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Revocable Commitments to Public Goods Provision under the Real-Time Protocol of Play

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ABSTRACT

Using the real-time protocol of play—a relatively new experimental mechanism in which the order of play and timing of decisions are determined *endogenously*—we investigate voluntary contributions to the provision of pure public goods. We consider the case where the good is binary, players are asymmetric, communication is prohibited, and all-or-none contributions to the public good can be withdrawn at any time during the round of play. Our results: (1) support an equilibrium in which contributors maximize the sum of their own payoffs; (2) show considerably higher levels of contribution than under the more commonly used simultaneous protocol of play; and (3) exhibit no decrease in level of contribution across multiple iterations of the stage game. On comparing our results to those of Goren et al. (2003), we conclude that modifying the mechanism so that contributions once made cannot be revoked yields significantly higher levels of contribution over the course of the game. Copyright © 2003 John Wiley & Sons, Ltd.

KEY WORDS binary public goods; binary contributions; equilibrium analysis; real-time protocol; commitments

INTRODUCTION

Pure public goods are defined in economics as goods satisfying 'nonrivalry' and 'nonexcludability.' Nonrivalry, also known as 'jointness of supply,' means that one individual's consumption of the good does not diminish the consumption possibilities of other members of her group. Nonexcludability implies that individual members of the group, irrespective of their level of contribution toward the good provision, cannot be excluded from consuming it once it is provided. Recognizing the possibility that individuals can 'free ride' on the contributions of others, economic theory predicts that public goods will be underprovided when

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funded with voluntary contributions. In sharp contrast to this socially undesirable prediction, there exists considerable evidence that mechanisms have evolved for the voluntary provision of public goods. Libraries, churches, art museums, public radios, political campaigns, and environmental cleanups continue to be financed by voluntary contributions to fund drives conducted by various private organizations and societies. This evidence by no means refutes the free-riding hypothesis, because we cannot know the optimal quantity of the public good that was actually provided (Rapoport, 1988). But it definitely casts doubt on its generality.

Two institutional mechanisms for public goods provision

This contradiction between economic theory predictions and field observations has given rise to an extensive program of experimental research that attempts to decompose group action into individual decisions in order to explain collective actions in terms of individual motivations. For partial reviews of this rapidly growing literature in both experimental economics and social psychology see Croson and Marks (1998), Dawes (1980), Kerr (1996), Ledyard (1995), and Sell (1997). Most of this literature has focused on one of two mechanisms for public goods provision. The first (e.g. Isaac & Walker, 1988) is the *voluntary contribution mechanism* (VCM) in which goods are provided in continuously divisible quantities, and players are symmetric with respect to the marginal rate of substitution between money contributed to private and public funds. In a typical VCM experiment, players are endowed with money and asked to divide it in any way between a private and a public (group) fund. Money placed in the private fund is kept by the individual, whereas the total money placed in the group fund is multiplied by some commonly known constant ($h > 1$) and then divided equally among the group members. For suitably chosen values of h, the VCM gives rise to a social dilemma (Dawes, 1980) of the Prisoner's Dilemma type in which zero contribution to the group fund is the unique Nash equilibrium. (A strategy profile where no individual can benefit by unilateral deviation. See, e.g. Colman, 1995; Dixit & Skeath, 1999 for non-technical explanations.)

The second institutional arrangement is the *provision point mechanism* (PPM) in which the public good is binary (step-level) and individual contributions are all-or-none (e.g. Bagnoli & Lipman, 1992; Bagnoli & McKee, 1991; Croson & Marks, 1998; Dawes, Orbell, & van de Kragt, 1988; Hovi, 1986; Kerr & Harris, 1995; Palfrey & Rosenthal, 1991; Rapoport & Eshed-Levy, 1989; Van de Kragt, Orbell, & Dawes, 1983). In a typical PPM experiment, n members of a small group are each endowed with e_i units ($i = 1, \ldots, n$) and asked to contribute all of them either to a private fund or group fund. If the total group contribution is equal to or larger than some commonly known provision threshold k, every group member receives a fixed reward (public good) r $(r > e_i)$. If not, no reward is given. Players who do not contribute to the group fund keep their endowments. In contrast to the VCM, contributing nothing to the group fund is not the only Nash equilibrium. The PPM has other pure-strategy equilibria, each of which consists of a vector of n individual decisions that together satisfy two conditions: (1) the total group contribution is either equal to or exceeds the provision threshold by no more than e_i; and (2) individuals do not contribute in excess of the benefit they derive from the good.

Protocols of play

Most of the experiments have studied the VCM and PPM under the *simultaneous protocol of play* in which group members make their decisions privately and anonymously. The simultaneous protocol has its advantages—it allows for straightforward derivations of the equilibrium solution in pure or mixed strategies, and it is easy to implement experimentally. However, it is an abstraction that does not capture the essence of many real-life voluntary contribution processes in which players often possess partial or complete information about the decisions of other group members *before* making their own decisions (Goren, Kurzban, & Rapoport, 2003, hereafter GKR). More recent experiments have shifted the focus of their investigation from testing the free-riding hypothesis under simultaneous play to assessing the effects of alternative protocols on the rate of public good provision. Erev and Rapoport (1990), Rapoport and Erev (1994), and Chen, Au, &

Komorita (1996) have studied the PPM with symmetric players (i.e. with identical endowments and rewards) under the *sequential protocol of play* in which group members make their decisions in turn with every member fully informed of her position in the sequence as well as the total contribution of all the players preceding her in the sequence. In the *positional protocol of play* (e.g. Budescu, Suleiman, & Rapoport, 1995; Rapoport, 1997), each player knows her position in the sequence as in the previous protocol. However, in contrast to the sequential protocol, she is no longer informed of the total contribution of the players who preceded her in the sequence. Both of these protocols have focused on binary contributions and step-level goods.

Neither of the latter two protocols fully captures the dynamics of real-life voluntary contributions to public goods. First, and most importantly, the order of play in these protocols is determined exogenously, whereas in real life no such order is typically imposed. When the order of play is endogenous (i.e. determined by the players themselves, and not by any external circumstances or authority), players can defer their decisions by waiting to see what other group members intend to do. Second, in real-life voluntary contribution processes time is continuous whereas in experiments it is divided into discrete stages (or rounds of play). As a result, information about the delays between successive decisions and the rate of contribution over time—factors that seem to affect behavior—are not accounted for. Dorsey (1992), and subsequently Kurzban et al. (2001) and GKR, proposed studying public good provision under the *real-time protocol of play* that we describe below.

