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Social loafing vs. social enhancement: Public goods provisioning in real-time with irrevocable commitments

Harel Goren,* Robert Kurzban, and Amnon Rapoport

University of Arizona, USA

Abstract

Whereas most experimental studies of public goods provisioning require that all players make their decisions simultaneously, in most organizational settings contribution decisions are made in real time. To account for this aspect of the decision process, we introduce a real-time protocol of play in which, at any point in time, players can either withhold or contribute their entire endowment to a step-level public good. Once contributed, the individual endowments—that in the present experiment differ from one group member to another—cannot be withdrawn. Our results show that contribution levels under the real-time protocol with irrevocable commitments significantly exceed those observed in previous studies under the more common simultaneous protocol of play, thereby considerably reducing social loafing (free riding). Consistent with our equilibrium analysis, over multiple iterations of the game play converges to an equilibrium set of players who maximize the sum of their individual benefit-to-contribution ratios.

Keywords: Binary public goods; Binary contributions; Equilibrium analysis; Real-time protocol of play

1. Introduction

The provision of public goods and the social loafing (free riding) that it typically elicits pervade many aspects of social interaction (Dawes, 1980) from the management of common pool resources to environmental conservation and population overcrowding. Within the context of organizational behavior, many researchers have noted a close similarity between questions of motivation and productivity in work groups and the problem of public goods provisioning (Earley, 1989; Kerr, 1983; McKie, 1974; Olson, 1965; Schnake, 1991). The rate of provisioning of public goods and the extent of free riding have been investigated under various institutional arrangements. These arrangements depend on several distinctions with regard to the properties of the public good (Hampton, 1987; Hovi, 1986; Ledyard, 1995; Olson, 1965). Each of them may apply to different real-life situations. We focus on three dimensions used to classify public goods problems. First, we consider goods that can only be provided in discrete steps or "lumps" (as opposed to continuously divisible amounts). In these threshold public goods situations (e.g., Croson & Marks, 1999), the size and associated cost of the project are predetermined. If the sum of contributions meets or exceeds the threshold, then the public good is provided. If not, then the good is not provided. Second, we consider the case in which contributions are made in discrete steps (as opposed to continuously). In particular, we focus on binary contributions. In these situations, the size of the contribution is fixed and predetermined (e.g., people who have to decide whether to volunteer to participate in a mission, and team members who have to decide whether to attend a meeting). Finally, we consider the case, most common in practice, in which group members are asymmetric with respect to their wealth (as opposed to symmetric).

1.1. The voluntary contribution and provision point mechanisms

Most of the experimental studies of public goods provisioning have used one of two alternative mechanisms. In the Voluntary Contribution Mechanism

* Corresponding author. Present address: Faculty of Management, Tel Aviv University, Ramat Aviv, Tel Aviv 69978, Israel. Fax: +972-3-6407739.
E-mail address: hgoren@post.tau.ac.il (H. Goren).

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(VCM), goods are provided in continuously divisible quantities, contributions are made in continuously divisible amounts, and players are symmetric with respect to size of their endowment ("wealth") (e.g., Isaac, McCue, & Plott, 1985; Isaac & Walker, 1988; Isaac, Walker, & Thomas, 1984). In VCM experiments, individual members of small groups are endowed with money and then asked to divide it in any way they wish into two separate accounts. Money placed in the Private account is kept by the individual, while money placed in the Public account is multiplied by some commonly known constant ($h > 1$)—the same for all players—and then divided equally among the group members. For certain values of h, this mechanism gives rise to a social dilemma (Dawes, 1980) of the Prisoner's Dilemma kind in which placing all the money in the Private account is the unique (Pareto deficient) Nash equilibrium solution. Several general findings have emerged from numerous experiments that used the VCM (see Ledyard, 1995, for a general survey). First, players typically contribute between 20% and 50% of their endowment to the Public account. Second, and most importantly for our study, when the game is iterated in time and group membership is fixed, contributions to the Public account begin at about 50% of the endowment size and then decline steadily, and the proportion of free riders—participants who consistently use the dominant strategy of zero contribution—increases (Palfrey & Prisbrey, 1997).

The incentive structure of certain work arrangements can be represented by the VCM. Work groups that perform simple additive tasks (e.g., teller shifts in banks, groups of manual laborers) share responsibility for producing a good that benefits all members. The size of that good is assumed to increase monotonically with group effort. However, each member who pursues self-interest has an incentive to free ride on the efforts of others by reducing her own effort (assuming individual behavior is not monitored and differentially rewarded). Simulation of such conditions in experiments has resulted in the documentation of social loafing (Latane, Williams, & Harkins, 1979), observed as early as the 1880s by Ringelmann (described in Kravitz & Martin, 1986), in which individual effort is lower when working in a group than working alone.

The Provision Point Mechanism (PPM)—the focus of the present study—is another major institutional arrangement that has been studied experimentally. In the PPM, the public good is binary and the individual contributions are all-or-nothing (Croson & Marks, 1998; Dawes, Orbell, Simmons, & van de Kragt, 1986; Palfrey & Rosenthal, 1991; Rapoport & Eshed-Levy, 1989; van de Kragt, Orbell, & Dawes, 1983). In a canonical experiment conducted under the PPM, participants are organized into groups of n players, and each player is endowed with e units. If m or more players ($1 < m < n$) contribute their entire endowments, every group member receives a reward (public good) worth r units ($e < r$). Players who do not contribute keep their entire endowments. If fewer than m players contribute their endowments, then the public good is not provided. The values of n, m, e, and r are commonly known. If $1 < m$, contributing nothing is a Nash equilibrium as in the VCM. However, in contrast to the VCM, this is not the only equilibrium as there exist $n!/(m!(n-m)!)$ additional equilibria in which exactly m group members contribute. Therefore, the PPM is essentially a game of (tacit) coordination in which the n players face a coordination problem of designating exactly m contributors. With a few exceptions (e.g., Croson & Marks, 1999; Murnighan, King, & Schoumaker, 1990; Rapoport, 1988), PPM experiments have been conducted with symmetric players. The major experimental findings resemble those reported above. Aggregate contribution rates range between 30% and 60%, individual differences are substantial, and contributions tend to decrease steadily when the game is iterated in time.

Many reward schemes imposed on work groups can be represented by the PPM. Consider the case in which a salary bonus is given to all group members if their joint product exceeds some predetermined quota. The quota is equivalent to the provision point and the public good (i.e., the bonus) is binary. In such cases independent group members should increase work effort if they think that their contribution would be necessary for exceeding the quota (thereby providing the good). Another example is research and development teams that are responsible for designing a single product. Product design completion is equivalent to exceeding the provision point (assuming members are collectively rewarded upon completion of the project). Consistent with the notion of threshold for public good provisioning, a number of experiments have produced a social compensation effect—an increase in individual effort when working in a group relative to working alone—when other members' effort seems inadequate for achieving the group's goal (e.g., Williams & Karau, 1991).

1.2. Alternative protocols of play

Most of the VCM and PPM experiments have been conducted under the *simultaneous protocol of play* in which group members make their decisions privately and anonymously. Although theoretically convenient and experimentally feasible, the simultaneous protocol of play—even when iterated in time—does not capture the essence of voluntary contribution processes that are frequently encountered in practice in which individuals possess partial information about the decisions of other group members *before* making their own decisions. In the *sequential protocol of play* (Erev & Rapoport, 1990; Rapoport & Erev, 1994), which has been proposed in order to capture this major feature of many voluntary contribution processes, group members make their decisions in turn, with every member knowing her position in the sequence as well as the decisions of all the players preceding her in the sequence. But this protocol, too, is still short of accurately capturing the dynamics of voluntary contribution processes encountered in practice. First, the order of play is determined exogenously, whereas in most public good situations it is determined endogenously. Second, in real-life voluntary contribution processes time is continuous rather than discrete. This allows potential contributors to wait, observe the total contribution which is updated periodically, obtain information about the timing of decisions, and then determine whether and how much to contribute. Most United Way community fund drives prominently display their updated totals throughout the community. Annual campaigns in the USA to raise money for public radio and public TV typically last a few days, and drives to raise money for constructing new churches or repairing them typically last for weeks. Casual observation suggests that this updating process—the cumulative total contribution, the time remaining before the fund drive concludes, and the rate of change in the cumulative total contribution—plays a significant role in the effectiveness of fund raising activities (Dorsey, 1992).

