments attained approximately Cournot-Nash equilibrium allocations.

Harstad and Marrese (1978, 1979) reported on six experiments with a mechanism identical to that in Smith's experiments and an iterative procedure which involved sequential rather than simultaneous reconsideration of messages. Only two of six experiments attained approximately Cournot-Nash equilibrium allocations.

Analysis of individual subject choices in these experiments and in Smith's comparable experiments showed that violations of Cournot behavior were observed in Smith's subjects with 50% or greater frequency, and nearly that often in the Harstad-Marrese subjects.

Perhaps Cournot behavior is too myopic to predict behavior in iterative experiments. Three characteristics of Cournot behavior which produce critical simplifications in the modeling of behavior are:

1. That the messages chosen depend only on the current messages of others, not upon their past messages.
2. That the messages chosen are solutions to a well-formulated maximization problem.
3. That each subject does not attempt to alter the behavior of other subjects for his own benefit (the non-manipulative characteristic).

In Section 2, we discuss alternative behavioral models which incorporate some of these simplifications. Section 3 presents and analyzes subject behavior during ten general equilibrium, public goods experiments in light of the Cournot model and the alternative behavior models. We conclude that after some number of iterations, nearly all subject behavior is consistent with a rough model for which all three characteristics hold. In addition, we note that the experiments attain nearly efficient allocations. The violation of Cournot behavior precludes use of the incentive-compatibility theorems to explain this extent of efficiency. Our rough model offers a partial explanation of the observed efficiency measures.

## Section 2: Alternative Behavioral Models

In all the public good experiments that are reported in section 3, Cournot behavior by all subjects in all iterations would have produced Cournot-Nash equilibrium allocations (which are Pareto-efficient subject to integer bid constraints). However, incentives for this behavior are at best unclear in an explicitly iterative experiment where only the final agreed-upon allocation affects earnings.

In particular, a subject can, by not agreeing, guarantee that the current proposal in any iteration is not adopted as the final allocation. Thus, there is no a priori reason to behave so as to maximize the earnings associated with the current proposal for any particular iteration.

If theories based on Cournot-Nash equilibrium do not explain a substantial share of behavior in iterative procedures, then it may be useful to borrow ideas from the search theory literature and from work on risk-averse behavior. Both explicitly allow for some of the uncertainty which subjects face.

Subjects in public goods experiments may not anticipate fully how much money they can reasonably expect to make. For instance, in both Smith's experiments and ours, there is anecdotal evidence that many subjects earn more than they expected. Given this uncertainty, it may be instructive to model a subject as expending time and mental effort in a search for as large a level of earnings as possible. Each period the subject obtains a possible earnings "quotation," by finding out how much he would earn if the current bid profile (we will use the terms "bid" and "message" interchangeably) is the final one. The subject then evaluates the situation, and would indicate a desire to search further by changing his bid (because only a repeated bid could reach agreement). A willingness to cease search would be indicated by repeating his bid, though whether this reaches agreement depends upon the other subjects repeating as well.

This search environment is somewhat more complex than we have seen treated in the literature. Clearly the subject can not be modeled as knowing the distribution of potential earnings he searches from, and it is even difficult to specify a sense in which the search is from the same "distribution." The level

of earnings which is attainable depends on where the experimenter has set the Pareto frontier and on what level of earnings is sufficient to induce other subjects to repeat; both of these are unknown to the subject.

Each iteration gives the subject information about these unknown parameters, which is presumably used to update the subjective probabilities of being able to obtain various monetary rewards. The determination of whether to search again or repeat, indicating acceptance, is based upon these updated subjective probabilities and the tradeoff indicated by an individual's preferences between his current level of money earnings and his current expenditure of time and mental effort. If there is a known maximum number of periods in the experiment, this will affect the perceived probabilities, as the subject will perceive a chance of zero earnings resulting from failure to reach agreement.

To the extent that this search problem as described can fit into more canonical search problems (see, for example, Harstad and Postelwaite, 1979), it is likely that reservation-earnings behavior is optimal. At any points in the experiment, there is a level of earnings below which the subject searches again, and above which the subject repeats, indicating a willingness to accept the outcome.

