BEHAVIORAL EXPLANATIONS OF EFFICIENT PUBLIC GOOD ALLOCATIONS

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Theorists have studied decentralized allocation mechanisms by characterizing the Cournot-Nash equilibria of the mechanism. However, when a mechanism is operationalized by an iterative decision process, and agents derive utility only from the final outcome, Cournot behavior may not be an appropriate solution concept. We suggest two alternative behavioral models, reservation behavior and satisficing behavior, which recognize the impact of the iterative process upon incentives, yet maintain some of the critical simplifications that have made Cournot behavior an attractive model.

We report on nine public good experiments with a Groves-Ledyard general equilibrium mechanism. Overall, the experiments attain highly efficient allocations, despite widespread violations of Cournot behavior. We suggest the explanation that most subjects initially followed reservation behavior, and then came to adopt satisficing behavior.

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. A public good has a value to any one consumer which does not diminish as additional consumers utilize it; exclusion of non-contributors is typically costly or technologically impossible. Decentralized decision procedures depend upon being able to infer an individual's marginal evaluation of the public good from the per unit cost share he voluntarily announces. Suppose cost shares are collected as a means of obtaining resources for public good production. The individual

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then faces a conflict between correctly revealing his marginal evaluation and
equing 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.2

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

An allocation is determined from information provided by all agents.
Messages transmitting information are necessary because the allocation
achieved cannot directly depend upon \((U_1, \ldots, U_I)\), which are unobservable.
So agent \(i\) is modeled as selecting a message \(m_i\) in \(M\), a set of feasible
messages, with a message profile \(m = (m_1, \ldots, m_I)\) in \(M^I = \times_{i=1}^I M\). Each \(m\)
determines an outcome, an allocation in \(Y\), based upon a particular rule.
Specifically, the relationship between message profiles \(m\) and allocations \(y\) is
summarized by an outcome function \(f(\cdot): M^I \rightarrow Y\). Let \((y_0, y_i) = f(m)\) denote a
component function of \(f\), indicating how much public good and private good
is allocated to agent \(i\). Agent \(i\), in selecting \(m_i\), has complete knowledge of the
outcome function. The theoretical literature labels the pair \((M^I, f)\) an
allocation mechanism.3

The solution concepts that are generally employed with allocation
mechanisms are Cournot–Nash equilibrium and dominant strategy
equilibrium. For any profile \(m\) in \(M^I\), let \(A_i(m) = \{m \in M^I | m_j = \hat{m}_j\}
for all \(j \neq i\}\), the set of message profiles which result from agent \(i\) changing unilaterally
from \(\hat{m}\). Given \(\hat{m}\), \(\hat{m}_i\) is \(i\)'s Cournot message if \(U_i[f(\hat{m})] \geq U_i[f(m)]\) for all \(m\)
in \(A_i(\hat{m})\). \(\hat{m}\) is a Cournot–Nash equilibrium if \(\hat{m}\) is a Cournot message for
each \(i = 1, \ldots, I\); thus, no agent can gain utility by changing unilaterally.

\(\hat{m}\) in \(M^I\) is a dominant strategy equilibrium if \(U_i[f(\hat{m})] \geq U_i[f(m)]\) for all \(m\)
in \(M^I, i = 1, \ldots, I\). Since each agent’s equilibrium message is an optimal
response to any message profile, a dominant strategy equilibrium does not
require coordination to the extent a Cournot–Nash equilibrium does.

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

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2Precisely, 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.