The real-time protocol

In the real-time protocol, players can continuously update their decisions in real time. The time interval $[0,T]$ is bounded from below by 0. The upper boundary, T, may be a commonly known constant, a stochastic variable whose distribution is commonly known, or a stochastic variable whose distribution is not known. During the interval $[0, T]$ summary or individual information about the contributions of all players is continuously updated and displayed (with a possible time lag). Both the order of play and time of decisions are determined *endogenously*. The player's allocation to the public good at time T, if any, is taken to be her contribution for the round. Although the real-time protocol can be used to study the VCM (as in Dorsey, 1992, and Kurzban et al., 2001), in the present study it is implemented under the PPM.

A major advantage of the real-time protocol, not shared by the protocols described above, is that it allows the study of the effects of individuals committing to their contribution decisions on the rate of public good provision. The term 'commitment' is taken here to mean that one will carry out those actions which she has promised or committed herself to perform (Kerr, 1995). In the psychological literature of social dilemmas the effects of commitment are typically studied in the context of pre-play communication (Braver, 1995; Dawes, McTavish, & Shaklee, 1977; Kerr, 1995). In contrast, under the real-time protocol of play commitment is operationalized as the time adjustment of the decision. We distinguish between two major types of time adjustment. In the first type, players are only allowed to increase their contributions at any time during the interval $[0,T]$. Under the PPM, this implies that a player can make, at most, a single decision—contribute her entire endowment to the provision of the good. GKR refer to these contributions as *irrevocable commitments*. In the second type, players can either increase or decrease their contributions at any time during the time interval $[0, T]$. Under the PPM, this implies that a player can make multiple decisions during the round—contribute her endowment to the good provision, withdraw her contribution, or recontribute. We refer to contributions under this type of time adjustment as *revocable commitments*. Although less frequently observed, revocable commitments occur when individual contributions are contingent on the decisions of others (e.g. 'I'll contribute my share if and only if m of the remaining $n-1$ group members contribute theirs' or 'I'll contribute my share if the total contributions of the others is no smaller than some fixed and pre-determined constant.'). If the contingency does not occur, the contribution is withdrawn. This has a parallel in real life, for example in fund drives with public pledges that are not always honored.

There are good reasons to believe that irrevocable commitments are more effective in eliciting contributions to the public good. A number of authors have suggested that the decay in contributions, which is almost always observed in multiround public goods games under simultaneous play, might be due to reactions from players who make high contributions in early rounds to the behavior of other players who are not reciprocating with similar high contributions. Generous players might be scaling back their contributions in later rounds because they perceive that their generosity is not being appropriately reciprocated (Andreoni, 1995; Fischbacher, Gächter, & Fehr, 2001). If this behavioral pattern holds in a real-time environment, then fears that others might revoke their contributions toward the end of the round might dissuade participants from contributing. Removing the exit option should reassure players who use this type of conditional strategy and, therefore, increase provisioning of the public good. Reciprocity models are currently insufficiently specified for formal theory development in real time, but it is worth noting that a mechanism of irrevocable commitment has been shown to increase contributions in linear games (Dorsey, 1992; Kurzban et al., 2001).

In a previous study, GKR (hereafter referred to as the 'previous study') investigated irrevocable commitments in real time under the PPM and reported especially high levels of provision that stayed steady over multiple iterations of the game. Such high levels of provision in step-level public good experiments have only been observed in groups that could communicate prior to making their decisions (van de Kragt et al., 1983). The present study continues this line of research but shifts the focus to revocable commitments. The two studies have jointly been designed to isolate and control the effects of non-verbal commitment in public good provision and study it experimentally. Their results are complementary.

Both studies have preserved the anonymity of participants, eliminating any possible effects of reputation (Milinski, Semmann, & Krambeck, 2002), which otherwise might induce cooperation through between-round reciprocity, which was not our immediate interest in this research.

Following the previous study by GKR, we investigate the effects of revocable commitments on the level of public good provision by asymmetric players known to differ from one another in their size of endowment ('wealth'). We do so because symmetry in wealth is clearly a very special case not often encountered in practice. We use the real-time protocol with continuous information updating and a value of T randomly drawn from a commonly known distribution. A random time boundary, T, models situations involving uncertainty regarding the amount of time available for public-good provisioning. It was chosen here because we believe that in actuality there are very few cases in which there is an absolute deadline for provisioning that is known in advance. Another reason for choosing this design feature was to increase comparability with the previous GKR study.

The remainder of the paper is organized as follows: Section 2 describes the game and states several testable hypotheses about the level of contribution at the end of the round; Section 3 describes the experimental procedure and game parameters; Section 4 describes the results of the present study; Section 5 compares the present study with the previous study; and Section 6 describes our conclusions. A major finding is that the real-time protocol with either revocable or irrevocable commitments induces higher levels of contribution than those typically observed under the simultaneous protocol. Moreover, in contrast to simultaneous protocol, these levels do not decrease under iterations of the stage game. This makes our results differ from a large proportion of public goods experiments. Further, our results indicate that low-endowment players are more likely to contribute than high-endowment players. This finding calls into question the emphasis on efficacy in decisions to contribute to public goods (Kerr, 1996). Finally, we find that the levels of contribution are significantly lower when commitments are revocable than when they are not.

GAME DESCRIPTION AND HYPOTHESES

The game

Consider a pure public good game played by a group of size $n = 5$ players, with exogenous and commonly known endowments of $e_1 = 5, e_2 = 10, e_3 = 15, e_4 = 20,$ and $e_5 = 25$. Players are ordered by the size of their endowments and referred to as players of types 1, 2, 3, 4, and 5, respectively. (Hereafter we use the term 'type' to refer to the player's endowment, with higher player types corresponding to larger endowments.) If provided (at time T), the public good is worth $r = 30$ to each player, with a commonly known provision point of $k = 30$. An endowment not contributed by the player at time T is kept. The value of T is randomly drawn from a commonly known uniform distribution defined over the interval [60,90]. Player j's contribution at time t ($0 \leq t \leq T$) is denoted $c_{j,t}$, and the total contribution at time t is denoted C_t. At any time t during the round, the player's entire endowment can be either contributed to the public good or withdrawn. The final payoff to player j at time T is denoted by x_j. The game is iterated for 45 rounds. At any time during the round, players observe all the updated individual contributions, the total group contribution, and the value of k.