In particular, a bid profile with proposed earnings above reservation earnings will induce a repeated bid whether that bid is a Cournot choice or not. Also, how much more the subject could earn by a Cournot choice rather than a repeat bid is irrelevant save for its impact upon the subjective probabilities.

Finally, the subject chooses not to repeat when agreement would be associated with below-reservation earnings, even if this means avoiding a Cournot choice. This is the only model we can find which supports selecting a new bid in cases where repeating would be a Cournot choice.

In this way, Reservation behavior is to some extent manipulative; it does not take as given the current bids of others, but rather indicates that the individual will not accept the current earnings situation, and that the other subjects are expected to alter their behavior. Of course, as time is spent and the individual's perceptions are updated, the reservation earnings level may fall.

The solution concept, a reservation equilibrium, is a message profile  $m^*$  for which

$$U_i[f_i(m^*)] \geq R_i, \text{ for all } i,$$

where  $R_i$  is the reservation-earnings level of agent  $i$ . If all agents follow Reservation behavior at  $m^*$ , then each will repeat  $m_i^*$ .

Reservation equilibria are not necessarily associated with highly efficient outcomes. Clearly low reservation earnings levels early in an experiment could produce quick agreements well inside the Pareto frontier. Also, we are not aware of any method by which subjects would iteratively update their beliefs in a manner which would necessarily lead to a final allocation near the Pareto frontier.

Without knowledge of the current level of a subject's reservation earnings, it is difficult to isolate reservation behavior in observations of subject choices. The major observable occurrence suggesting reservation behavior over known alternative models is the failure to make a Cournot-repeat bid (avoid repeating, when it would be a Cournot choice).

A subject, in failing to make a Cournot-repeat bid, reveals a lower bound on his reservation earnings level which is equal to the "earnings quotation" of that iteration. When a subject repeats, he reveals an upper bound on his reservation earnings level which is equal to the "earnings quotation" of that iteration. Under the presumption that the reservation earnings level is non-increasing as iterations increase (not too implausible after a couple

of iterations), this upper bound ought to apply to all succeeding iterations, providing a test of whether this subject follows reservation behavior. Reservation behavior is violated if a subject chooses not to repeat his bid when the potential earnings associated with repeating is greater than the upper bound of the reservation earnings level.

Beyond this, the amount by which Cournot choice earnings exceed repeat earnings is not of much relevance in reservation behavior; it does not affect the decision on whether to repeat (only the absolute level of repeat earnings does). The Cournot choice earnings may affect the perceived probabilities of being able to attain various earning levels, and through these perceptions may affect the reservation earnings level. However, if this indirect affect is less substantial than the effect the Cournot choice earnings have in alternative models, then the relative value of the Cournot choice earnings statistic, and the "Cournot choice earnings minus repeat earnings" statistic in predicting behavior will be low, and the absolute level of repeat earnings will be a more useful statistic.

Another possible explanation of subjects' bidding selection is Satisficing behavior. During a particular iteration, Satisficing behavior involves repeating the bid chosen during the previous iteration (hereafter referred to as the repeat bid or choice) if the percentage difference between the potential earnings gained from a Cournot choice and the potential earnings gained from a repeat bid is less than some threshold level. Otherwise, a subject following Satisficing behavior would make a Cournot choice. This threshold percentage may change as the experiment progresses, but it does not vary with the level of earnings.

When we (Harstad-Marrese, 1979) first described this behavior as Satisficing, we thought a subject was simply not making the effort to maximize earnings, but settled for coming close. It is possible, however, that Satisficing behavior is the result of maximizing, for a particular perception of the problem a subject faces.

The subject is modeled as maximizing expected utility of earnings (and perhaps time spent) for some concave utility function (that is, the subject is risk-averse). On any iteration, the selection of a bid is viewed as a choice over lotteries, with earnings determined by whether and when all subjects choose to repeat. After some iterations, the subject comes to view a Cournot bid as riskier than a repeat bid, thus, there exists a threshold level of greater expected earnings which is the minimum the subject requires to accept the added risk.