3See Groves (1979) for a discussion of major results.
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. 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, 1980) 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, their
instructions implied that each subject received a prespecified fraction of the
total return on all subjects' investment in the public exchange. The total

4 The outcome function for the Groves–Ledyard mechanism is \( f(m) = \left( \sum_i m_i - w_i - c_i(m) \right)^2 \). Agent i's share of total public good production cost is

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

where

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

\[ \mu_i = \frac{1}{I-1} \sum m_i, \]

\[ \sigma_i = \alpha(l) \sum_{j \neq i} (m_j - m_i)^2, \]

and

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

\( q \) is the unit cost of the public good and \( \gamma \) is the 'strength' of incentives' parameter.
return did not increase directly with an individual’s contribution to the
public exchange because the total return was specified as a step function,
with the distance between steps much larger than any individual’s entire
endowment of tokens. A significant fraction of token endowments was
provided to the public exchange though any subject choosing unilaterally
should have preferred, in most cases, to switch all his tokens to the private
exchange — that would have been a subject’s dominant strategy in 96.9
percent of the possible message profiles.

These results do not imply that subjects whose messages deviate from
Cournot messages would maintain their behavior as they became familiar
with the situation, although one group of Marwell–Ames subjects did show
similar behavior when participating a second time (after an unspecified
delay). 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 six
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.

Harstad and Marrese (1981) reported on twelve experiments with a partial
equilibrium, incentive compatible mechanism. Six trials employed an iterative
procedure which involved simultaneous reconsideration of messages, and six
used sequential reconsideration. Only three of the twelve experiments
attained approximately Cournot–Nash equilibrium outcomes. Analysis of
individual subject choices in these experiments and in other comparable
experiments showed that violations of Cournot behavior, namely consistently
selecting Cournot messages, were observed with 50 percent or greater
frequency across subjects.

Despite this experimental evidence, many economists have not abandoned
models based on Cournot behavior. In large part we attribute the
attractiveness of Cournot behavior to three characteristics which produce
critical simplifications in the modeling of behavior.

(1) That the messages chosen depend only on the current messages of
others, not upon the past messages.

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5Smith (1979) conducted six earlier experiments with simultaneous reconsideration. His
experiments were designed to incorporate a partial equilibrium, incentive compatible allocation
mechanism, but subjects’ cost shares were incorrectly calculated away from equilibrium. Because
of this, it is difficult to interpret the conclusion that Smith’s experimental environment yields
approximately Cournot–Nash equilibrium outcomes.

6Ledyard (1972) also found 50 percent and greater frequencies of violations of Cournot
behavior in analyzing data drawn from Smith (1979).
(2) That the messages chosen are solutions to a well-formulated maximization problem.

(3) That each subject does not attempt to manipulate the behavior of other subjects for his own benefit.

In section 2 we discuss alternative behavioral models which incorporate some of these simplifications. Section 3 presents and analyzes subject behavior during nine general equilibrium, public goods experiments in light of the Cournot model and the alternative behavioral models. The isolation of subjects at separate PLATO computer terminals, and the programmed control over information transmittal in these experiments, effectively blocked any possibility of cooperation among subjects; this allowed us to limit our search for behavioral models to a noncooperative game theory context. 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. Widespread violations of Cournot behavior preclude use of the incentive-compatibility theorems to explain this extent of efficiency; our rough model offers a partial explanation of the observed efficiency measures.

2. Alternative behavioral models

To observe behavior when subjects have an opportunity to become familiar with their economic environment, the experiments reported below involve iterative message transmittal until all subjects agree upon an allocation. Cournot behavior by all subjects throughout would produce Cournot–Nash equilibrium allocations (which are Pareto-efficient given that messages must take integer values). However, incentives for Cournot behavior on any particular iteration are at best unclear; a subject can, by not agreeing, guarantee that the current proposal in any iteration is not adopted as an 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 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 many economic experiments, ours included, 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 perhaps mental effort, in a search for as large a level of earnings as possible.
A subject begins the experiment with a prior subjective probability distribution over the set of possible earnings. Each iteration, the subject spends one unit of time, and observes a proposed earnings level, the amount of money he would earn if all subjects agree to the current message profile. The subject uses this proposed earnings level to update, according to Bayes' Rule, his prior distribution over earnings. He then evaluates investing additional time for uncertain additional earnings prospects, considering his updated beliefs, the time spent so far, and the current level of earnings. This evaluation leads either to the conclusion that ceasing search is acceptable, or that continued search is desirable. If ceasing search is acceptable, he agrees to the current proposal; he indicates the desirability of continuing search by rejecting it. The experiment continues unless all subjects agree to the current proposal, implying that a subject cannot individuate determine when the search ends.