As formulated above, the step-level public good game played under the real-time protocol of play shares elements with games in network contexts (e.g. Greenwald, Friedman, & Shenker, 2001). These games are played in asynchronous fashion. There need not be any notion of definable 'rounds of play' in these games as players can update their strategies at any time. A complete theory of behavior under the real-time protocol of play should account for the order of play by different types of players, effects of time delays between decisions to either contribute or withdraw their contribution, and effects of time left before the (stochastic) termination of the round on the final outcome. From a game theoretic perspective, the contribution decision and its timing and the withdrawal decision and its timing should all be part of the players' strategy space.

In the absence of such a theory, we have separated between the formal analysis of the final outcomes and the descriptive analysis of the dynamics of play. The hypotheses stated below are based on static analysis; they only refer to the final outcome when the game terminates at time T, and ignore the behavior of the players in the interval [0,T]. Although this analysis is clearly incomplete, it is not without merit or precedence. For example, there is a large body of experimental literature both in economics and psychology (see Kahan & Rapoport, 1984, for a partial review) designed to test solution concepts like the kernel, bargaining set, Shapley value, and the core for n-person cooperative games in characteristic function (coalitional) form. Whereas the solution concepts are static, they have been tested in experiments that evolve over time and include offers, counter-offers, and other strategic moves not accounted for by these solution concepts. Similarly, we argue that there is merit in focusing on the final outcomes while ignoring the presently intractable process of contributions and withdrawals of contributions that evolve over time. This analysis is particularly useful and informative when the purpose of the investigation is to compare degrees of free riding under alternative protocols of play or to compare the effects of revocable vs. irrevocable commitments on the level of contribution, as we do in Section 5. In contrast, the purpose of the dynamic analysis reported in Section 4 is to reveal patterns of behavior during the round that may, hopefully, serve later to construct a descriptive theory of the decision processes leading to the final outcomes.

Equilibrium analysis of final outcomes

With binary strategy spaces and mutual independence between players, there are $2^5 = 32$ possible outcomes (e.g. no player contributes; all five players contribute; only players 3 and 5 contribute; etc.). Of these 32 outcomes, 8 are in equilibrium (see Table 1). Column 1 of Table 1 shows the equilibrium vectors, called 'contributing sets' (where {Ø} denotes the null set). Column 2 shows the corresponding total group contribution, and columns 3–7 present the resulting individual payoffs. The sum of the individual payoffs for each of the eight equilibria, denoted by X, is presented in column 8. Inspection of this column shows that three of the eight equilibrium contributing sets (rows 2, 3, and 8) maximize total group payoff, as they reach (rather than exceed) the provision threshold ($C_T = k$).

Although the equilibrium analysis reduces the number of possible outcomes from 32 to 8, it does not resolve the coordination problem (that arises in any noncooperative game with multiple equilibria) since it does not yet specify exactly how each player should act. Additional considerations may be invoked to reduce the size of this set. The first consideration is that, in choosing among the equilibria, players prefer

Table 1. Pure strategy equilibria and associated individual and group payoffs

Equilibrium contributing set	C_T	x_1	x_2	x_3	x_4	x_5	X
{Ø}	0	5	10	15	20	25	75
{1, 5}*	30	30	40	45	50	30	195
{2, 4}*	30	35	30	45	30	55	195
{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

C_T, total contribution at the round's end; x_j, player *j*'s payoff; *X*, total group payoff.
*This equilibrium maximizes total group payoff.
**This equilibrium, in addition, maximizes the sum of net payoffs of the contributors.

an equilibrium that maximizes total group payoff. This consideration follows from a more basic hypothesis, common to psychology and economics, of maximization of individual outcome. Instructed that in the present experiment player types randomly vary from round to round with each participant having the same opportunity to be assigned to each of the five player types, maximizing group payoff (within the equilibrium set) across rounds also maximizes individual payoff. A focal point argument (Schelling, 1960) further supports this consideration: the equilibria that maximize total group payoff are the only ones (Table 1) in which $C_T = k$ so that excess contribution $(C_T - k)$ is not wasted. These considerations give rise to the following two hypotheses:

Hypothesis 1. The game will end in equilibrium.

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

If more than a single efficient equilibrium is designated, ensuring individual payoff maximization becomes difficult. The individual player will have to assign per-type contribution probabilities that reflect the frequencies with which other types choose any of the different efficient equilibria. The individual's per-type contribution pattern will have to be consistent and time-coordinated with those of the other players. Therefore, there is a strong incentive for the players to coordinate on just a single efficient equilibrium outcome.

We propose that in attempting to solve the coordination problem, the players will search for an equilibrium that maximizes the sum of their own net payoffs. Denote by $s_j = r - e_j$ the net payoff for player *j* (after contributing the endowment that cannot be refunded). Of the three equilibria suggested by Hypothesis 2, contributing players will select the one that maximizes the sum of their *net payoffs*. (These sums equal 30, 30 and 60 for the contributing sets $\{1, 5\}, \{2, 4\}$and$\{1, 2, 3\}$, respectively.) Hence, maximization of the net payoff within the set of equilibria that maximize group payoff will solve the coordination problem. This leads to:

Hypothesis 3. The game will end in the equilibrium that maximizes the sum of the contributors' net payoffs, namely, the contributing set $\{1, 2, 3\}$.

We next show that a mixed-strategy equilibrium, in which player types 1, 2, 3, 4, and 5 each contributes with certain positive probability, does not exist. In doing so, we make use of the notion of criticality that is closely related to the notions of efficacy and self-efficacy studied by Bandura (1986), Kerr (1992; 1996), Kerr and Harris (1995), Kerr and Kaufman-Gilliland (1994), and many others. Bandura defined *perceived* self-efficacy as a 'judgment of one's capability to accomplish a certain level of performance' (1986, p. 391). Narrowing the definition to self-efficacy in social dilemmas, Kerr defined it as a *judgment* 'of the degree to which one's cooperative behavior will increase the chances of the group achieving some valued collective outcome' (1996, p. 212). In our experiment, the assignment of a player to one of the five types is likely to influence her judgment about the likelihood that her contribution will have an effect on the probability of reaching the provision threshold. Because we did not independently measure this judgment, we only used the player's actual endowment for our expected utility analysis. Note that unlike efficacy, criticality can be defined without reference to (subjective) perceptions on the part of participants. We employ the notion of criticality with the understanding that it is the perception of criticality or efficacy that ultimately influences actual decision making.