This added risk associated with a Cournot bid stems from (a) the diminished chance of agreement in the current and next few iterations; and (b) the strategic risk of reactions by other players which could possibly diminish attainable earnings. In experiments with a known maximum number of periods, the risk associated with a diminished chance of agreement in the next few iterations (and thus effectively an increased chance that agreement is not reached within the time limit) is heightened. When no maximum experiment length is announced, the subjects will still generally expect a limit, and this risk of non-agreement may be perceived as increasing over time.

It is not uncommon for the bid pattern to become less volatile after some iterations, and a subject may perceive the experiment as having arrived on a convergent path, along which his earnings will not vary much. A Cournot bid could be viewed as carrying an increased risk of throwing the experiment off that path, and thus spreading the distribution of earnings. It may also carry an increased risk of altering the strategies of the other subjects, again associated with a possible spread of the earnings distribution. If the current level of Cournot earnings is only slightly above the current repeat earnings, it is reasonable for the subject to perceive these spreads in the earnings

distribution as involving no more than a small increase in the mean of that distribution, and thus to be unfavorable.

This situation involves complications not dealt with in the risk-aversion literature, but the similarities are enough to suggest the possibility of a maximizing model which yields Satisficing behavior as its solution.

A satisficing equilibrium is a message profile  $m^*$  for which

$$\frac{U_i [F_i (m^i)] - U_i [F_i (m^*)]}{U_i [F_i (m^*)]} < \epsilon_i, \text{ for all } i,$$

where  $m^i$  is agent  $i$ 's Cournot response to  $m_{-i}$ ,  $m^i = m^*$ , and  $\epsilon_i$  represents agent  $i$ 's risk-perception threshold. If all agents follow such Satisficing behavior at  $m^*$ , then each will repeat  $m^*$ .

If any  $m^c$  is a Cournot-Nash equilibrium, then  $m^c$  is also a Satisficing equilibrium since

$$\frac{U_i [F_i (m^i)] - U_i [F_i (m^c)]}{U_i [F_i (m^c)]} = 0, \text{ for all } i.$$

Because the set of Cournot-Nash equilibria coincide with the set of Pareto-efficient allocations, all Pareto-efficient allocations are satisficing equilibria. Furthermore, there exists a nondecreasing function  $\delta(\epsilon)$  so that any  $\hat{m}$  for which  $f(\hat{m})$  is within  $\delta(\epsilon)$  of the Pareto frontier (in allocation space) is a satisficing equilibrium with  $\epsilon_i = \epsilon$ , for all  $i$ .

Unfortunately, it is (to our knowledge) an open question to specify sufficient conditions to insure that  $\delta(\epsilon)$  converges to zero with  $\epsilon$ ; that is, to insure that no satisficing equilibria can occur "well inside" the Pareto frontier. An example suggests that the curvature of the agents' indifference surfaces is relevant to the efficiency of satisficing equilibria. Experiment 3-4, reported in the next section, reached an allocation (3, 4, 9, 5) with

the message profile (1,1,1), which included the Cournot bids for agents 2 and 3. This allocation is 77.64% efficient, considerably within the Pareto frontier. Since agent 1 repeated to earn \$6.01, when a Cournot choice of \$8.19 was available, this is not a satisficing equilibrium if  $\epsilon_1 \leq .35$ . The Groves-Ledyard "strength of incentives" parameter,  $\gamma$ , was 0.67 for the experiment. Raising  $\gamma$  to 7.0, which is similar in effect to increasing the convexity of indifference surface,<sup>6</sup> would have reduced agent i's Cournot bid earnings at  $m_1 = (1,1,1)$  to \$6.11, within 2% of the level of earnings obtained by repeating. This change in curvature makes the 77.64% efficient outcome a satisficing equilibrium with  $\epsilon = .02$ .

The three characteristics of Cournot behavior discussed in Section 1 play a major role in the underlying simplifications which are inherent in Reservation behavior and in Satisficing behavior. Both types of behavior depend only on the current messages of others, and not upon their past messages (although past messages may well alter the threshold level of earnings, an important characteristic of Reservation behavior). Also both could be motivated by a solution to a maximization problem. However, only Satisficing behavior maintains the non-manipulative characteristic of Cournot behavior.