As outlined, this search problem is a special case of that analyzed in Harstad and Postlewaite (1981). Under their assumptions, the optimal search strategy exhibits the reservation-price property: a subject who, searching optimally, would accept a proposal yielding earnings of \( x \), would also accept any proposal yielding \( y \geq x \), given the same history of proposals during the previous iterations. Thus, his critical decision variable at any iteration is a reservation earnings level, which is a function of his beliefs, his preferences, and the history of proposals to date. Furthermore, after some initial time for familiarization, the reservation earnings level is likely to decrease over time.

In the experiments reported below, once subjects had become accustomed to the mechanics of submitting messages, there was very little variation in the amount of time one iteration consumed. At any time rate, from a theoretical standpoint, the presumption that the time consumed by one iteration is a known constant can be made without loss of generality.

The first of two assumptions is mild. Consider any earnings level \( x_0 \) and any increment in earnings \( d > 0 \). The following is assumed about a subject's own trade-off between money \( x \) and time spent \( t \), as indicated by his indirect utility function \( V(x, t) \) (not observable to the experimenter): \( V(x_0 + d, t_1) - V(x_0, t_1) \geq V(x_0, t_2) - V(x_0, t_1) \) for any \( t_1, t_2 \) where \( t_1 \leq t_2 \). That is, the added utility value of extra money earned does not increase with time spent in the experiment.

Searching from an unknown distribution is an intractable theoretical problem unless the search's prior probability beliefs are distributed Dirichlet. Suppose the earnings quotation a searcher observes at some iteration is \( x_1 \). In essence, to assume a Dirichlet distribution is to assume that the subject updates his beliefs by regarding \( x_1 \) as more likely, and equiproportionately lowering all other probability assessments, thus leaving the relative perceived probability unchanged for any two earnings levels \( x_2 \) and \( x_3 \) which he did not observe this iteration.

All searchers come with sufficient sampling to form a Dirichlet-distributed prior, but applying the Harstad–Postlewaite theorem requires assuming the distribution early in a subject's search. There is a paucity of stimuli available as a basis for updating beliefs; the Dirichlet would appear to be a likely candidate for an approximation to a subject's actual (but unobservable) prior distribution.

Suppose the subject comes to perceive the distribution from which earnings level quotations are drawn as being less spread (or less 'risky') than what he perceived earlier, before he had obtained sample earnings quotes. Then his reservation earnings level will not increase over time [Harstad and Postlewaite (1981, Proposition 4)].
Agreement during any iteration is operationalized by having all subjects repeat the previous iteration's messages. In particular, when a proposal is initially sent to a subject, the associated earnings reported to him are calculated from others' current messages and his own previous message. Thus, reservation behavior implies that a message profile with proposed earnings above reservation earnings will induce a repeat message whether that message is Cournot or not. Also, how much more the subject could earn by a Cournot message rather than repeating is irrelevant save for its impact upon the subjective probabilities.

Finally, the subject chooses not to repeat whenever a proposed allocation would yield below-reservation earnings, even if this means avoiding a Cournot message. Given that altruistic considerations are inapplicable to our experimental environment, this is the only model we can find which supports selecting another message in cases where repeating would be Cournot.10

In this way, reservation behavior is to some extent manipulative; it does not take as given the current messages 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

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

where \( R_i \) is the reservation earnings level of agent \( i \). If all agents follow reservation behavior at \( m^* \), then each will repeat \( m^* \).

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 other

10 In the experiments reported here, subjects are isolated at separate PLATO computer terminals, and only receive information on the aggregate of others' messages, not on other individuals' choices or utility functions. The Groves-Ledyard mechanism does not have individuals directly making contributions to public good production; individual cost shares are determined by the opaque formula in footnote 4. Thus, a subject seeing an opportunity to gain utility by moving from message \( m \) to \( m' \) does not have sufficient information to distinguish between circumstances in which other subjects also gain by moving to \( m' \), and circumstances in which his gain is at the others' expense. For these reasons a subject who attempted to incorporate altruistic, or any other nonindividualistic concerns into his decisionmaking would not find the information available which would allow these concerns to affect his behavior.
behavioral models we discuss is the failure to select a Cournot-repeat message.