In deciding whether to contribute a player can find herself in one of three mutually exclusive and collectively exhaustive states. Given the joint decisions of the other $n-1$ players, player j's contribution is said to be:

insufficient, if the sum of others' contributions (denoted by e_{-j}) is smaller than the provision threshold k, and the addition of player j's endowment to this sum leaves the resulting total contribution smaller than k;
critical, if the sum of others' contributions is smaller than the provision threshold k, and the addition of player j's endowment to this sum renders the resulting total group contribution equal to or larger than k; or
superfluous, if the sum of the others' contributions is already equal to or exceeds k.

Table 2 presents these three states and the corresponding payoffs associated with the decision to either contribute or not. We show that while all players may become critical for provisioning, those with larger endowments (higher types) are more critical than others. Therefore, 'criticality' in our experiment is an increasing function of the player's type.

The probabilities of the three states, which assume different values for different player types, are denoted by $P_{IN}(j)$, $P_{CR}(j)$, and $P_{SU}(j)$. To characterize them, assume that types 1, 2, 3, 4, and 5 contribute their endowments with respective probabilities p_1, p_2, p_3, p_4, and p_5 $(p_j \geq 0)$. In equilibrium, the expected utility of contributing and not contributing should be the same for every player j. From Table 2, we obtain directly that

$$u(r)[P_{CR}(j) + P_{SU}(j)] = u(e_j)[P_{IN}(j) + P_{CR}(j)] + u(r + e_j)P_{SU}(j).$$

Using the fact that $P_{IN}(j) + P_{CR}(j) + P_{SU}(j) = 1$, this equation reduces to

$$u(r)P_{CR}(j) = u(e_j)[1 - P_{SU}(j)] + u(r)P_{SU}(j) + u(r + e_j)P_{SU}(j)$$

Under the assumption of common risk-neutrality, these equations further reduce to

$$P_{CR}(j) = e_j/r, \qquad j = 1, 2, \ldots, 5 \tag{1}$$

Table 2. Individual payoff matrix for player type* j

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

e_{-j} denotes the endowments of all the players, except player j, who are assumed to contribute; k denotes the provision threshold; 0, r, e_j, $r + e_j$ denote the payoffs to player j following the decision to contribute/not to contribute, and the contribution status—insufficient, critical or superfluous for provisioning. The bottom row displays the notations of the probabilities that each of these contribution statuses hold.
*'Type' refers to the size of the player's endowment, e_j, at a particular round.

Equation 1 shows that in equilibrium the probability of being critical for the good provision should be equal to the ratio of player *j*'s endowment to the value of the public good. With unequal endowments, the probability of being critical for the good provision increases linearly in the size of the endowment. Writing $P_{CR}(j)$ in terms of the five probabilities p_j, we can show that there exist no five probabilities $p_1, \ldots, p_5$ that simultaneously satisfy these five equations. Consequently, the equilibrium analysis that we have conducted together with additional considerations introduced to resolve the coordination problem by reducing the number of equilibria yields the hierarchy of Hypotheses 1–3.

METHOD

Participants

Undergraduate students at the University of Arizona were recruited to participate in an experiment on group decision making. They were promised \$5 for showing up, and additional payments contingent on their performance. Two sessions with 25 subjects in each were conducted, each lasting about two hours. The mean individual payment across sessions was \$22.20, with individual payoffs ranging between \$20.00 and \$26.75.

Procedure

Upon arriving at the laboratory, participants were assigned to one of 25 computer terminals. Partitions separating the computers prevented the participants from observing one another's screens. Written instructions explained the public goods game and informed the participants of the following:

(1) They would play a large number of rounds of an 'interactive decision-making experiment.' (The number of rounds was not disclosed to prevent end effects.)
(2) They would be assigned to groups of five players on each round of play.
(3) Group composition would vary randomly from round to round. Therefore, players would not be informed of the identity of the other four members of their group.
(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 be made randomly at the beginning of each round.
(5) Each round would last between 60 and 90 seconds with any value in this range having the same probability. During the round participants would be able to change their decision from no contribution to contribution and vice versa at any time and as often as they wished. A clock counting time in seconds would be displayed on all five individual 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.

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 total group contribution at time $t(C_t)$.
(4) A message indicating whether the provision threshold was reached or exceeded and the individual payoffs for the round.

Players had no access to their previous decisions and payoffs. Nor did they receive any information about the identity and payoffs of the other group members. With the exception of the option allowing withdrawal of the contribution, the instructions were identical to those of GKR.

RESULTS: PRESENT STUDY

As mentioned earlier, we separate between the analyses of the final outcomes and dynamics of play. The static analysis provides strong support for Hypotheses 1–3 and shows that the contributing set $\{1, 2, 3\}$ formed more frequently over iterations of the stage game. The dynamic analysis reveals a complex decision process where different player types use the options of contribution and withdrawal of contribution in an attempt to balance two goals of: (1) forming a contributing set and thereby receiving the public good; and (2) inducing others to contribute and thereby increasing one's own payoff. Fear of not receiving the good and greed operated differentially for the five types reflecting the different degrees of their criticality for the good provision.

Static analysis

We first tested whether the two sessions were similar to each other on three different measures: mean payoff per round; proportion of good provision; and proportion of contribution by player types. We first tested the null hypothesis of no difference between the mean payoffs (across 45 rounds) of the two sessions. This hypothesis could not be rejected (mean individual payoffs were 31.7 and 30.7 tokens in Sessions 1 and 2, respectively; $t_{(48)} = 1.62, p = 0.11$). The proportions of public good provision also did not differ significantly between sessions (73.8% and 72.4% for Sessions 1 and 2, respectively.) Next, we computed the proportion of contribution decisions by player type. Given that each player was assigned to each type nine times, each proportion could assume one of ten values (0, 1/9, 2/9, ..., 1). Treating the five proportions for each player as repeated measures, we analyzed them using a mixed-design two-way ANOVA with one between-subjects factor (Session) and one repeated-measures factor (Type). The effect of Type was significant ($F_{(4,192)} = 61.7, p < 0.001$), but the Session effect was not. However, the analysis also yielded a significant Session by Type interaction effect ($F_{(4,192)} = 3.11, p < 0.05$). Therefore, sessions are treated separately in subsequent analyses. Table 3 (top panel) presents the mean percentage of contribution by player type and session.