### Section 3: Subject Behavior

We conducted nine iterative experiments in Urbana on the PLATO computer system using an integer-bid version of the general equilibrium Groves-Ledyard quadratic mechanism.<sup>7</sup> PLATO, besides providing a greater degree of standardization of experimental procedures than could be provided by human control of subject interaction, quickly handles the complicated cost share function which is an element of the Groves-Ledyard quadratic mechanism. These experiments represent the first attempt to combine two features: (1) budget balance, and (2) use of a mechanism for which there is a theorem establishing the coincidence of Cournot-Nash equilibria and Pareto-efficient allocations.

Cash payments were used to induce valuations of the public good upon subjects. The theory of induced valuation is developed in Smith (1976). Subjects typically received rewards that average well above the wages commonly paid to part-time employees, and the rewards varied considerably. We attempted to have enough additional monetary incentive available whenever a significant decision was expected of a subject. This is always an important consideration in order to avoid boredom or gaming that arises when the extra cash to be earned is slight.

Subjects consisted solely of volunteers, primarily students at the University of Illinois. On one occasion, as a check for subject population bias, nonstudent subjects were used. Results from this experiment did not appear to involve any procedural differences from the other experiments.

Each subject was placed at an isolated PLATO terminal, and proceeded through the programmed instructions at his own pace. Subjects sequentially and privately selected messages until unanimous support of an allocation was indicated by repeating messages or until an upper bound on the number of iterations was reached. If an allocation was unanimously supported, then the allocation was instituted, and subjects were paid according to the amount of the public good produced and their own private good consumption. If the upper bound on the number of iterations would have been reached (this did not occur), then earnings would have equalled zero for each subject.

All recruited subjects who showed up for a scheduled experiment were paid \$2. In addition, participants were paid their earnings in cash at the end of the experiment.

Data generated from the nine experiments has been summarized in Tables 1-4. Table 1 contains the final bid of each subject, the agreed-upon quantity of the public good, the earnings of each subject, an efficiency measure of the experiment and an indication of the procedural options that were employed. The parameters for the 3-subject trials implied the unique Cournot-Nash equilibrium, which is shown in the 1st row of Table 1. The 4-subject trials were with two Cournot-Nash equilibrium allocations, as shown in the 2nd and 3rd rows. The values of the parameters used in the 3-subject and 4-subject experiments appear in Appendix A.

The next-to-last column provides efficiency data. Experiments 3-3 and 4-1 reached Cournot-Nash equilibria, while experiments 3-5, 4-2 and 4-3 were characterized by high efficiency measures. In fact, the general level of efficiency figures suggests that public good decisionmaking procedures can be specified that are approximately Pareto-efficient.

The efficiency measure which appears in Table 1 is the coefficient of resource utilization (Debreu, 1951), which is the ratio of the minimum aggregate endowments required to achieve the observed utility levels, to actual aggregate endowments.

Another efficiency measure, which has been utilized in similar experiments, is the ratio of actual total earnings over the maximum possible earnings along the Pareto frontier (subject to integer constraints and other technical constraints). This is not a measure in allocation space of the distance from the Pareto frontier. However, since it appears in the literature, the ability

Table 1  
Experimental Results

<1>	<2>	<3>				<4>	<5>				<6>	<7>
		Subject					Facility	Subject				
# of	iter.	1	2	3	4	size	1	2	3	4	Options	
		n	n	n	n	T	\$	\$	\$	\$	Efficiency	
CN3		4	3	3		10	17.93	19.27	21.28		.99996	
CN4		2	1	1	1	5	17.80	23.35	19.47	19.47	.9945	
CN4		2	2	2	2	8	25.85	18.05	15.55	15.55	.9707	
3-1	3	1	2	2		5	10.31	20.25	17.31		.8906	0
3-2	6	3	1	2		6	12.14	19.19	21.42		.9271	1
3-3	10	4	3	3		10	17.93	19.27	21.28		.99996	1
3-4	17	1	1	1		3	6.01	18.92	11.94		.7764	1
3-5	38	4	4	2		10	19.81	20.27	14.06		.9963	2
4-1	14	2	2	2	2	8	25.85	18.05	15.55	15.55	.9707	1
4-2	10	2	2	1	2	7	26.41	21.33	10.47	18.90	.9987	1
4-3	17	3	2	2	4	11	36.75	14.01	9.49	0.00	.9709	1
4-4	24	1	1	1	1	4	17.30	22.29	17.59	17.59	.9442	1