From a subject's avoidance of a Cournot-repeat message, the experimenter may infer the current earnings proposal to be a lower bound on his reservation earnings level. From a repeat message, the experimenter may infer the subject's current earnings proposal to be an upper bound on his reservation level. The upper bound, once established, supplies a test of reservation behavior: a subject violates this model if he chooses not to repeat his previous message when the earnings associated with repeating exceed this upper bound.

Another possible explanation of subjects' message selection is satisficing behavior. During a particular iteration, satisficing behavior is defined as (a) selecting the Cournot message when repeating the previous message is Cournot, (b) selecting the Cournot message when the earnings associated with repeating (given the others' current messages) are less than some threshold percentage of the earnings associated with the Cournot message, and (c) repeating the previous message when the earnings associated with repeating are at least this threshold percentage of the earnings associated with the Cournot message. This threshold percentage may change as the experiment progresses, but it does not vary with the level of earnings.

Satisficing behavior also arises from maximization, at least for a particular perception of the problem a subject faces. The subject is modeled as maximizing expected utility of earnings and time spent for some concave utility function (indicating risk aversion). During any iteration, the selection among alternative messages is viewed as a choice among alternative lotteries. The subject associates with each message a probability distribution, \( \Pr(\text{earnings} \geq x, \text{agreement occurs by iteration } t) \), over earnings levels, and the iterations required to extract an agreement yielding that earnings. After some iterations, this model assumes that each subject comes to view every nonrepeat message as riskier than the repeat message. The added risk associated with a nonrepeat message stems from (a) the zero chance of agreement in the current iteration and the diminished chance in the next few, and (b) the strategic risk of detrimental reactions by other subjects.\(^{11}\) To accept the added risk, that is, to select a nonrepeat message, the subject requires at least some threshold level of added earnings (excess of expected earnings, given this nonrepeat message, over earnings expected, given a repeat). Whenever this threshold is breached, the subject does not repeat. If his subjective assessment assigns considerable weight to the earnings associated with the current messages of others, then the nonrepeat message he selects will be Cournot.

\(^{11}\)A subject may perceive the experiment as having arrived on a convergent path, along which his earnings will not vary much. A nonrepeat message could be viewed as carrying an increased risk of throwing the experiment off the path, and thus spreading the distribution of earnings.
A satisficing equilibrium is a message profile \( m^* \) for which

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

where \( f(\cdot) \) is the \( i \)th component of the outcome function, \( m' = (m'_1, \ldots, m'_j, \ldots, m'_{i-1}, m'_i, m'_j, \ldots, m'_n) \) for all \( j \neq i \), \( m'_i \) is subject \( i \)'s Cournot message given \( m^* \), and \( \epsilon_i > 0 \) is \( i \)'s risk threshold. If all subjects follow satisficing behavior at \( m^* \), each will repeat \( m^* \).

If \( m' \) is a Cournot–Nash equilibrium, then \( m' \) is also a satisficing equilibrium, because

\[
\frac{U_i[f(m')] - U_i[f(m^*)]}{U_i[f(m^*)]} = 0, \quad \text{for all } i.
\]

Because the set of Cournot–Nash equilibria coincide with the set of Pareto-efficient allocations, all Pareto-efficient allocations are satisficing equilibria. However, any allocation, no matter how far inside the Pareto frontier, is a satisficing equilibrium for some cardinalizations of the subjects' utility functions. For that profile of cardinalizations which represents the actual risk postures of some group of subjects, and a particular \( \epsilon = (\epsilon_1, \ldots, \epsilon_I) \), one can define an area bordering the Pareto frontier within which every allocation is a satisficing equilibrium. Unfortunately, it remains an open question to specify conditions sufficient to ensure that no allocation further from the Pareto frontier than this border can be a satisficing equilibrium.