The *real-time protocol of play* narrows the gap between the stylized design of laboratory experiments and real-life voluntary contribution processes. Under this protocol, players are given a fixed time interval ("round") in which to update their decisions. During the round the players receive continuous updates of other players' contributions. The order of play and timing of the decisions are determined *endogenously*. The player's allocation to the public good, if any, when the rounds ends is taken to be her contribution for that round. The real-time protocol of play can be used to study the VCM, PPM, and other mechanisms that have not been discussed above (e.g., continuous contribution and discrete public goods, discrete contributions and continuous public goods). More importantly, in a very natural way it allows a comparison of two different types of time adjustments. Under one type, whether the contribution is discrete or continuous, players are only allowed to either take no action or increase their contribution within the round. When contributions are all-or-nothing, as they are under the PPM, they constitute *irrevocable commitments*. Under a second type of time adjustment, players may contribute nothing, increase, or decrease their contribution at any time during the round. In this case, to be studied in a subsequent paper, their contributions constitute *revocable commitments*.

To our knowledge, there have been only three studies that have examined voluntary contributions to public goods under the real-time protocol (Dorsey, 1992; Güth, Levati, & Stiehler, 2002; Kurzban, McCabe, Smith, & Wilson, 2001). Our experiment differs from these studies in several major respects. First, whereas previous studies used the VCM, the present study examines the PPM. As contributions are not allowed to be withdrawn, our major focus, therefore, is on the process of making irrevocable commitments in real time. Second, we focus on irrevocable commitments made by *asymmetric players* (but see Güth et al.). As mentioned earlier (Rapoport, 1988), symmetric public good games constitute a special case of the more general asymmetric games in which the players' outcomes may differ from one another (Croson & Marks, 1999; Murnighan et al., 1990). Asymmetry is manipulated by providing the players different and commonly known endowments. This allows the study of the effects of commonly known individual "wealth" on the rate and timing of contribution. Third, we increase the number of rounds from the typical 10–12 to 45 in order to study better the effects of learning. Fourth, in order to prevent or at least weaken end effects, we allow for rounds with a variable rather than fixed time interval. Because of these changes, our results are not directly comparable to those conducted under the VCM. The more appropriate comparison is to the findings of PPM experiments conducted under the simultaneous and sequential protocols, in particular the ones investigating the effects of asymmetry in endowments (Rapoport, 1988).

Our experiment is ideally suited to study the dynamics of work in organizational task forces (e.g., Gersick, 1988). Task forces are groups of workers assembled to achieve specific organizational goals in limited time. Note the similarity between this characterization and the strategic features of our game. Achieving the task force's goal is similar to providing the group's binary public good. Members' ability and importance for achieving the group's goal typically vary—they have different "endowments" that they can contribute to the group effort. The task is time limited; it has some termination point after which further group effort can no longer affect the group's goal. In many cases, this deadline need not be known with certainty. Our study is best perceived as a controlled laboratory experiment designed to study factors that might very well operate in realistic work settings. As such it might offer insight into the processes that determine effort and productivity in work groups that face time constraints while attempting to achieve a common organizational goal.

The rest of the paper is organized as follows. Section 2 describes the game and derives several hypotheses from an equilibrium analysis of our model. An important implication of this analysis is that contribution is expected to decrease monotonically with endowment size. Section 3 describes the method, and Section 4 presents the results. Section 5 concludes.

2. Predictions

The present experiment was conducted with groups of five ($n = 5$) players. The endowments for players 1, 2, 3, 4, and 5 assumed the values $e_1 = 5$, $e_2 = 10$, $e_3 = 15$, $e_4 = 20$, and $e_5 = 25$. The provision threshold was set at $k = 30$, and the valuation of the good-the same for all players-was also set at $r = 30$. The duration of the round, T, was uniformly distributed between $T_{\min} = 60$ and $T_{\max} = 90$ s. During the time interval $0 \leqslant t \leqslant T$, a player could only make a single decision, namely, irrevocably commit her endowment to the provisioning of the good or withhold contribution. Individual contributions made at time t are denoted by $c_{j,t}$ and the total group contribution by C_t. The public good was provided if and only if $C_t \geqslant k$. The parameters e_j, n, k, and r as well as the distribution of T were commonly known. The values of $c_{j,t}$ were updated continuously and displayed on the PC screens. All five players had the same information displayed on their screen.

2.1. Equilibrium analysis

When decision processes evolve in real time, it is useful to differentiate between the analysis of final outcomes and the dynamics of play. This is common in game-theoretical analyses of real-time bargaining and coalition formation. We adopt a similar approach here. In this section, the analysis is restricted to the decisions recorded at the end of the round. Analysis of the dynamics of play is deferred to Section 4.

Focusing first only on the game outcomes, Table 1 lists the eight pure-strategy equilibria of our game. In one case, no player contributes; in six other cases the equilibrium set includes two contributors; and in one case three contributors. The total contributions at time T (C_T) that are associated with these equilibria are presented in column 2. Columns 3–7 present the individual payoffs x_j associated with each equilibrium (including payoffs to contributors and non-contributors), and column 8 shows the total group payoff: $X = \sum x_j$.

An important feature of the present experiment is that the stage game was iterated 45 times and the player roles (or types) as well as group membership were varied from round to round in a random-group design. Players could anticipate being assigned to each of the five roles an equal number of times. Moreover, because the number of combinations of endowments was rather small, it was rather trivial for the players to realize that only three subsets of players, namely {1,5}, {2,4}, and {1,2,3}, could maximize total group payoff (Table 1). These features of the design give rise to a hierarchy of three hypotheses that are presented in an increasing order of strength.

Table 1
Pure strategy equilibria and associated individual and group payoffs

Equilibrium set	C_T	x_1	x_2	x_3	x_4	x_5	X
{∅}	0	5	10	15	20	25	75
{1,5}	30	30	40	45	50	30	195[a]
{2,4}	30	35	30	45	30	55	195[a]
{2,5}	35	35	30	45	50	30	190
{3,4}	35	35	40	30	30	55	190
{3,5}	40	35	40	30	50	30	185
{4,5}	45	35	40	45	30	30	180
{1,2,3}	30	30	30	30	50	55	195[a]

[a] This equilibrium maximizes total group payoff.

Hypothesis 1. The game will end in equilibrium.

Hypothesis 2. The game will end in an equilibrium that maximizes total group payoff.

Denote any of the eight equilibrium contributing sets listed in Table 1 (column 1) by S, a player's payoff to endowment ratio by $R_j = x_j/e_j$, and the sum of these ratios for the set of contributors S by $SR(S) = S_{j \in S}(R_j)$. Using this notation, we formulate the following hypothesis:

Hypothesis 3. The game will end in an equilibrium in which the sum $SR(S)$ is maximized.