Table 3 shows that in both sessions the percentages of contribution were negatively correlated with endowment size. The effects are quite strong—across sessions, type 1 and 2 players contributed about four times more often than type 5 players. These results suggest that the same process linking type (wealth) and contribution rates operated in both sessions with some variation in the quantitative relationship between them.

Table 3. Percentage of contribution by player type and session in the present study (top panel) and previous study (bottom panel)

Type (endowment)	Session 1	Session 2	Across sessions
Present study			
1 ($e_1 = 5$)	66.7	58.2	62.4
2 ($e_2 = 10$)	67.1	60.0	63.6
3 ($e_3 = 15$)	57.3	44.4	50.9
4 ($e_4 = 20$)	22.7	27.1	24.9
5 ($e_5 = 25$)	10.7	21.3	16.0
Previous study			
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

Table 4. Observed percentages of contributing sets by blocks in the present (top panel) and previous (bottom panel) studies

Contributing set	Block 1 (1–15)	Block 2 (16–30)	Block 3 (31–45)	Total
Present study				
{Ø}	7.3 (11)	10.0 (15)	8.7 (13)	8.7 (39)
{1, 5}*	12.7 (19)	6.7 (10)	3.3 (5)	7.6 (34)
{2, 4}*	11.3 (17)	10.7 (16)	10.0 (15)	10.7 (48)
{2, 5}	5.3 (8)	2.0 (3)	2.0 (3)	3.1 (14)
{3, 4}	7.3 (11)	4.0 (6)	2.7 (4)	4.7 (21)
{3, 5}	1.3 (2)	1.3 (2)	0.7 (1)	1.1 (5)
{4, 5}	2.7 (4)	0.7 (1)	0.0 (0)	1.1 (5)
{1, 2, 3}**	24.7 (37)	37.3 (56)	47.3 (71)	36.4 (164)
Other	27.3 (41)	27.3 (41)	25.3 (38)	26.7 (120)
Total	150	150	150	450
Previous study				
{Ø}	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 (0)	0.7 (1)	0.2 (1)
{3, \4}	2.0 (3)	0.0 (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 (0)	0.0 (0)
{1, 2, 3}**	46.7 (70)	63.3 (95)	66.7 (100)	58.9 (265)
Other	37.3 (56)	30.0 (45)	24.0 (36)	30.4 (137)
Total	150	150	150	450

Block = 15 consecutive rounds of play. 'Other' includes all non-equilibrium outcomes with both provisioning and no provisioning rounds.
*This equilibrium maximizes total group payoff.
**This equilibrium, in addition, maximizes the sum of net payoffs of the contributors.

Tests of Hypotheses 1–3

The upper panel of Table 4 presents the percentages of the contributing sets that were formed at time *T*. The percentages are presented in three blocks of 15 rounds each and across the 45 rounds (right-hand column). About 27% (120 cases) of all the outcomes in the top panel of Table 4 are included in the 'Other' category. In 38 of these cases, the public good was provided with contributing sets that included as a subset one of the seven nonempty sets in Table 1. In the remaining 82 cases, the public good was not provided, although either one player (51 cases) or two players (31 cases) contributed their endowment. Equilibrium contributing sets occurred in 73.3% of all the rounds across sessions in support of Hypothesis 1. Under the assumption that all 32 (2^5) contributing sets are equally likely, the null hypothesis that the 8 equilibrium-contributing sets only account for 25% of the outcomes was overwhelmingly rejected ($\chi^2_{(1)} = 560.7$, $p < 0.001$); this was the case for each session separately (Session 1: $\chi^2_{(1)} = 301.3$, $p < 0.001$; Session 2: $\chi^2_{(1)} = 260.1$, $p < 0.001$). A stronger null hypothesis asserts that any one of the 22 'winning' contributing sets (that ensure provision) 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 overwhelmingly rejected ($\chi^2_{(1)} = 486.4$, $p < 0.001$). Importantly, the fraction of rounds ending in equilibrium neither increased nor decreased significantly across blocks as players gained experience ($\chi^2_{(2)} = 0.21$, $p = 0.90$; Table 4).

These results contrast sharply with traditional simultaneous play public goods game results in two important ways. First, the overall rate of provisioning of the public good is considerably higher than in other experiments, excluding those in which face-to-face communication was permitted (Dawes et al., 1977) or a sanctioning system was imposed (Fehr & Gächter, 2000; Yamagishi, 1986). Second, we do not observe the characteristic steep decline of rate of provision over iterations frequently observed in multiround experiments.

In support of Hypothesis 2, the three contributing sets maximizing total earnings together accounted for 74.6% of all the rounds ending in equilibrium (see top panel of Table 4). This percentage is significantly above what would be expected by chance (37.5%) if all eight equilibrium sets were equally likely ($\chi^2_{(1)} = 193.2$, $p < 0.001$). It holds in each session separately (133 out of 169 rounds that end in equilibrium in Session 1, and 113 out of 161 rounds in Session 2).

Consistent with Hypothesis 3, the contributing set {1,2, 3} formed with the greatest frequency: 36.4% of the time (42.7% and 30.2% of the time in Sessions 1 and 2, respectively). This rate is much higher than what would be expected by chance. This result holds 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 total group earnings. Much more importantly, the frequency of formation of the contributing set {1, 2, 3} *doubled* from block 1 to block 3 (Table 4). This increase was statistically significant (${\chi_{(2)}}^2 = 16.71$, $p < 0.001$) when cross-tabulating blocks on an indicator variable that codes the set {1, 2, 3} as one category and all other sets as another category. The same observation holds separately in each session. The corresponding percentages are 32.0, 46.7, and 49.3 in Session 1 ($\chi^2_{(2)} = 5.34$, $p = 0.07$), and 17.3, 28.0 and 45.3 in Session 2 ($\chi^2_{(2)} = 14.21$, $p < 0.001$). In summary, although not all rounds ended in equilibrium, there is strong evidence of convergence toward the formation of the contributing set {1, 2, 3}.

We also tested the hypothesis that participants with more to gain from the good provision are more likely to contribute their endowment. The aggregate data support this hypothesis (see Table 3). The mixed-effects ANOVA described above also yielded a strong and significant player-type effect (see above). Planned contrasts comparing each endowment size to the next showed that, starting at player-type 2 ($e = 10$), the contribution proportion of type j was significantly higher than the proportion of type $j + 1$ ($F_{(1,48)} = 0.11$, $p = 0.74$; $F_{(1,48)} = 14.81$, $p < 0.001$; $F_{(1,48)} = 39.02$, $p < 0.001$, and $F_{(1,48)} = 7.04$, $p < 0.05$, respectively).