- <1>: Experiment identifier, first digit is number of subjects. First 3 rows display the Cournot-Nash equilibrium allocations.
- <2>: Number of periods the experiment ran.
- <3>: Final bid by each subject.
- <4>: Final public good quantity.
- <5>: Earnings of each subject (excludes initial \$2).
- <6>: Efficiency (coefficient of resource utilization).
- <7>: Options (2: subjects told of 63-period maximum, 0: subjects could touch box on screen to repeat, 1: neither of these).

to capture maximum earnings measure is:

<u>experiment #</u>	<u>efficiency</u>	<u>experiment #</u>	<u>efficiency</u>
3-1	.8186	4-1	.9364
3-2	.9020	4-2	.9628
3-3	1.0000	4-3	.7523
3-4	.6288	4-4	.9336
3-5	.9258		

The correlation coefficient between the two efficiency measures is .8278.

Table 2 gives an indication of the extent to which individual subject behavior can be explained by a variety of categorizations, most of which were introduced by Ledyard (1978), in his examination of individual subject data from Smith's Groves-Ledyard experiments. The table states that 11 of the 31 subjects made Cournot choices for over 80% of the occasions when they reconsidered their messages. "Partial Cournot" choices are messages intermediate between a repeated message and a Cournot message, and might possibly be chosen in a belief that a sizeable change required for a Cournot choice would destabilize the process. These categories, together with Unexplained choices, are defined to be mutually exclusive.

Satisficing, developed in Section 2, as benchmarked in Harstad and Marrese (1978), consists of repeating the previous message if repeating would yield at least 95% of the earnings associated with the Cournot message, and otherwise choosing the Cournot message.

Finally, Cost-Minimizing choices result from selecting the integer approximation to the average of the messages of others and might reflect unexplained preferences, a misunderstanding of the instructions, or a simplistic notion

Table 2  
Subject Adherence to Choice Classifications

<u>Frequency</u>	<u>C</u>	<u>R</u>	<u>P</u>	<u>S</u>	<u>M</u>	<u>U</u>
0-19%	5	20	28	4	7	19
20-39%	3	4	3	2	2	7
40-59%	8	4	0	8	6	4
60-79%	4	1	0	6	8	1
80-100%	11	2	0	11	8	0

Entries are number of subjects who exhibited classified behavior as abbreviated with listed frequency. Abbreviations:

C: Cournot choice

R: Repeated choice (not C)

P: "Partial Cournot" choice

S: Satisficing choice

M: Cost-Minimizing choice

U: Unexplained choice

of indicating agreement with the others.<sup>8</sup>

Cournot behavior is far from being the whole story in this data; it accounts for over 80% of the choices of only 1/3 of the subjects, and for over 60% of choices for only 1/2. Satisficing performs only somewhat better, with still frequent violations.

Table 3 contains information concerning the number of consecutive concluding Satisficing choices. Section 1 presented three characteristics of Cournot behavior are presented which simplify an individual's decision-making process. It may be that subjects adopt these characteristics only after a period of trial and error with other strategies. For instance, behavior which depends on the past messages of others, the perceived reactions of past messages of others to the subject's own past message, the current messages of others, and expectations of the future messages of others conditional on the subject's current message, may initially seem quite appealing to a subject. However, after a number of iterations the subject may become frustrated or exhausted in his attempt to integrate these