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 can be motivated as a solution to a maximization problem. However, only satisficing behavior maintains the nonmanipulative characteristic of Cournot behavior.

3. Subject behavior

We conducted nine iterative experiments in Urbana on the PLATO computer system, using a integer-bid version of the general equilibrium Groves–Ledyard quadratic mechanism.\(^{12}\) PLATO provides a greater degree

\(^{12}\)In addition, we conducted a three-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. The individual behavior of all three subjects in the pilot experiment was identical to that of subject 3-1-2 described in table 2.
of standardization of experimental procedures than could be provided by human control of subject interaction and quickly evaluates the complicated cost share function which is an element of this 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.\(^13\) We attempted to have enough additional monetary incentive available whenever a significant decision was expected of a subject.\(^14\) 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 of 31 volunteers, primarily students at the University of Illinois. On one occasion, as a check for subject population bias, nonstudent subjects were recruited on campus. Results from this experiment did not appear to involve any procedural differences from the other experiments.

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.

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.

Data generated from the nine experiments has been summarized in tables 1 and 2. Table 1 indicates how many iterations each experiment had, and lists each subject’s final message, and the agreed-upon quantity of the public good. When \(\sum MRS/MRT > 1\) (column (5)), the allocation attained is Pareto-dominated by another allocation with a greater public good quantity; for \(\sum MRS/MRT < 1\), Pareto improvements require a reduction in public good output. The efficiency measure (column (6)) 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. Finally, under heading (7) each subject’s earnings are reported.

\(^{13}\)Reported in table 1, under heading (7).
\(^{14}\)Details are in the appendix, discussed as 'strength of incentives'.
Table 1
Summary of results.

<table>
<thead>
<tr>
<th>(1) Number of iterations</th>
<th>(2) Final message (1 2 3 4)</th>
<th>(3) MRS Facility size</th>
<th>(4) Efficiency</th>
<th>(5) Subject 1</th>
<th>(6) Subject 2</th>
<th>(7) Subject 3</th>
<th>(8) Subject 4</th>
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<tbody>
<tr>
<td>CN3</td>
<td>4 3 3 10</td>
<td>1.026</td>
<td>0.99996</td>
<td>17.93</td>
<td>19.27</td>
<td>21.28</td>
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<td>17.50</td>
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<td>0.520</td>
<td>0.9707</td>
<td>25.85</td>
<td>18.05</td>
<td>15.55</td>
<td>15.55</td>
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<tr>
<td>3-1</td>
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<td>0.99996</td>
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<td>17.59</td>
</tr>
</tbody>
</table>

Column headings

(1): Identifier: first three rows display the Cournot-Nash equilibrium allocations, the others experimental results. For the latter, the first digit is the number of subjects.
(2): Number of iterations needed to reach an allocation.
(3): Final message of each subject.
(4): Final public good quantity.
(5): Indicates underproduction (>1) or overproduction (<1) of the public good.
(6): Efficiency (coefficient of resource utilization).
(7): Earnings of each subject (excludes initial $2).
*Subjects could repeat simply by touching 'repeat' box on screen.
*The 63-iteration limit was announced to subjects, in instructions.

The parameters for the three-subject trials yielded the unique Cournot-Nash equilibrium which is shown in row 1 of table 1. The four-subject trials exhibited two Cournot-Nash equilibrium allocations, which are shown in rows 2 and 3. The parameters values used in the experiments are reported in the appendix.

Experiments 3-3 and 4-1 reach Cournot-Nash equilibria, while experiments 3-5, 4-2 and 4-3 were characterized by high efficiency measures. In general, the level of efficiency figures suggests that public good decisionmaking procedures can be specified that are approximately Pareto-efficient, at least for economies with a small number of agents and technological barriers to cooperation.