Hypothesis 1—the weakest of the three—simply asserts that the game will terminate at time T with any of the eight equilibrium sets listed in Table 1. This hypothesis can be refuted if, for example, not enough players contribute at time T. It may also be refuted if the contributing set includes any of the seven non-empty equilibrium sets in Table 1 as a proper subset. Hypothesis 2 states that $S \in \{\{1,5\},\{2,4\},\{1,2,3\}\}$. It is justified by the fact that the players' types were randomly assigned on each round. The total group contribution in equilibrium, X, might simply serve as a coordination device (e.g., Schelling, 1960) to help the players coordinate their actions and eliminate equilibria that are inefficient across the 45 iterations of the game. To justify Hypothesis 3, we invoke an auxiliary assumption that players evaluate their prospects in the game relative to their individual endowments. This implies that if player j decides to contribute, she attempts to maximize the ratio x_j/e_j. As no player, if contributing alone, can maximize this ratio, Hypothesis 3 asserts that players will attempt to form an equilibrium contributing set S that maximizes the *sum* of these ratios, namely, $SR(S)$.

To illustrate Hypothesis 3, consider the three equilibrium contributing sets {1,5}, {2,4}, and {1,2,3}, each of which is sufficient for efficient provisioning of the good. The respective values of $SR(S)$ are 7.2 ($30/5 + 30/25$), 4.5 ($30/10 + 30/20$), and 11 ($30/5 + 30/10 + 30/15$). Hypothesis 3 implies that only players 1, 2, and 3 will contribute: $S = \{1,2,3\}$.

All three hypotheses are testable with other values of the provision threshold. For example, if the threshold for provisioning is increased from $k = 30$ to $k = 35$, it is easy to verify that Hypothesis 3 implies that only players 1, 2, and 4 will contribute. The equilibrium set that maximizes the sum of benefit-to-contribution ratios will not necessarily include only the low endowment players.

2.2. Non-existence of mixed strategy equilibrium

Let e_{-j} denote the sum of contributions of all the players excluding player j. Then, whether or not player j contributes, one of three conditions will hold:

1. $e_{-j} < k$ and $e_{-j} + e_j < k$.
2. $e_{-j} < k$ and $e_{-j} + e_j \geqslant k$.
3. $e_{-j} \geqslant k$ (and $e_{-j} + e_j \geqslant k$).

In both Cases 1 and 3 player j's contribution has no effect on the provisioning of the good; it is provided in Case 3 and not provided in Case 1 no matter what player j does. In Case 2, player j's contribution is *critical* for provisioning. Denote the probability that Cases 1, 2, and 3 obtain for player j by $P_{IN}(j)$, $P_{CR}(j)$, and $P_{SU}(j)$ (IN = insufficient, CR = critical, SU = superfluous), where $P_{IN}(j) + P_{CR}(j) + P_{SU}(j) = 1$ for all j. Table 2 presents the payoff matrix for player j ($j = 1, 2, \ldots, n$).

The expected utility for player j of contribution (C) is

$$EU_C(j) = u(r)[P_{CR}(j) + P_{SU}(j)],$$

whereas the expected utility for player j of no contribution (NC) is

$$EU_{NC}(j) = u(r)P_{SU}(j) + u(e_j).$$

The difference between these two expressions, $D(j) = EU_C(j) - EU_{NC}(j)$, is given by

$$D(j) = u(r)P_{CR}(j) - u(e_j)$$

showing that, in addition to the endowment e_j and reward r, only the probability of being critical for the provisioning of the good matters. In equilibrium the expected utility of contribution equals the expected utility of no contribution, or $D(j) = 0$. This equality yields the following condition

$$P_{CR}(j) = u(e_j)/u(r). \quad (1)$$

In words, in equilibrium the player's probability of being critical should be equal to the ratio of the utility of her endowment to the utility of the reward. If we assume risk-neutrality (see Rabin, 2000, for a justification of this assumption), then the values of the probabilities that solve Eq. (1) are 1/6, 1/3, 1/2, 2/3, and 5/6 for players 1, 2, 3, 4, and 5, respectively.

We turn next to an analysis of the probability $P_{CR}(j)$ in Eq. (1). Note that player j is critical if certain events happen and not critical otherwise, where by "event" we mean that some subset of the remaining players contributes. For example (see below), player 1 is critical for the provisioning of the good if either player 5 alone contributes or players 2 and 3 contribute jointly, but not otherwise. Denote the set of events for player j in which she is critical by W_{-j}. Thus,

$$W_{-1} = \{\{5\}, \{2,3\}\},$$

$$W_{-2} = \{\{4\}, \{5\}, \{1,3\}, \{1,4\}\},$$

$$W_{-3} = \{\{4\}, \{5\}, \{1,2\}, \{1,4\}\},$$

$$W_{-4} = \{\{2\}, \{3\}, \{5\}, \{1,2\}, \{1,3\}, \{2,3\}\},$$

$$W_{-5} = \{\{1\}, \{2\}, \{3\}, \{4\}, \{1,2\}, \{1,3\}, \{1,4\}, \{2,3\}\}.$$

Clearly, the number of events for which player j is critical is non-decreasing in the player's endowment.

Now, assume that each player j contributes with probability p_j and this is common knowledge. Then, the probability of criticality, $P_{CR}(j)$, can be expressed in terms of the individual contribution probabilities p_j. For example, for $j = 1, 2$ –

$$P_{CR}(1) = (1-p_2)(1-p_3)(1-p_4)p_5 + p_2p_3(1-p_4)(1-p_5),$$

$$\begin{aligned} P_{CR}(2) = {} & (1-p_1)(1-p_3)p_4(1-p_5) \\ & + (1-p_1)(1-p_3)(1-p_4)p_5 \\ & + p_1p_3(1-p_4)(1-p_5) + p_1(1-p_3)p_4(1-p_5), \end{aligned}$$

and so on for players 3, 4, and 5. All the five players should contribute—albeit with possibly different probabilities—if we can find values of p_j ($0 \leqslant p_j \leqslant 1$) that satisfy Eq. (1). However, we find no such probabilities that simultaneously satisfy the five constraints set by Eq. (1) for $j = 1$, 2, 3, 4, and 5. In other words, there exist no five probabilities p_j such that the equalities $P_{CR}(j) = e_j/r$ are jointly satisfied for all j. This result establishes the fact that there exists no mixed strategy equilibrium for the game in which each of the five types contributes with some (non-negative) probability.

Table 2
Payoff matrix for type j players

Decision	*Case 1* $e_{-j} < k$, $e_{-j} + e_j < k$	*Case 2* $e_{-j} < k$, $e_{-j} + e_j \geqslant k$	*Case 3* $e_{-j} \geqslant k$, $(e_{-j} + e_j \geqslant k)$
Contribute	0	r	r
Not contribute	e_j	e_j	$r + e_j$
Probability	$P_{IN}(j)$	$P_{CR}(j)$	$P_{SU}(j)$

3. Method

3.1. Participants

Fifty participants were recruited from the population of undergraduate students at the University of Arizona. When recruited, they were asked to volunteer to a group decision making experiment with payoff contingent on performance. In addition, they were promised a $5.00 show-up payment. Two sessions were conducted, each including 25 participants. Each session lasted approximately two hours. The mean individual payoff across the participants in both sessions was $23.30. Excluding the show-up payment, individual payoffs ranged from a minimum of $10.00 to a maximum of $27.00.

3.2. Procedure

The experiment was conducted at the University of Arizona Economic Science Laboratory. Upon arriving at the laboratory, the participants were checked in and assigned to one of 25 computer terminals. These terminals were separated from one another by partitions preventing users from seeing others' screens. Communication among the participants was strictly forbidden.

Once all the participants were seated, written instructions were handed out (the complete set of instructions are available upon request). The instructions described the public good game and illustrated it with several examples. In particular, the participants were informed of the following:

1. They would play a large number of rounds of an "interactive decision making experiment." (The actual number of rounds (45) was not disclosed to prevent end effects.)
2. They would be assigned to groups of five players each on each round of play.
3. Group composition would vary randomly from round to round. Players would not be informed of the identity of the other four members of their group on any given round.
4. The five group members would be assigned five different endowments, namely, 5, 10, 15, 20, and 25 tokens. The assignment of endowments to group members would also be randomly made at the beginning of each round.
5. Each round would last between 60 and 90 s with any value in this range having the same probability of being chosen. A clock counting time in seconds would be displayed on all five PC screens.
6. The final payoff would be determined at the end of the session by a random selection of three rounds of play, the same for all 25 participants. The conversion ratio for determining the payoff would be $1.00 = 9 tokens.