Table 3

Consecutive Satisficing Choices

Each entry below represents one subject

Columns are classified by  $100\% \cdot \frac{A}{C}$

Entries appear as (A,B,C) where

A = number of consecutive Satisficing choices at the end of the experiment

B = total number of Satisficing choices

C = total number of choices

<u>0%</u>	<u>7% - 33%</u>	<u>40% - 55%</u>	<u>75% - 100%</u>
			(6,6,6)
			(4,4,4)
			(3,3,4)
			(3,3,3)
			(3,3,3)
		(7,9,13)	(3,3,3)
		(4,4,6)	(3,3,3)
(0,3,12)		(2,2,5)	(3,3,3)
(0,0,6)		(2,3,4)	(3,3,3)
(0,0,5)	(2,5,6)	(1,1,2)	(1,1,1)
(0,1,2)	(1,8,14)	(1,1,2)	(1,1,1)
(0,0,2)	(1,4,6)	(1,1,2)	(1,1,1)
(0,0,1)	(1,2,5)	(1,1,2)	(1,1,1)

considerations. Over time he may adopted the simplification of basing his choice on the current messages of others and on some consideration of the riskiness of not repeating. Such a simplification may lead to Satisficing behavior. We take the point at which a subject begins a consecutive string of Satisficing choices at the end of the experiment as an indication of when an individual may have adopted Satisficing behavior.

The 13 subjects represented in the right-most column are clearly consistent with Satisficing. However, the strongest indication of a change to Satisficing behavior during the experiment comes from the first 3 of the 8 subjects in the third column. Suppose as a null hypothesis, that, given the overall frequency of Satisficing behavior for any particular subject, any ordering of Satisficing and non-Satisficing choices was equally likely to be observed. Under that hypothesis, the probabilities of observing as long a consecutive concluding sequence of Satisficing choices for these 3 individuals are  $3/143$ ,  $1/15$ , and  $1/10$ , respectively. There are ten other subjects for whom this probability is less than or equal to one-half. To this extent, the evidence suggests that, for the amount of Satisficing behavior observed, Satisficing choices were disproportionately frequent toward the end of the experiments.

It is difficult to summarize the data in a manner which clearly illustrates the role of Reservation behavior. Table 4 presents the iteration during which each behavioral type, including Reservation behavior, was first rejected for the 31 subjects of our nine experiments. The entry N in Table 4 indicates that a particular strategy was never rejected by

Table 4

Time of Strategy Rejection

ID = code specifying the number of people in the experiment, the experiment number, and the subject under consideration

# = total number of choices made by each subject

C = iteration during which Cournot behavior was first rejected

R = iteration during which Repeat behavior was first rejected

PC = iteration during which Partial Cournot behavior was first rejected

S = iteration during which Satisficing behavior was first rejected

Res = (a,b) where a is the iteration during which the upper bound was revealed and b is the iteration during which the upper bound was violated

<u>ID</u>	<u>#</u>	<u>C</u>	<u>R</u>	<u>PC</u>	<u>S</u>	<u>Res</u>
3-1-1	1	1	N	1	1	N
3-1-2	1	N	N	1	N	N
3-1-3	1	N	N	1	N	N
3-2-1	2	1	1	2	1	N
3-2-2	2	1	N	1	1	N
3-2-3	2	1	1	1	1	N
3-3-1	4	2	1	1	3	(2,3)
3-3-2	3	N	1	1	2	N
3-3-3	3	N	1	1	1	N
3-4-1	6	1	1	1	1	N
3-4-2	6	2	2	1	2	(1,2)
3-4-3	5	1	1	1	1	N
3-5-1	13	3	1	1	3	(8,9)
3-5-2	14	2	1	1	1	(3,5)
3-5-3	12	1	2	1	1	(1,2)
4-1-1	4	1	1	1	1	N
4-1-2	4	2	2	1	2	N
4-1-3	3	N	1	1	N	N
4-1-4	3	N	1	1	N	N
4-2-1	3	N	1	1	N	N
4-2-2	3	N	2	2	2	N
4-2-3	2	2	N	2	2	N
4-2-4	2	1	1	1	1	N
4-3-1	5	1	1	3	1	N
4-3-2	4	3	2	2	2	N
4-3-3	4	4	1	1	4	N
4-3-4	4	1	1	1	1	N
4-4-1	5	1	1	3	1	N
4-4-2	6	4	1	1	4	(2,3)
4-4-3	6	N	1	1	1	N
4-4-4	6	1	1	1	1	N

the subject under consideration. Reservation behavior is rejected at some time during the experiment for only 6 of 31 subjects, whereas Cournot behavior is rejected for 22 subjects and Satisficing behavior for 26 subjects.<sup>9</sup> Given that our criteria for rejection of Reservation behavior allows for a wide range of message selection, we can only conclude that Reservation behavior may be an important element in understanding subject choices during public good decisionmaking experiments.