The player-type effect was strong and significant in both sessions ($F_{(4,96)} = 50.21$, $p < 0.001$ in Session 1, and $F_{(4,96)} = 18.06$, $p < 0.001$ in Session 2). Moreover, with more experience in playing the stage game, contribution decisions by types 1, 2, and 3 steadily increased whereas the percentages of contribution by types 4 and 5 steadily decreased (see Table 5). The effects for types 3, 4 and 5 are particularly strong—an increase of 18% from 41.3% to 59.3% for type 3, a decrease of 18% from 34.7% to 16.7% for type 4, and a decrease of 24% from 30.0% to 6.0% for type 5.

Dynamic analysis

For the remainder of this section we use the term 'entry' to denote a decision to contribute, and 'exit' to denote a decision to withdraw one's contribution. We focus on the frequency and timing of these two decisions. A major question is how often and in what way the entry and exit decisions were used by different player types, and how they affected the rate of provision. Recall that each participant was assigned to each type nine times, and therefore player types are not identical to participants.

Table 5. Percentage of contributions by player type* and block: present study

Player type	Block 1 (1–15)	Block 2 (16–30)	Block 3 (31–45)	Total
1	58.0 (87)	61.3 (92)	68.0 (102)	62.4 (281)
2	58.0 (87)	63.3 (95)	70.0 (105)	63.8 (287)
3	41.3 (62)	52.0 (78)	59.3 (89)	50.9 (229)
4	34.7 (52)	23.3 (35)	16.7 (25)	24.9 (112)
5	30.0 (45)	12.0 (18)	6.0 (9)	16.0 (72)

Block = 15 consecutive rounds of play.
*'Type' refers to the player's endowment at a particular round.

Frequencies of entry and exit decisions

For each round and each player, we coded whether or not she used the exit option. Overall, across player types, the exit option was used 40.5% of the time. It was used differentially by player types and significantly decreased with the endowment size. Player types 1, 2, 3, 4, and 5 exercised the exit option 51.6%, 50.4%, 45.1%, 30.2% and 25.1% of the time respectively. These percentages were submitted to a mixed-design two-way ANOVA with one between-subjects factor (Session) and one within-subjects factor (Type). The main effects of both factors were significant ($F_{(4, 192)} = 21.3$, $p < 0.001$, for Type, and $F_{(1, 48)} = 4.46$, $p < 0.05$, for Session), but the two-way interaction effect was not ($F_{(4, 192)} = 0.33$, $p = 0.86$). The exit option was exercised more frequently by players with lower type, even though they eventually contributed more often than did players with large endowments.

During a round, players could enter, exit, and reenter as many times as they wanted. For each player in each round we counted the number of entries. The mean number of entries per round was 1.62, 1.55, 1.33, 0.84 and 0.58 for player types 1, 2, 3, 4, and 5, respectively. We submitted these measures (mean number of entries per round) to the same kind of ANOVA as above. The analysis yielded a significant Type main effect ($F_{(4, 192)} = 36.2$, $p < 0.001$). Neither the Session main effect nor the Session by Type interaction effect was significant. Taken together, the latter two analyses show a strong negative relationship between endowment size and the frequency of using the entry and exit options.

Timing of entry and exit decisions

The analysis of entry and exit decisions is incomplete without examining the timing of these decisions. Figure 1 displays the frequency distributions of entry time by player type in three-second intervals. It shows that entry for all five types peaked quickly in the first ten seconds or so, and that in that time period the frequency of contribution was inversely related to the endowment size. This relationship did not appear to hold in a second and considerably smaller peak between 55 and 69 seconds.

The results displayed in Figure 1 include all entry decisions. Figure 2 displays the distribution of entry times divided into first-time entry (dark-shaded) and reentry (light-shaded) decisions. The results are presented separately by player type. For all player types, first-entry decisions are seen to occur long into the round's duration. Some even persist after the time $t = 60$ seconds. In many cases, players of all types

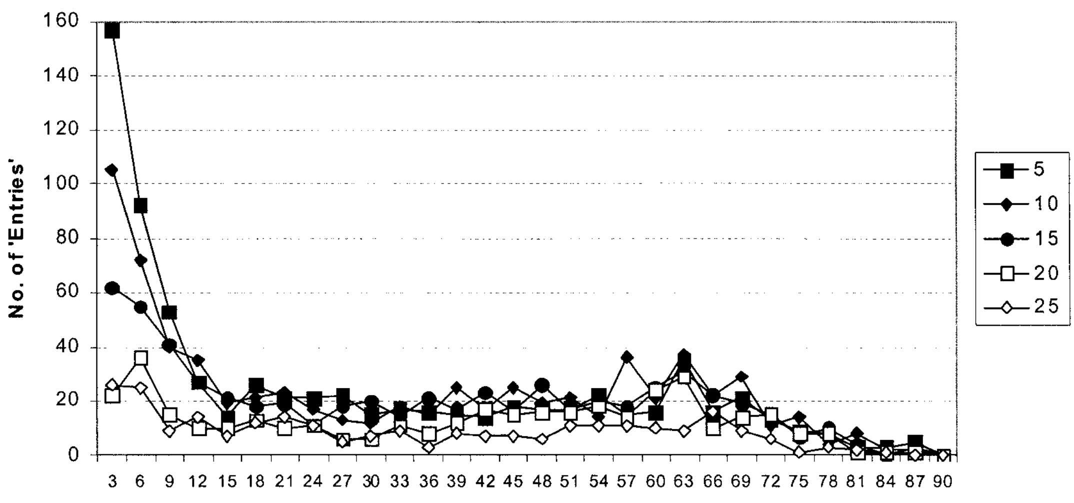

Figure 1. Frequencies of entries by time and player type. 'Type' refers to the player's endowment at a particular round