The public good game was framed as a choice between investing one's endowment in a Group account and not doing so. In particular, the subjects were instructed as follows:

> You may decide *not to invest*. In this case, one of two events will occur. If the number of the tokens in the Group Account is equal or greater than the threshold, you will receive a payoff of 30 tokens in addition to your endowment. If the number of tokens in the Group Account is less than 30 tokens, you will end up with your endowment only.
>
> You may decide *to invest* your endowment. (Recall that you can do so at any time before the end of the round.) In this case, if the number of tokens in the Group Account is equal to or greater than 30, you will receive a payoff of 30 tokens. If the number of tokens in the Group Account is smaller than the threshold, you will end the round with 0 tokens.

The random re-matching of players to roles was structured in such a way that each player was assigned each of the five types exactly nine times. During each round, each player was informed of:

1. The amount of time (in seconds) elapsed in the round.
2. The current decisions of all members of the group listed by endowment.
3. The current total investment in the Group Account (C_t).
4. A message indicating whether the threshold was reached or exceeded and the individual payoffs (x_j) for the round.

Players had no access to their previous decisions and payoffs. Nor did they receive any information about the other group members.

4. Results

4.1. Static analysis

We first test whether the main results of the experiment are similar for both experimental sessions. In order to do so, we compared the two sessions on the following three measures.

4.1.1. Mean individual payoff

For each player, we computed the mean payoff (across all 45 rounds) in tokens and subjected the per-session scores to a t test. The analysis yielded no significant difference between the two sessions ($M_{\text{session1}} = 34.4$, $M_{\text{session2}} = 33.6$; $t_{(48)} = 1.18$, $p = .24$).

4.1.2. Proportion of public good provisioning

Each session included 45 rounds with 5 different 5-person groups in each round. This resulted in a total of 225 rounds per session. Despite the random re-matching of players and assignment to player type, these 225 rounds cannot be taken to be statistically independent. Although reputation effects were minimized by the design, the possibility of *population learning* could not be excluded. The public good was provided 88.9% and 81.8% of the time in sessions 1 and 2, respectively.

4.1.3. Proportion of contribution by player role

For each participant separately, we computed the proportion of contribution decisions he/she made under the five different roles (endowment sizes). Given that each role was replicated nine times, each of the five proportions could take one of ten values (i.e., 0, 1/9, 2/9,...,1). We treated the five proportions under the five roles as repeated measures for the same player, and analyzed these using a mixed-design ANOVA with one between-subject factor (Session) and one repeated measures factor (Role). The Role main effect was highly significant as expected. The Session main effect was not significant, showing no overall difference in contribution proportions between the sessions. However, the ANOVA yielded a significant Session by Role interaction ($F_{(4,192)} = 4.38$, $p < .01$). Table 3 presents the percentages of contribution by role in the two sessions. (We discuss the Role factor main effect in greater detail below.)

In both sessions, the percentages of contribution were negatively correlated with the endowment size. However, relatively large between-session differences (over 10%) in the percentage of contribution were found for player types 3 and 4. These two differences were statistically significant using separate t tests for $e = 15$ ($t_{(48)} = 2.11, p < .05$), and $e = 20$ ($t_{(48)} = 2.54, p < .05$). The three other t tests for types 1, 2, and 5 yielded non-significant differences between the two sessions. The results suggest that the same process linking endowment size and contribution rates operated in both sessions with some variation in the exact quantitative relationship between endowment size and contribution proportion. Because of the significant Session by Role interaction effect, subsequent analyses report the results both across the two sessions and for each session separately.

Table 3
Percentage of contribution by player role and session

Role (endowment)	Session 1	Session 2	Across sessions
1 ($e_1 = 5$)	92.9	86.2	89.6
2 ($e_2 = 10$)	82.7	78.2	80.4
3 ($e_3 = 15$)	80.0	68.9	74.4
4 ($e_4 = 20$)	9.3	23.6	16.4
5 ($e_5 = 25$)	12.0	10.7	11.3

4.1.4. Tests of Hypotheses 1–3

Table 4 presents the percentages of the observed contributing sets (see Table 1) at the end of each round for blocks of 15 rounds each. These percentages pertain directly to Hypotheses 1–3.

Hypothesis 1. About 30% of all the outcomes in Table 4 are included in the category "Other." In more than half of these (75 cases) the public good was provided with contributing sets that include one of the seven non-empty sets in Table 1 as a subset. This excessive contribution often (29 cases) resulted from two players contributing more or less simultaneously (see below). In the remaining 62 cases in the "Other" category, the public good was not provided, although at least one of the players contributed her endowment. Table 4 shows that equilibrium contribution sets occurred in about 70% of all the rounds across both sessions. We take this result as evidence in support of Hypothesis 1. Note that the game may end in any one of the 32 (2^5) contributing sets, whereas Hypothesis 1 predicts that any one of only 8 equilibrium sets will form. Under the assumption that all 32 contributing sets are equally likely, the null hypothesis that the 8 equilibrium sets only account for 25% of the outcomes is significantly rejected ($\chi^2_{(1)} = 476.4$, $p < .001$). A stronger null hypothesis can be formulated stating that any one of the 22 "winning" contributing sets (that ensure provisioning) will form. Seven of these 22 "winning" sets are in equilibrium. Under the stronger hypothesis that all 22 "winning" sets are equally likely, the null hypothesis that the 7 equilibrium sets only account for 31.82% (7/22) of the outcomes was also significantly rejected ($\chi^2_{(1)} = 418.95$, $p < .001$).

Support for Hypothesis 1 held separately for each of the two sessions. Equilibrium contributing sets were formed in 78.2% and 60.9% of all the rounds in Sessions 1 and 2, respectively. Both of these percentages are

Table 4
Observed percentages of contributing sets

Contributing set	Block 1 (trials 1–15)	Block 2 (trials 16–30)	Block 3 (trials 31–45)	Total
{∅}	0.7 (1)	1.3 (2)	0.7 (1)	0.9 (4)
{1,5}*	8.7 (13)	4.0 (6)	2.7 (4)	5.1 (23)
{2,4}*	4.0 (6)	0.7 (1)	2.7 (4)	2.4 (11)
{2,5}	0 (0)	0 (0)	0.7 (1)	0.2 (1)
{3,4}	2.0 (3)	0 (0)	0.7 (1)	0.9 (4)
{3,5}	0.7 (1)	0.7 (1)	2.0 (3)	1.1 (5)
{4,5}	0 (0)	0 (0)	0 (0)	0 (0)
{1,2,3}*	46.7 (70)	63.3 (95)	66.7 (100)	58.9 (265)
Other	37.3 (56)	30 (45)	24 (36)	30.4 (137)
Total	150	150	150	450

significantly higher than those stated in each of the two null hypotheses tested above. (Session 1: $\chi^2_{(1)} = 339.9$, $p < .001$, $\chi^2_{(1)} = 285.8$, $p < .001$; Session 2: $\chi^2_{(1)} = 154.6$, $p < .001$, $\chi^2_{(1)} = 142.6$, $p < .001$.)

Not only are the outcomes supportive of Hypothesis 1, but—most importantly—Table 4 shows that this support increases with experience gained in playing the game. The percentage of rounds in which equilibrium contributing sets were formed increased over blocks by about 13% from 62.7% in block 1 through 70.0% in block 2 to 76.0% in block 3. This learning trend across blocks is statistically significant ($\chi^2_{(2)} = 6.21$, $p < .05$). Moreover, it holds separately in each of the two sessions (72.0%, 77.3%, and 85.3% in Session 1, and 53.3%, 62.7%, and 66.7% in Session 2). Notwithstanding the caution with which one should approach extrapolation to a larger number of trials, the same trend in both sessions suggests slow convergence to the formation of equilibrium contributing sets.