One approach to the analysis of Reservation behavior is to determine how much it adds to behavior unexplained by the other message strategies. On the negative side, the Reservation model adds nothing to "adequate" explanations of the behavior of 12 subjects, but only 2 of these explicitly violated the Reservation model. In addition, one subject apparently believed that the object of the experiment was to make exactly zero earnings -- not an attractive example of Reservation behavior. Still another person selected four completely inexplicable bids, then his last two bids were Cournot. Nonetheless, he did not violate the Reservation model. Finally, a third person's bids were only consistent with Reservation behavior and a sharp drop in the reservation earnings level.

On the positive side, there were 6 subjects who made early choices that we can only explain with Reservation behavior and who never rejected Reservation behavior. Among these subjects, 3 consistently selected Satisficing choices at the end of the experiment and 3 reached agreement rather quickly. Then there were 10 subjects who made early choices that we can only explain by reference to Reservation behavior, but who later were somewhat inconsistent with Reservation behavior (4 explicitly violated the model and 6 required a sharp drop in the reservation earnings level to remain consistent throughout

the experiment). Most of these 10 subjects followed Satisficing behavior at the end of the experiment. So Reservation behavior during the early stages of an experiment coupled with Satisficing behavior from then on seems to give rise to the most complete explanation of subject behavior we have uncovered so far.

This explanation of behavior is consistent with the observance of generally high efficiency levels in the experiments. A few individual subjects who did not regularly follow Satisficing behavior are apparently the cause of the couple cases of somewhat lower efficiency; hence, these are not examples of inefficient satisficing equilibria. Nonetheless, an understanding of the circumstances under which non-negligibly inefficient satisficing equilibria can occur, and how likely they are to be observed in decisionmaking environments, would carry the explanation a substantial step further.

APPENDIX A

Using the notation developed in section L, the parameters for the  
(1) 3-person experiments with (4,3,3) as the Nash equilibrium are:

$$\begin{aligned} U_1(y_0, y_1) &= 2.00 y_0^{.96} y_1^{.24} - 2 & \text{where} & & w_1 &= 5 \\ U_2(y_0, y_2) &= 1.95 y_0^{.24} y_2^{.96} - 2 & \text{where} & & w_2 &= 10 \\ U_3(y_0, y_3) &= 1.70 y_0^{.80} y_3^{.80} - 3 & \text{where} & & w_3 &= 6 \end{aligned}$$

A feel for the strength of incentives at the Nash equilibrium may be obtained by examining the payoffs at the equilibrium and at surrounding points. Let  $U_i | m$  be the utility of individual  $i$  at the message profile  $m$ .

$$\begin{array}{lll} U_1 | (4,3,3) = 17.93 & U_2 | (4,3,3) = 19.27 & U_3 | (4,3,3) = 21.28 \\ U_1 | (5,3,3) = 14.53 & U_2 | (4,3,3) = 18.74 & U_3 | (4,3,4) = 20.66 \\ U_1 | (3,3,3) = 17.47 & U_2 | (4,2,3) = 18.43 & U_3 | (4,3,2) = 18.63 \end{array}$$

Cost share parameters:  $\gamma=0.67$ , unit cost of the public good = 2

(2) 4-person experiments with (2,2,2,2) as the Nash equilibrium are:

$$\begin{aligned} U_1(y_0, y_1) &= 7.35 y_0^{.72} y_1^{.18} - 7 & \text{where} & & w_1 &= 5 \\ U_2(y_0, y_2) &= 7.35 y_0^{.18} y_2^{.72} - 16 & \text{where} & & w_2 &= 9 \\ U_3(y_0, y_3) &= 7.35 y_0^{.39} y_3^{.51} - 8 & \text{where} & & w_3 &= 6 \\ U_4(y_0, y_4) &= 7.35 y_0^{.39} y_4^{.51} - 8 & \text{where} & & w_4 &= 6 \end{aligned}$$

(3) 4-person experiments with (2,1,1,1) as the Nash equilibrium are:  
the same utility functions, initial endowments, and cost share  
parameters as (2); however, the strength of parameters is  
evaluated around a different Nash equilibrium.