These allocative results are a pleasing development; however, our principal concern is microanalysis of subject behavior during the allocation-reaching process. Why? An important way to test whether a solution concept is valid for a particular class of allocation settings is to measure the extent to which individual subject behavior supports that solution concept. For example, a
subject who follows Cournot behavior will repeat at any Cournot–Nash equilibrium — supporting that allocation — and will not repeat whenever the repeat message is not Cournot. (If all subjects follow Cournot behavior, it is impossible to agree to any allocation but a Cournot–Nash equilibrium.) Because an individual does not know when all other subjects will repeat, anytime he has an opportunity to select a Cournot-repeat message, he faces a situation indistinguishable from Cournot–Nash equilibrium. Thus, several observations testing support for Cournot–Nash equilibrium, or for other solution concepts, are typically available in each subject's choices during an experiment. Moreover, Cournot behavior by all subjects is essential for stability theorems on Cournot–Nash equilibrium to be applicable.

In broad overview, our analysis of individual behavior concludes, first, that Cournot messages were selected with an overall frequency of about 50 percent, and satisficing messages approximately as often. Secondly, an explanation that subjects followed reservation behavior initially and satisficing behavior after some point in the experiment is consistent with roughly four-fifths of the observations; an explanation relying upon a combination of reservation behavior and then Cournot behavior fares nearly as well. Finally, we note some support for preferring satisficing behavior to Cournot behavior as an explanation of choices near the end of experiments.

First of all, each subject's messages for all iterations can be categorized by reporting the frequencies with which they were Cournot, satisficing, and repeat messages. These categories overlap, and disentangling them requires the five columns in the middle of table 2. Regular typeface indicates that the column beneath is consistent with the classification; boldface indicates that the classification is violated with the frequencies shown beneath. For example, the column beneath CSR contains the percentages of each subject's message that were Cournot, but neither satisficing nor a repeat.

Nonrepeat messages which were neither Cournot or satisficing are further disaggregated in the three rightmost columns of table 2. If a subject avoided the Cournot-repeat message to choose a nonrepeat message, this is listed in the first of the three columns, headed AVD; it is seemingly the strongest indication of reservation behavior that can be observed in a single message. In the next column are messages that move partway (P) from the repeat message toward the Cournot choice; possibly a subject avoids the Cournot message when it would be a large change from the repeat message because he perceives such a large change as potentially destabilizing. The last column is the residual. To land here, a subject's message must move from the repeat message in the direction away from the Cournot choice, or must overshoot the Cournot choice; hence the last column was labeled 'unexplained' (U).

For example, subject 4–4–2, who drew the second subject parameters in the last experiment selected six messages in all; three (50 percent) were Cournot-repeat messages (thus consistent with satisficing), one (17 percent) was a
Table 2
Classification of subject messages.

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<th>CSR</th>
<th>CSR</th>
<th>CSR</th>
<th>CSR</th>
<th>CSR</th>
<th>AVD</th>
<th>P</th>
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<td>13.0</td>
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</table>

*The first two digits identify which experiment, the last which subject. Total identifies the row describing the messages of all subjects.

*Number of messages selected by the subject.

*C if Cournot, C if not; S if satisficing, S if not; R if repeat, R if not; AVD if a Cournot repeat was avoided; P if Payday, a strict convex combination of C and R messages; U if unexplained, outside the convex hull of C and R.

Reassembling frequency of messages consistent with Cournot behavior requires summing percentages in the first three columns; satisficing choices
show up in the second, third and fourth columns. Summing in this way, table 2 shows that of all messages in all iterations, 50.6 percent were consistent with Cournot behavior and 48.5 percent were satisficing.

These aggregate frequencies reflect a pattern which can be noted in table 2. Namely, experiments tend to be partitioned into two groups: those which exhibit relatively high frequencies of either Cournot or satisficing behavior by all subjects, and those in which all exhibit comparatively low frequencies. We tested two null hypotheses: that the frequency with which each subject adopted (a) Cournot, (b) satisficing behavior is uncorrelated with the frequency of that behavior observed in the remaining messages of the same experiment. The null hypotheses (a) and (b) are rejected at the 10 percent and the 0.1 percent levels of confidence, respectively, via two-way classifications with 50 percent as the borderline frequency.