Hypothesis 2. Hypothesis 2 asserts that rounds would end in equilibrium sets that maximize group earnings. There are three contributing sets maximizing group earnings. Table 4 shows that together they account for 95.7% of all the rounds ending in equilibrium. This result is well above the expected percentage (37.5) if all eight equilibrium sets are equally likely ($\chi^2_{(1)} = 466.3$, $p < .001$). The same conclusion holds in each session separately: none of the other equilibrium results occur with greater frequency than the three contributing sets that maximize group earnings.

Hypothesis 3. Hypothesis 3 predicts the formation of the contributing set {1,2,3}. Table 4 shows that no other contributing set appears with a greater frequency. The percentage of rounds in which the three players with the smallest endowments contributed was 58.9, which is much higher than what would be expected by chance. (This is true whether we compute the percentage within all rounds, within only those rounds that ended in equilibrium, or within only those rounds that ended in the contributing sets that maximize group earnings). In Session 1, the round ended with the contributing set {1,2,3} 68.9% of the time and in Session 2 only 48.9% of the time.

Most importantly, Table 4 shows that the frequency of the contributing set {1,2,3} increased with experience in playing the game. The percentage of rounds that ended with the set {1,2,3} was 46.7 in the block 1, 63.3 in block 2, and 66.7 in block 3. This increase of 20% across blocks is statistically significant ($\chi^2_{(2)} = 14.23$, $p < .001$) when cross-tabulating blocks on an indicator variable that codes the set {1,2,3} as one category and all other sets into another category. The same observation holds separately in each session. The corresponding percentages are 61.3, 69.3, and 76.0 in Session 1 ($\chi^2_{(2)} = 3.77$, $p = .15$), and 32.0, 57.3 and 57.3 in Session 2 ($\chi^2_{(2)} = 12.84$, $p < .01$).

4.1.5. Wealth effects

Hypothesis 3 was based on the auxiliary assumption that when forming an equilibrium contributing set players attempt to maximize the ratio of reward to endowment. This assumption implies that players who have relatively more to gain from provisioning would be more likely to contribute, and hence players' likelihood of contribution should decrease with endowment size. The ANOVA mentioned in the preceding section yielded a strong and significant player type effect ($F_{(4,192)} = 265.2$, $p < .001$), attesting to the differing contribution levels for the different roles. A series of planned contrasts comparing each endowment size to the next one showed that the contribution proportion at each endowment size was significantly higher than the proportion at the next level ($F_{(1,48)} = 15.34$, $p < .001$; $F_{(1,48)} =4.88$, $p < .05$; $F_{(1,48)} = 218.94$, $p < .001$ and $F_{(1,48)} = 5.42$, $p < .05$, for the four successive comparisons, respectively). Across both sessions we obtain clear evidence for a strong negative correlation of contribution frequency with endowment size.

As mentioned earlier, the two sessions differed in the exact numerical relationship between endowment size and contribution proportion. Still, the endowment size effect was very strong and significant in both sessions ($F_{(4,96)} = 174.88$, $p < .001$ in Session 1, and $F_{(4,96)} = 100.91$, $p < .001$ in Session 2). Contribution decreased monotonically with endowment size in both sessions: in no case was the contribution level at a high endowment size significantly higher than the contribution level at the previous (lower) endowment size.

Looking at the change in contribution percentages over time we observe that with more experience in playing the stage game the frequency of contribution by players 1, 2, and 3 steadily increased, whereas that of players 4 and 5 steadily decreased. This pattern indicates stronger support for Hypothesis 3 as the game progresses. The effect for all five players, except player 1, is quite strong—at least 9% change in contribution between blocks 1 and 3. (Block 1 to block 3 increase for players 1, 2, and 3: 85–90%, 74–85%, and 66–81%, respectively. Decrease for players 4 and 5: 23.3–14.7%, and 18–6%, respectively.) Clearly, as the game was repeated, the players' behavior showed a stronger wealth effect.

4.2. Dynamic analysis

No attempt is being made here to propose a formal model that accounts for the dynamics of play. Not only is such a model beyond the scope of the present paper, but its formulation is premature because of insufficient data on the effects of the real-time protocol. Rather, we have a more modest aim of identifying behavioral regularities that might prove useful in the construction of such a model. In describing the dynamics of play, we consider separately the *order* and *timing* of contributing, given that a contribution decision was made. Taken together, these two measures help to explain how players either attempt to elicit contributions from others by signaling their cooperativeness or withhold their contribution in an attempt to free ride.

4.2.1. Order of contribution

There are multiple ways for subsets of players to form a "winning" coalition that provides the good. Table 5 lists the most frequent orderings of contribution, those that occurred at least six times. Using one second as the smallest measurable unit of time, the symbol "$\rightarrow$" means that a player on the left of the symbol contributed no less than one second before a player to the right of the symbol. The symbol "$\approx$" means that the two players on both sides of it contributed within the same second.

Wealth effects are clearly manifested in the orderings of the contributions. In general, players with smaller endowments contributed earlier than players with larger endowments. In 80 cases where the public good was provided, players 1, 2, and 3 contributed in this order. There are six possible orderings in which these three players could have contributed. Table 5 shows that the most common orderings are the ones in which type 1 players ($e_1 = 5$) contributed first, least common when type 3 players ($e_3 = 15$) contributed first, and intermediate when type 2 players ($e_2 = 10$) contributed first. This wealth effect holds whether the public good was provided; if it was provided, whether the outcome was in equilibrium, and whether the sum $SR(S)$ was maximized.

Simultaneous play or "ties" in contribution occurred in 42 rounds. Most of them can be attributed to a combination of response times on the order of magnitude of 500 ms on the part of the players and inevitable computer delays in recording and communicating a contribution decision (recall that 25 players participated jointly in the same session). The same effect of endowment size reported above is also present in the case of ties (lower panel of Table 5).

4.2.2. Time of contribution

Additional insight into the dynamics of play comes from an analysis of the time of contribution. Fig. 1 (upper panel) shows the frequency distributions of contribution time by player type. The horizontal axis is divided into 30 equal intervals of 3 s each. The vertical axis presents the frequencies of contribution. The top panel of Fig. 1 shows that the contribution levels for types 1, 2, and 3 peaked at the first 10 s or so. There is a second smaller peak between 58 and 64 s. In the first ten seconds, the frequency of contribution was inversely related to the endowment size. The smaller the endowment size the quicker the player was to contribute. The second peak occurred around the time that the random termination of the round could take place. The frequencies at this peak no longer reflect the endowment size. The second peak provides clear evidence for brinkmanship with some players holding their contribution until the "last second" ($t = 60$) and often exceeding this threshold in an attempt to apply pressure on others to contribute. These attempts were only partly successful due to the random termination of the round in the interval [60, 90].

To better understand the distributions of contribution time in the upper panel of Fig. 1, we differentiated between two contribution categories. The first includes contributions that are *insufficient* for provisioning the good, and the second contributions that are *critical* for its provisioning. The middle and lower panels of Fig. 1 display the frequency distributions (by type) of insufficient and critical contribution times, respectively. These two panels show that insufficient contributions were made early in the round with a sharp decline in frequencies around 10–12 s. In contrast, players whose contributions became critical waited until it was barely "safe" to contribute and often beyond this threshold. This "waiting time" interaction among the critical players resembles a real-time version of the game of Chicken. When players misjudge the termination time and wait too long, the good is not provided. Analogously, when drivers wait too long before swerving, the outcome is a fatal crash. The bottom panel of Fig. 1 shows higher frequency of contribution around $t = 60$ for type 3 than types 4 and 5 players. The frequencies of contribution at that peak by types 1 and 2 are intermediate (rather than negligible) because they are not always the first to contribute, and thus still sometimes become critical toward the round end. Fig. 1 shows that no type of player is immune to brinkmanship once her contribution becomes critical.