$U_1   (2,1,1,1) = 17.80$	$U_2   (2,1,1,1) = 23.35$	$U_3   (2,1,1,1) = 19.47$	$U_4   (2,1,1,1) = 19.47$
$U_1   (3,1,1,1) = 0.00$	$U_2   (2,2,1,1) = 20.87$	$U_3   (2,1,2,1) = 17.89$	$U_4   (2,1,1,2) = 17.89$
$U_1   (1,1,1,1) = 17.30$	$U_2   (2,0,1,1) = 16.19$	$U_3   (2,1,0,1) = 12.14$	$U_4   (2,1,1,0) = 12.14$

Footnotes

- 1 See Samuelson (1954).
- 2 The term marginal evaluation may be defined as the corresponding public good support price of the hyperplane tangent to an indifference curve, or equivalently as the ratio of marginal utility of public good consumption to marginal utility of income.
- 3 Precisely, this means that there exists an allocation which Pareto-dominates the allocation resulting from the decentralized procedure, such that the Pareto-dominant allocation contains a higher level of public good production.
- 4 The outcome function for the Groves-Ledyard Mechanism is  $f(m) = [ \sum_j m_j, w_i - c_i(m), \dots, w_I - c_I(m) ]$ .

Agent  $i$ 's share of total public good production cost is

$$c_i(m) = \frac{q}{I} \sum_j m_j + \frac{\gamma}{2} \rho_i,$$

$$\text{where } \rho_i = \left[ \frac{I-1}{I} \right] (m_i - \mu_i)^2 - \sigma_i,$$

$$\mu_i = \left[ \frac{1}{I-1} \right]_{j \neq i} \sum m_j,$$

$$\sigma_i = \alpha(I) \sum_{j \neq i} \sum_{k \neq i} (m_j - m_k)^2 \quad \text{and}$$

$$\alpha(I) = 2 \left[ (I-1) (I-2) \right]^{-1}.$$

$q$  is the unit cost of the public good and  $\gamma$  is the

"strength of incentives" parameter.

- 5 Earnings are the basis of the reward structure which connects an explicitly known preference ordering to a participant's primitive preference ordering.

Footnes (cont'd.)

- 6 The cost-share formula (see footnote 4) includes in  $\rho_i$ , the squared deviation of an individual's message from the mean of the messages of others. Increasing the impact of  $\rho_i$  by increasing  $\gamma$  is analogous to decreasing agent  $i$ 's marginal rate of substitution at a faster rate. For Cobb-Douglas utility functions (as in the example and the experiments in section 3),

$$\frac{\partial}{\partial \gamma} \left[ \frac{\partial \left( \frac{\partial y_o}{\partial y_i} \mid \bar{u}_i \right)}{\partial y_i} \right] > 0.$$

- 7 In addition, we conducted a 3-person experiment prior to the nine reported. This experiment must be regarded as a pilot experiment, because we discovered an error in the computerized calculation of the cost shares. The error makes analysis of the final allocations and efficiency figures meaningless for the pilot experiment. Individual choices, however, may be analyzed in terms of the opportunities the subjects actually faced, and these data--which are limited by only 4 iterations in the pilot experiment--are mentioned in succeeding footnotes.
- 8 The four choices by the subjects in the pilot experiment were all Cournot choices. (Of course, the last 3 were also repeats.)
- 9 The analogously categorized time of strategy rejection data for the pilot experiment are:

	<u>#</u>	<u>C</u>	<u>R</u>	<u>PC</u>	<u>S</u>	<u>Res</u>
1	2	N	1	1	N	N
2	1	N	N	1	N	N
3	1	N	N	1	N	N

The experiment was too short to provide any useful data on Satisficing or Reservation behavior.

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