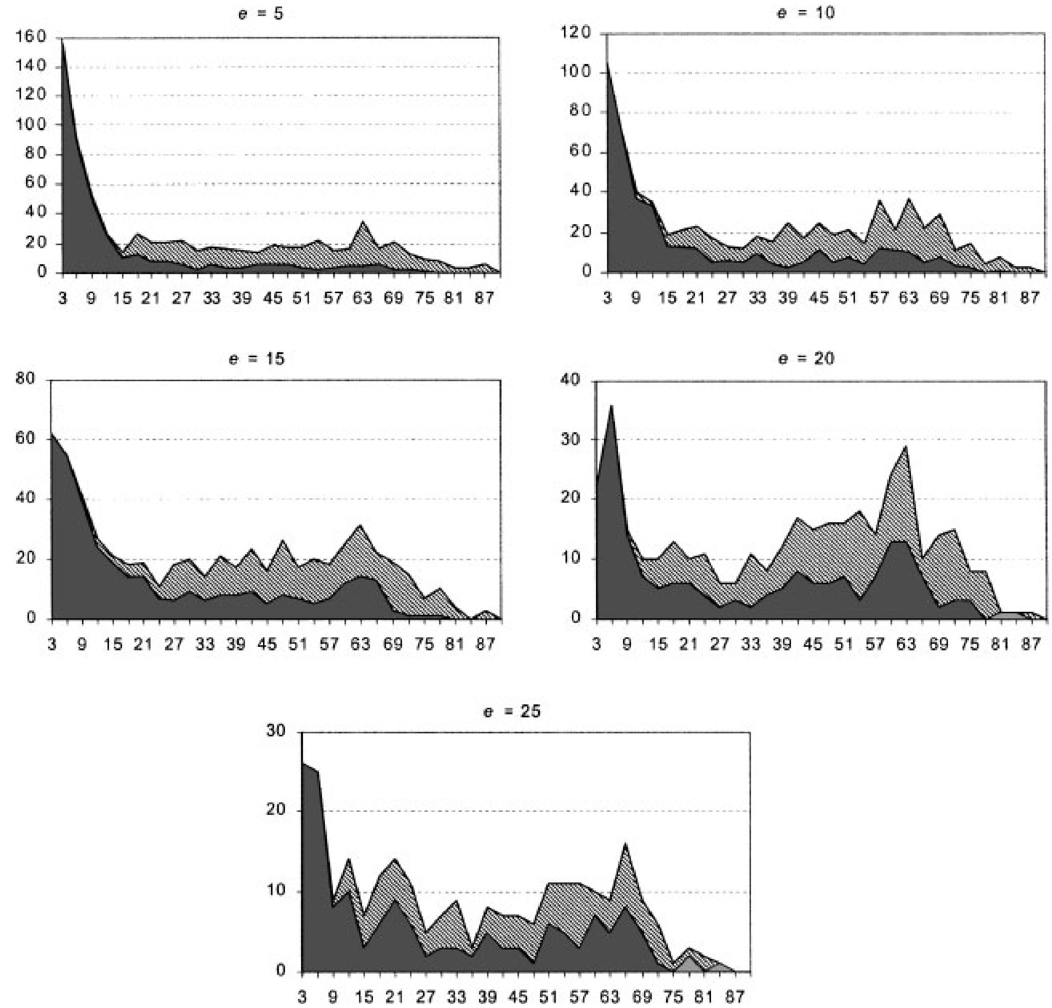

Figure 2. Frequencies of first entries (heavy-shaded) and later entries (light-shaded) by time and player type. (Vertical axes, frequencies; horizontal axes, time in seconds)

withheld their contribution to apply pressure on others to contribute or simply observe whether their contribution would be critical for successful provision of the good.

Another important aspect of the results exhibited in Figure 2 is the ratio of the number of first entries to number of all entries during the second peak towards the end of the round (seconds 55 to 69). Now we observe a pattern that is the reverse of the one that occurred in the first ten seconds, with first entries constituting 18.4%, 31.7%, 42.6%, 46.2% and 50.9% of all entries in this time interval for player types 1 to 5, respectively. The 'wealthier' player types, who have a greater effect on reaching or exceeding the provision threshold, tended more than the 'poorer' players to withhold their first contribution until the round might end.

This suggests that criticality of the contribution, in the sense described before, played a significant role in the timing of the entry decisions. Figure 3 displays the entry-time distributions, divided into entries made when players' endowments were insufficient (black), critical (gray), or superfluous (white) for the good provision. The results are shown separately by player type. Figure 3 shows that when the player's contribution was superfluous, entry decisions occurred with negligible frequency. The fraction of critical entries increased