Why did players (mostly of types 1, 2, and 3) make their insufficient contributions so early in the round? Intuition would suggest no contributions by any type of player within the first 30–40 s of the round. Our results suggest that contributing early by players who have relatively more to benefit might have been intended to signal cooperativeness, good will, or willingness to take risks for provisioning. We divided all the rounds into those ending with the good being provided and those ending with the good not being provided. For each of these two classes, we calculated the means of the time of insufficient contributions. When the good was provided, mean contribution times were 11.9, 16.1, 20.8, 19.9 and 8.8 s for players 1–5, respectively. When it was not provided, means were 14.2, 27.6, 38.1 and 35 s for players 1–4, respectively. (There were no cases of insufficient contribution by player 5 without the good being later provided.) These results show clearly that for each player type insufficient contributions were made earlier in rounds ending

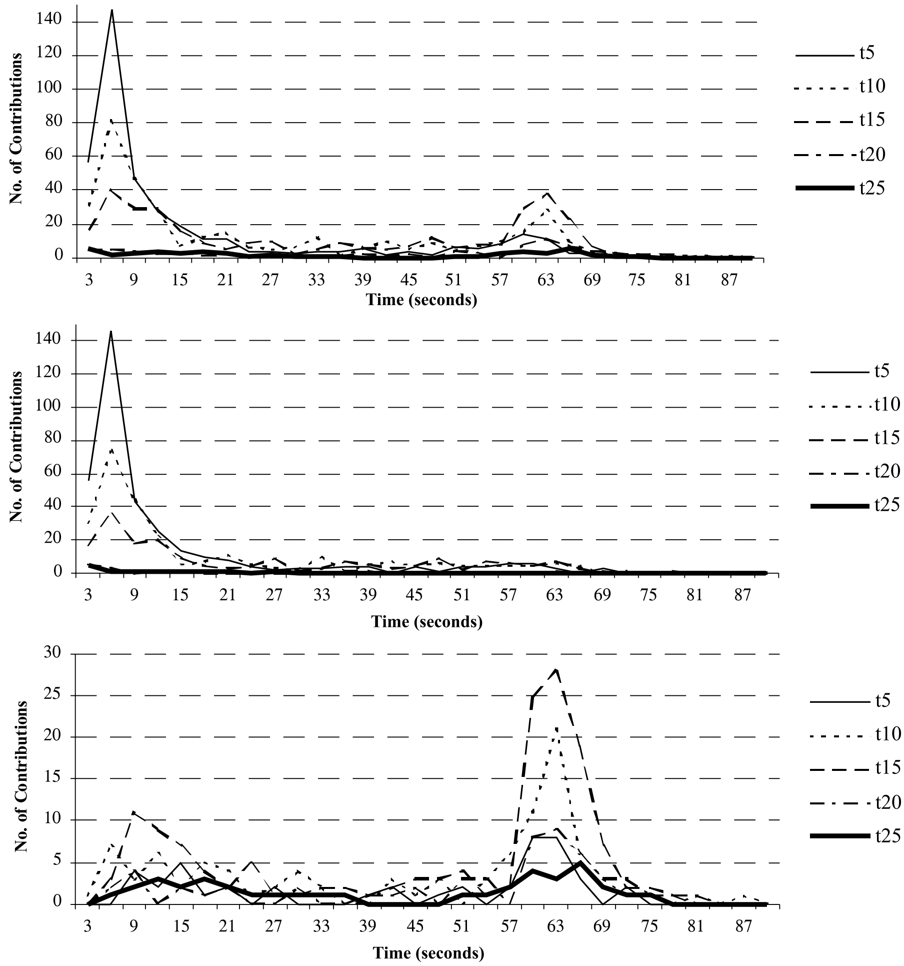

Fig. 1. Distribution of contribution times by player type (general, top; insufficient contributions, middle; critical contributions, bottom).

Table 5
Frequent orderings of contribution

Public good provisioning	Equilibrium status	$SR(S)$ Maximization	Ordering	Frequency (session: 1, 2)
Provided	In equilibrium	Maximized	5 → 10 → 15	80 (52, 28)
			5 → 15 → 10	48 (30, 18)
			10 → 5 → 15	49 (27, 22)
			10 → 15 → 5	24 (13, 11)
			15 → 5 → 10	28 (8, 20)
			15 → 10 → 5	13 (8, 5)
		Not maximized	10 → 20	7 (0, 7)
			5 → 25	18 (10, 8)
	Not in equilibrium		5 → 10 → 20	9 (4, 5)
			5 → 15 → 20	8 (2, 6)
			10 → 5 → 20	6 (1, 5)
Not provided			5	14 (4, 10)
			5 → 10	12 (5, 7)
			5 → 15	11 (6, 5)
		Tie cases associated with frequent orderings		
			5 ≈ 10 → 15	10 (6, 4)
			5 ≈ 15 → 10	9 (8, 1)
			10 → 5 ≈ 15	3 (2, 1)
			10 ≈ 15 → 5	1 (1, 0)

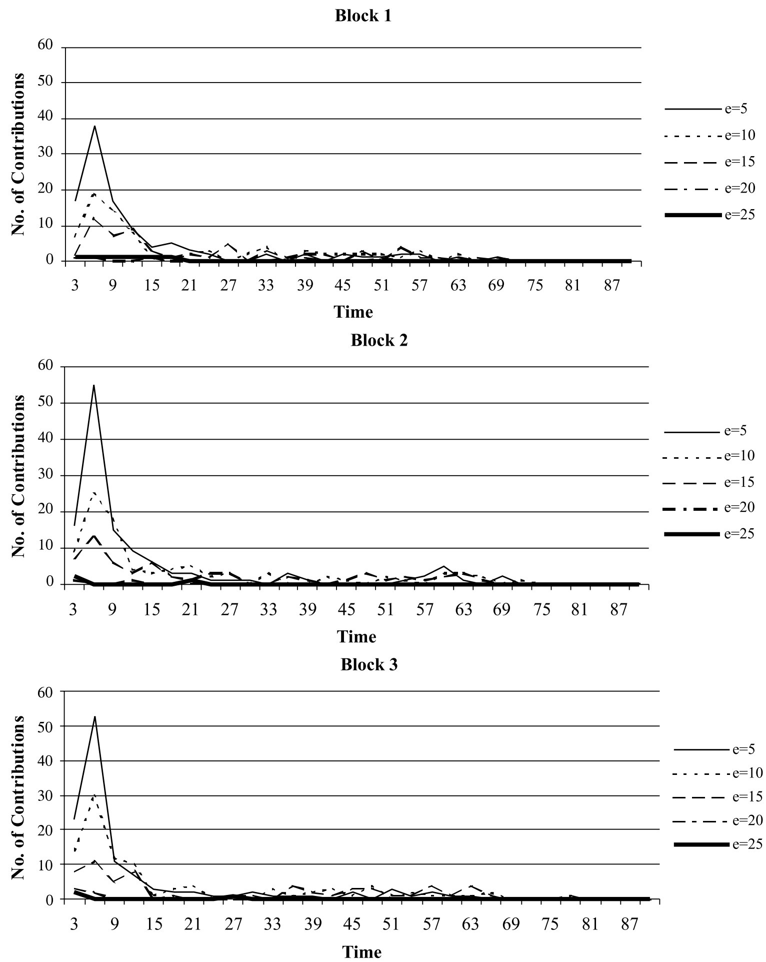

Fig. 2. Distribution of insufficient contribution times by player type and 15-round blocks (block 1, top; block 2, middle; block 3, bottom).

with the good being provisioned than with rounds ending with no provisioning. It certainly paid off to contribute early in the round.