In particular, this implies that these aggregate frequency statistics are a harsh indicator of the support for Cournot or satisficing behavior. Aggregating places less weight on experiments with fewer iterations, which happened to be experiments with frequent Cournot and/or satisficing behavior. Of the 31 subjects, 21 satisfied Cournot behavior at least half the time, 20 satisfied satisficing behavior at least half the time, and only 8 fell outside these two groupings.

A much larger share of subject behavior can be explained by a model which suggests that subjects switch from reservation behavior to satisficing behavior after some number of iterations. Each message classified as AVD in table 2 is consistent with such a pattern; moreover, so are two-thirds of the messages listed under P and U. Because the bulk of satisficing choices occur at the end of experiments, the 'reservation followed by satisficing' model is consistent with over 80 percent of all observed messages.

Two concerns urge caution in drawing conclusions from this result. First of all, an alternative model that could be proposed is that subjects initially follow reservation behavior, then switch to Cournot. While distinctions are drawn below, this model fares nearly as well, being consistent with over 75 percent of the observations.

Secondly, the added explanatory capability of either of these models may be largely the result of greater leeway. Without knowing the reservation earnings level of a subject, a wider range of actions is consistent with reservation behavior than with either Cournot or satisficing. In particular, only a fifth of the subjects violated the test of reservation behavior described in section 2. It is not surprising that Cournot and satisficing behavior perform similarly. They are not all that different as behavioral models; only

15Specifically, the following characterizes those messages: they are not satisficing or Cournot, and they avoid a repeat message in circumstances where a reservation earnings level can be specified so that the subject appears to follow reservation behavior. Up through the iteration where any such message occurred, the subject's choices have been consistent with reservation behavior.
when the Cournot message yields earnings within 5 percent of the repeat message earnings can the data distinguish between them.

Nonetheless, some distinction is possible. Apparently because it allows more leeway for repeat messages, satisficing behavior fares somewhat better as an explanation for observed behavior at the end of experiments. Even with nine experiments, distinguishing observations are not numerous: only during 20 out of 138 iterations were subjects faced with a repeat message which was satisficing but not Cournot (CSR).

However, the only CSR message which was followed by consistent Cournot behavior was the second of three choices by subject 4-2-2. The other 9 CSR messages were by subjects who violated Cournot behavior in later iterations. Thus the evidence which directly favors Cournot over satisficing behavior comes almost entirely from subjects who at that time had not settled into a pattern of Cournot behavior.

In contrast, 6 of the 7 CSR messages are amid strings of consecutive satisficing choices at the end of experiments. Only one CSR was by a subject who violated satisficing behavior on a later iteration. Consequently, almost none of the evidence which directly favors satisficing behavior over Cournot is disqualified by later indications that the subject was not consistently following satisficing behavior.

In conclusion, a considerable argument can be made that the incorporation of reservation behavior as a description of observations early in the experiment increases our explanatory capability. Once subjects abandon reservation behavior, the explanation that they adopt satisficing behavior fits end-of-experiment data better than Cournot behavior, but these data support only the most tentative conclusions.

Neither of the two lapses in otherwise very high efficiency measures appears to be an inefficient satisficing equilibrium. Instead, they resulted from one or two subjects selecting a repeat message that was inconsistent with satisficing. While we have not been able to rule out inefficient satisficing equilibria, the adoption of satisficing behavior after some amount of exploration is the best explanation we have uncovered for the observed tendency of decentralized procedures in small noncooperative economies to attain highly efficient allocations.