Since early insufficient contributions were generally rewarded (by provisioning of the public good) it is interesting to find out whether players changed the timing of their insufficient contributions across iterations of the game. Fig. 2 shows the distribution of insufficient contribution times by endowment in each block of 15 rounds. Player types 1 and 2 slightly increased the speed of their contribution with repetitions of the game. However, the inverse relation between the frequency of early contribution and endowment size was already apparent in block 1. Furthermore, the small changes in early contribution frequencies did not result in significant changes of mean contribution time. (Mean insufficient contribution time of player 1: 12.8, 12.7 and 11.2 s in blocks 1–3, respectively. For player 2: 18.9, 17.7, and 15.8 s.) Thus, there is weak evidence for low endowment players learning to contribute early in the round because this tendency is already quite strong in the initial repetitions of the game.

5. Discussion and conclusions

5.1. Protocol effects

Based on the results of many public goods experiments with the VCM or PPM, a common view has emerged that some sort of verbal communication that precedes the decision is required for raising the level of contribution. Our findings show that, even without preplay communication, irrevocable commitments made under the real-time protocol of play result in levels of contribution to binary public goods not observed under the more common simultaneous protocol. More importantly, we do not observe the commonly reported decline in contribution levels over iterations of the game, which is characteristic of the simultaneous protocol (e.g., Davis & Holt, 1993). Rather, as shown in Fig. 3, which portrays the running average (in steps of 10 rounds) of the contribution level across both sessions, the percentage of time the public good was provided remained relatively stable, around 82% over a fairly large number of iterations of the stage game. Our results

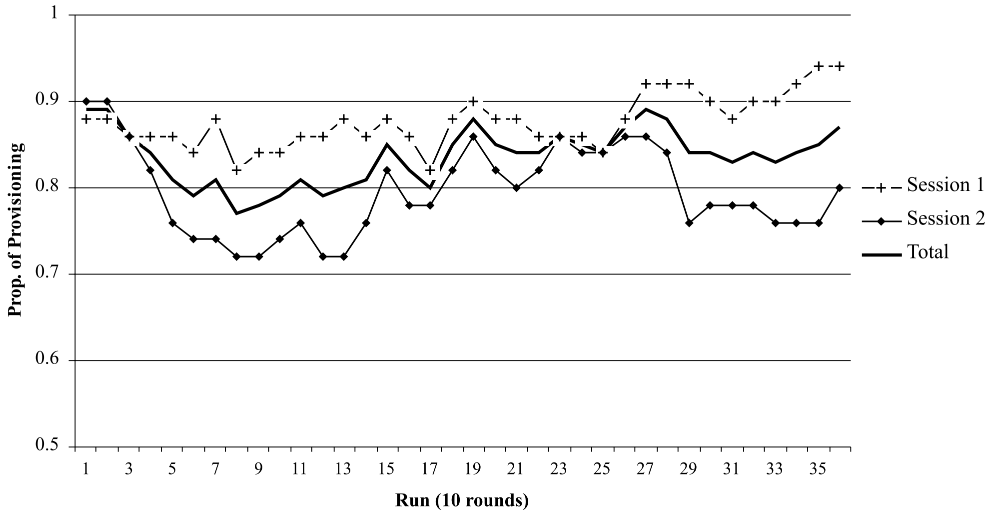

Fig. 3. Running means of public good provisioning by session ('run' = 10 rounds).

suggest that the real-time protocol of play can substitute for verbal communication followed by simultaneous play. The real-time mechanism is potentially more efficient, as it saves the transaction costs associated with open verbal discussions. The results further indicate that the bleak conclusions drawn from many iterated public goods experiments have to be qualified.

From an organizational perspective, one might hypothesize that the practice of delegating tasks to work groups that share responsibility for goal attainment would not have persisted if groups were unsuccessful in performing their tasks. Our results show that public good attainment is very likely when the dynamic real-time aspect of groups' public good situations is experimentally implemented. Therefore, it seems reasonable to assume that one factor contributing to work groups' ability to achieve successful goal attainment is members' ability to observe irrevocable commitments to group effort during the time period allotted for the task.

In the social loafing literature, experimenter-(Williams, Harkins, & Latane, 1981) and self-evaluations (Szymanski & Harkins, 1987) of individual effort have been found to positively affect group performance. The hypothesis that group members' ability to identify and evaluate each other's effort would improve group performance was never directly tested. Usually, it is assumed that the pooling together of individual efforts prevents group members from identifying each individual's contribution (Harkins, 1987). In other cases, the tasks chosen were such that accurate monitoring of other individuals' contributions was difficult (Latane et al., 1979). However, it is arguable that there are work group tasks that allow members to monitor each other's contribution. Based on our results, we would hypothesize that group performance in these tasks would show little evidence of social loafing.

Our study is pertinent mainly to groups with pooled task interdependence. Members of work groups with pooled task interdependence can carry on their work individually, and their contributions to the group's total product are interchangeable. In contrast, members of groups with reciprocal task interdependence rely on each other's performance for fulfilling their own task requirements (Thompson, 1967). At the extreme case, where each member's task fulfillment is dependent on others' performance, all group members need to perform well in their task for the group to meet its goal. This case can be more adequately modeled by a PPM mechanism where the number of contributors necessary for provisioning is equal to the total number of players in the group ($m = n$). Clearly, the effects of implementing the real-time protocol on individual contribution and good provisioning can also be studied in this context.

5.2. Wealth effects

We report strong evidence for "wealth effects" that were not observed in experiments with the simultaneous protocol of play (Rapoport, 1988). This wealth effect is quite strong, with type 1 players contributing eight times more often than type 5 players. Moreover, the endowment effect increases with experience. The analysis of the dynamics of play helps in understanding this effect. Players with relatively small endowments, who have relatively more to gain from the provisioning of the good, contribute early in an attempt to signal cooperativeness and elicit more contributions. Our analysis shows that they are often, but not always, successful. Evidence for the inclination to free ride is provided by those players who wait for 60 s or more in an attempt to elicit contributions by other players. It is mostly because of this inclination that 100% provisioning rate was not achieved even after 45 rounds of play.

A signaling interpretation of early contributions of low endowment players is supported by the results of a subsequent study by Goren, Rapoport, and Kurzban (2002) that used the same experimental design with the only exception that contributions, once made, could be withdrawn at any time during the round. The three low-endowment players in this experiment contributed roughly seven times as frequently as the two high-endowment players in the opening seconds of the round. Moreover, the initial contributions on the part of low-endowment players were effective; high-endowment players tended to contribute only after their contribution became critical for provisioning the public good. This pattern is consistent with our conjecture that small contributions are made early in the round to elicit contributions from high-endowment players.

Whether similar wealth effects in the frequency and timing of contribution would obtain in real-life groups facing public good provision problems under time constraint is a question for future research. Gersick's (1988) study on organizational task forces did not directly address the questions of the amount of work conducted during the time allotted for the task and the internal division of labor within the group.

5.3. Alternative explanations

Altruism, reciprocity, and equity considerations have been forwarded as basic behavioral principles explaining contributions to public goods with the PD property (e.g., Fehr & Schmidt, 1999). Our results neither refute nor support these explanations. On the one hand, we note that the equilibrium reached most frequently was also the one resulting in the greatest variation in individual payoffs within a group. If there were equity concerns, they were certainly not manifested within individual rounds. On the other hand, knowing that roles were randomly assigned on each round, players could expect approximately the same payoff across all the rounds if they were to converge on an equilibrium contributing set that maximized group earnings.

Although the latter explanation that assumes farsightedness on the part of all the players seems compelling, it does not account for the fact that the equilibrium contributing set {1,2,3} was most frequently formed in both sessions. As shown in Table 1, the players had three (rather than one) equilibrium sets that maximize group earnings to choose from. Rather, our results largely support Hypothesis 3 (and, consequently, Hypotheses 1 and 2). The most common outcome is an equilibrium contributing set that maximizes group earnings and includes players who have the most to gain relative to their investment. Moreover, with multiple iterations of the stage game play seems to be converging to the {1,2,3} equilibrium contributing set while the frequencies of the {1,5} and {2,4} equilibrium sets seem to decrease.

5.4. Limitations

If individuals are influenced by equity considerations, which were set off in the current design by randomizing player roles, then results should differ if the experiment is repeated with fixed rather than randomly determined roles for individual participants. Randomizing roles might have also helped participants to take the perspective of the other players in their group and thereby facilitated coordination on the {1,2,3} equilibrium set. Although their experimental setting is not comparable to our study, Güth et al. (2002) also reported different contribution proportions of players with different roles when roles were fixed throughout the experiment and the updating of contributions could only increase. This pattern leads in some cases to stable payoff differences between players with different initial endowments. However, there are many differences between Güth et al. and our study, and the effects of equity considerations on behavior in public good situations with the real time protocol merit further research.

Another limitation of our study is the all-or-nothing nature of contribution. In many real-life contexts contribution can be much more gradual. Although there may be cases in which contribution to group effort involves a binary irrevocable commitment, as when a number of volunteers are needed for performing a unique task, the binary contribution was used here as an approximation for the continuous case. We intend to conduct additional experiments using a continuous contribution mechanism.

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References

Croson, R. T. A., & Marks, M. (1998). Identifiability of individual contributions in a threshold public goods experiment. *Journal of Mathematical Psychology, 42*, 167–190.

Croson, R. T. A., & Marks, M. (1999). *The effects of heterogeneous valuations for threshold public goods: An experimental study*. Unpublished manuscript, University of Pennsylvania.

Davis, D. D., & Holt, C. A. (1993). *Experimental economics*. Princeton, NJ: Princeton University Press.

Dawes, R. M. (1980). Social dilemmas. *Annual Review of Psychology, 31*, 169–193.

Dawes, R., Orbell, J., Simmons, R., & van de Kragt, A. (1986). Organizing groups for collective action. *American Political Science Review, 80*, 1171–1185.

Dorsey, R. E. (1992). The voluntary contributions mechanism with real time revisions. *Public Choice, 73*, 261–282.

Earley, P. C. (1989). Social loafing and collectivism: A comparison of the United States and the People's Republic of China. *Administrative Science Quarterly, 34*, 565–581.

Erev, I., & Rapoport, A. (1990). Provision of step-level public goods: The sequential contribution mechanism. *Journal of Conflict Resolution, 34*, 401–425.

Fehr, E., & Schmidt, K. (1999). A theory of fairness, competition, and cooperation. *Quarterly Journal of Economics, 114*, 817–868.

Gersick, C. J. G. (1988). Time and transition in work teams: Toward a new model of group development. *Academy of Management Journal, 31*, 9–41.

Goren, H., Rapoport, A., & Kurzban, R. (2002). *Revocable commitments to public goods provision under the real-time protocol of play*. University of Arizona, Department of Management and Policy, Unpublished manuscript.

Güth, W., Levati, M. V., & Stiehler, A. (2002). *Privately contributing to public goods over time—An experimental study*. Report No. 01-2002, Max Planck Institute for Research into Economic Systems, Jena, Germany.

Hampton, J. (1987). Free-rider problems in the production of collective goods. *Economics and Philosophy, 3*, 245–273.

Harkins, S. G. (1987). Social loafing and social facilitation. *Journal of Experimental Social Psychology, 23*, 1–18.

Hovi, J. (1986). Binary games as models of public goods provision. *Scandinavian Political Studies, 9*, 337–360.

Isaac, R. M., McCue, K. F., & Plott, C. R. (1985). Public goods provision in an experimental environment. *Journal of Public Economics, 26*, 51–74.

Isaac, R. M., & Walker, J. M. (1988). Communication and free-riding behavior: The voluntary contribution mechanism. *Economic Inquiry, 26*, 585–608.

Isaac, R. M., Walker, J., & Thomas, S. (1984). Divergent evidence on free riding: An experimental examination of possible explanations. *Public Choice, 43*, 113–149.

Kerr, N. (1983). Motivation losses in small groups: A social dilemma analysis. *Journal of Personality and Social Psychology, 45*, 819–828.

Kravitz, D. A., & Martin, B. (1986). Ringelmann rediscovered: The original article. *Journal of Personality and Social Psychology, 50*, 936–941.

Kurzban, R., McCabe, K., Smith, V. L., & Wilson, B. J. (2001). Incremental commitment and reciprocity in a real time public goods game. *Personality and Social Psychology Bulletin, 27*, 1662–1673.

Latane, B., Williams, K. D., & Harkins, S. (1979). Many hands make light the work: The causes and consequences of social loafing. *Journal of Personality and Social Psychology, 37*, 822–832.

Ledyard, J. O. (1995). Public goods: A survey of experimental research. In J. Kagel & A. E. Roth (Eds.), *Handbook of experimental economics* (pp. 111–194). Princeton, NJ: Princeton University Press.

McKie, J. W. (1974). *Social responsibility in the business predicament*. Washington, DC: Brookings Institution.

Murnighan, J. K., King, T. R., & Schoumaker, F. (1990). The dynamics of cooperation in asymmetric dilemmas. In E. Lawler, B. Markovsky, C. Ridgeway, & H. Walker (Eds.), *Advances in group processes* (Vol. 7, pp. 179–202). Greenwich, Conn: JAI Press.

Olson, M. (1965). *The logic of collective action*. Cambridge, MA: Harvard University Press.

Palfrey, T. R., & Prisbrey, J. (1997). Anomalous behavior in public goods experiments: How much and why? *American Economic Review, 87*, 829–846.

Palfrey, T. R., & Rosenthal, H. (1991). Testing for effects of cheap talk in a public goods game with private information. *Games and Economic Behavior, 3*, 183–220.

Rabin, M. (2000). Risk aversion and expected-utility theory: A calibration theorem. *Econometrica, 68*, 1281–1292.

Rapoport, A. (1988). Provision of step-level public goods: Effects of inequality in resources. *Journal of Personality and Social Psychology, 54*, 432–440.

Rapoport, A., & Erev, I. (1994). Provision of step-level public goods: Effects of different information structures. In U. Schulz, W. Albers, & U. Mueller (Eds.), *Social dilemmas and cooperation* (pp. 147–171). New York: Springer.

Rapoport, A., & Eshed-Levy, D. (1989). Provision of step-level public goods: Effects of greed and fear of being gypped. *Organizational Behavior & Human Decision Processes, 44*, 325–344.

Schelling, T. (1960). *The strategy of conflict*. Cambridge, MA: Harvard University Press.

Schnake, M. E. (1991). Equity in effort: The "sucker effect" in coacting groups. *Journal of Management, 17*, 41–55.

Szymanski, K., & Harkins, S. G. (1987). Social loafing and self-evaluation with a social standard. *Journal of Personality and Social Psychology, 53*, 891–897.

Thompson, J. D. (1967). *Organizations in action*. New York: McGraw-Hill.

van de Kragt, A. J. C., Orbell, J. M., & Dawes, R. M. (1983). The minimal contributing set as a solution to public goods problems. *American Political Science Review, 77*, 112–122.

Williams, K. D., & Karau, S. J. (1991). Social loafing and social compensation: The effects of expectations of co-worker performance. *Journal of Personality and Social Psychology, 61*, 570–581.

Williams, K. D., Harkins, S. G., & Latane, B. (1981). Identifiability as a deterrent to social loafing: Two cheering experiments. *Journal of Personality and Social Psychology, 40*, 303–311.

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