Appendix: Experiment parameter values

1. Experiments 3-1 through 3-5.
1.1. Individual subject valuation functions:

\[ U_1(y_0, y_1) = 2.00 y_0^{0.96} y_1^{0.24} - 2, \quad \text{where } w_1 = 5, \]
\[ U_2(y_0, y_2) = 1.95 y_0^{0.24} y_2^{0.96} - 2, \text{ where } w_2 = 10. \]
\[ U_3(y_0, y_3) = 1.70 y_0^{0.80} y_3^{0.80} - 3, \text{ where } w_3 = 6. \]

Recall that \( y_0 \) is the public good quantity, \( y_i \) is subject \( i \)'s quantity of the private good, and \( w_i \) is subject \( i \)'s private good endowment.

1.2. Cost-share parameters: \( \gamma = 0.67 \), public good unit cost is 1.

1.3. Strength of incentives at the Cournot–Nash equilibrium, \( m^* = (4, 3, 3) \):

\[ U_1[f_1(4, 3, 3)] = 17.93, \quad U_2[f_2(4, 3, 3)] = 19.27, \]
\[ U_3[f_3(4, 3, 3)] = 21.28, \]
\[ U_1[f_1(5, 3, 3)] = 14.53, \quad U_2[f_2(4, 2, 3)] = 18.74, \]
\[ U_3[f_3(4, 3, 4)] = 20.66, \]
\[ U_1[f_1(3, 3, 3)] = 17.47, \quad U_2[f_2(4, 2, 3)] = 18.43, \]
\[ U_3[f_3(4, 3, 2)] = 18.63. \]

2. Experiments 4-1 through 4-4.

2.1. Individual subject valuation functions:

\[ U_1(y_0, y_1) = 7.35 y_0^{0.72} y_1^{0.18} - 7, \text{ where } w_1 = 5, \]
\[ U_2(y_0, y_2) = 7.35 y_0^{0.18} y_2^{0.72} - 16, \text{ where } w_2 = 9, \]
\[ U_3(y_0, y_3) = 7.35 y_0^{0.39} y_3^{0.51} - 8, \text{ where } w_3 = 6, \]
\[ U_4(y_0, y_4) = 7.35 y_0^{0.39} y_4^{0.51} - 8, \text{ where } w_4 = 6. \]

2.2. Cost-share parameters: \( \gamma = 3 \), public good unit cost is 2.

2.3. Strength of incentives at a Cournot–Nash equilibrium \( m^* = (2, 1, 1, 1) \):

\[ U_1[f_1(2, 1, 1, 1)] = 17.80, \quad U_2[f_2(2, 1, 1, 1)] = 23.35, \]
\[ U_3[f_3(2, 1, 1, 1)] = 19.47, \]
\[ U_1[f_1(3, 1, 1, 1)] = 0.00, \quad U_2[f_2(2, 2, 1, 1)] = 20.87, \]
\[ U_3[f_3(2, 1, 1, 1)] = 17.89, \]
\[ U_1[f_1(1, 1, 1, 1)] = 17.30, \quad U_2[f_2(2, 0, 1, 1)] = 16.19, \]
\[ U_3[f_3(2, 1, 0, 1)] = 12.14. \]
The figures for subject 4 are identical to those for subject 3.

2.4. Strength of incentives at a Cournot-Nash equilibrium, \( m^* = (2, 2, 2, 2) \):

\[
U_1(f_1(2, 2, 2, 2)) = 25.05, \quad U_2(f_2(2, 2, 2, 2)) = 18.05, \\
U_3(f_3(2, 2, 2, 2)) = 15.55, \\
U_1(f_1(3, 2, 2, 2)) = 0.00, \quad U_2(f_2(3, 2, 2, 2)) = 10.21, \\
U_3(f_3(2, 2, 3, 2)) = 2.50, \\
U_1(f_1(1, 2, 2, 2)) = 18.01, \quad U_2(f_2(2, 1, 2, 2)) = 14.19, \\
U_3(f_3(2, 2, 1, 2)) = 10.47.
\]

The figures for subject 4 are identical to those for subject 3.

References

Brubaker, Earl. 1979. 13% golden rule, 16% free ride and \( 71\% \) free revelation?: An experimental test of the free rider hypothesis (University of Wisconsin, Dept. of Economics).