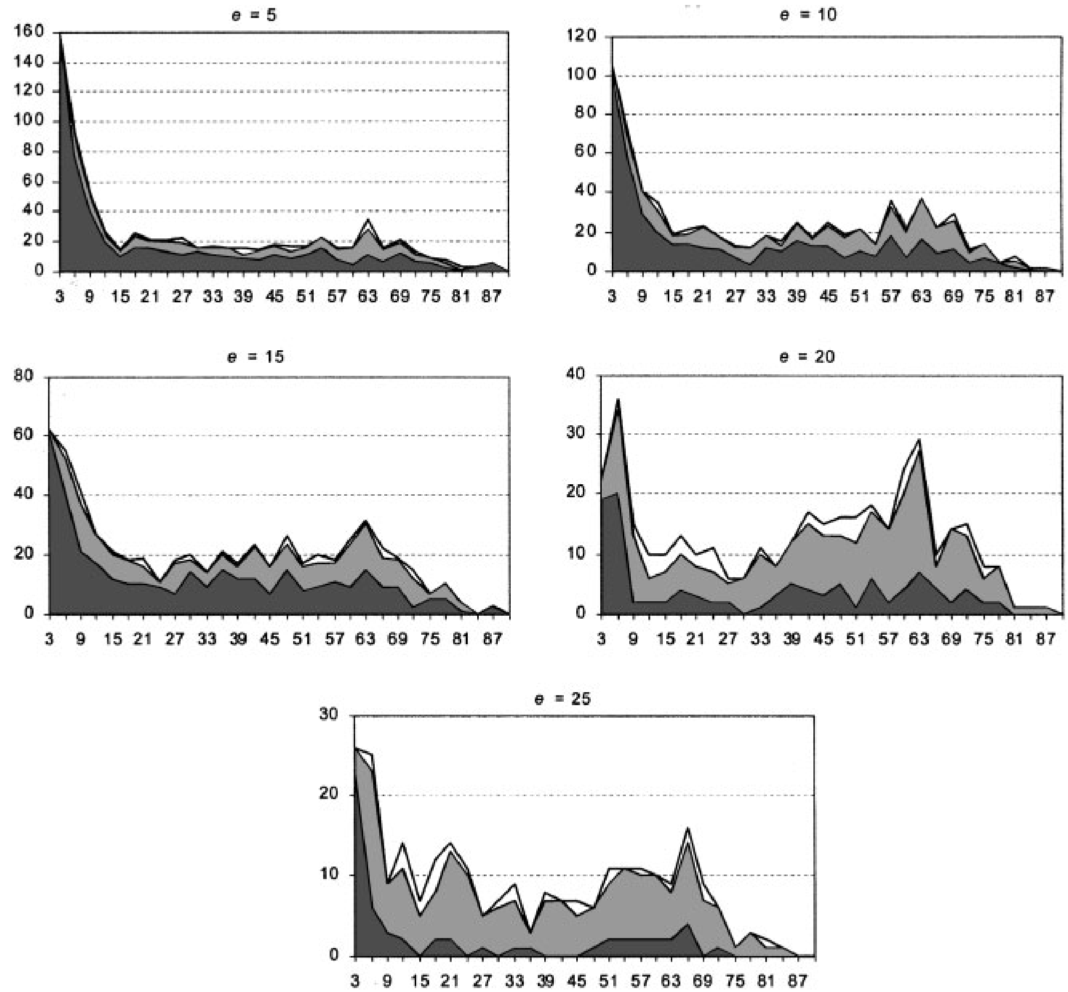

Figure 3. Frequencies of insufficient entries (black area), critical entries (gray area) and superfluous entries (white area) by time and player type. (Vertical axes, frequencies; horizontal axes, time in seconds)

dramatically with the size of the endowment. In the time interval [55,69] seconds, the percentage of critical entries was 46.6, 53.1, 47.0, 70.3 and 70.9 for types 1 through 5 respectively.

Taken together, the results displayed in Figures 2 and 3 reveal a clear pattern of greater brinkmanship by 'wealthier' players. Player types 4 and 5 tend not to contribute. When they do contribute, more than other player types, they tend to: (a) withhold their first contribution until the round's end; (b) do so only when critical for the public good provision.

Exit decisions of the five player types were less distinct than their entry decisions (Figure 4). Overall, more exit decisions were made by player types 1 through 3 than by player types 4 and 5, most likely because these latter types entered less frequently. Exit decisions peaked at the interval of 55 to 69 seconds, exactly when the second peak in entries occurred. The reasons for this peak in exit decisions at the 'normal' end of the round become clear when the exit decisions are categorized into exits made when the player's endowment was insufficient, critical, or superfluous for the good provision (Figure 5). The majority of the exit decisions of player types 1 through 3 occurred when their contribution was insufficient for providing the good. For

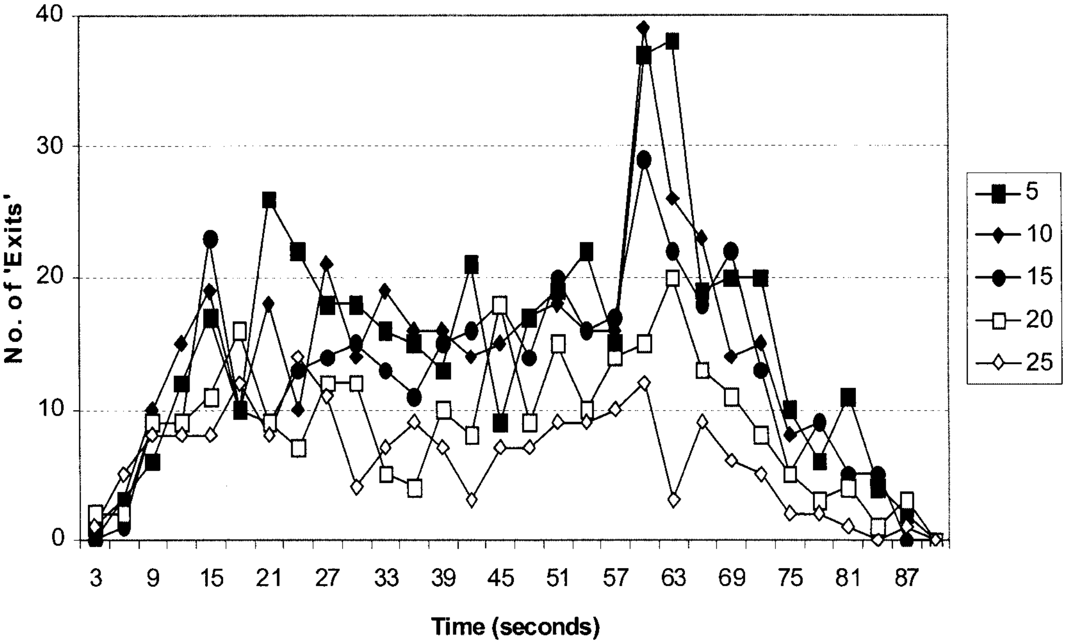

Figure 4. Frequencies of exits by time and player type. 'Type' refers to the player's endowment at a particular round

player types 4 and 5, however, the majority of exit decisions occurred when their endowment was critical for the good provision.

Exit decisions seemed to have served two different strategic purposes—minimizing losses and inducing others to contribute. When assigned low endowments, players exited most often when they observed that others' contributions were not sufficient to provide the good, especially when the round was about to terminate. When assigned high endowments, players exited most often when their contribution was critical for the good provision. This move was possibly intended to induce others to contribute if they wished the good to be provided. This behavior also peaked towards the round's end. Since for provisioning to occur in such cases at least one other player with lower endowment had to react quickly and contribute, the behavior of player types 4 and 5 can be characterized as high-risk brinkmanship.

Strategic play by wealthy players

The entry and exit data seem to suggest that player types 4 and 5 tend to both contribute and withdraw contribution when critical for the good provision. The question then arises whether the same individuals entered when critical and then exited while critical—a pattern that appears deceitful—or whether these are opposing decisions by different individuals. An alternative possibility is that in some cases a decision to exit when critical preceded a decision to reenter while still critical for provisioning, a pattern that would suggest that the player reconsidered the benefits of cooperation.

To answer these questions, all critical entries and exits were categorized according to the previous move made by the same player. Critical exits were placed into two categories: critical exits following a critical entry (of the same player); and critical exits following insufficient or superfluous entries (of the same player). Note that the latter category necessitates moves by other players between the previous entry and current exit of the player, while the former category does not necessitate such additional moves. Critical exits following critical entries accounted for the majority (59.4%) of all critical exits. This move was more frequent for player types 4

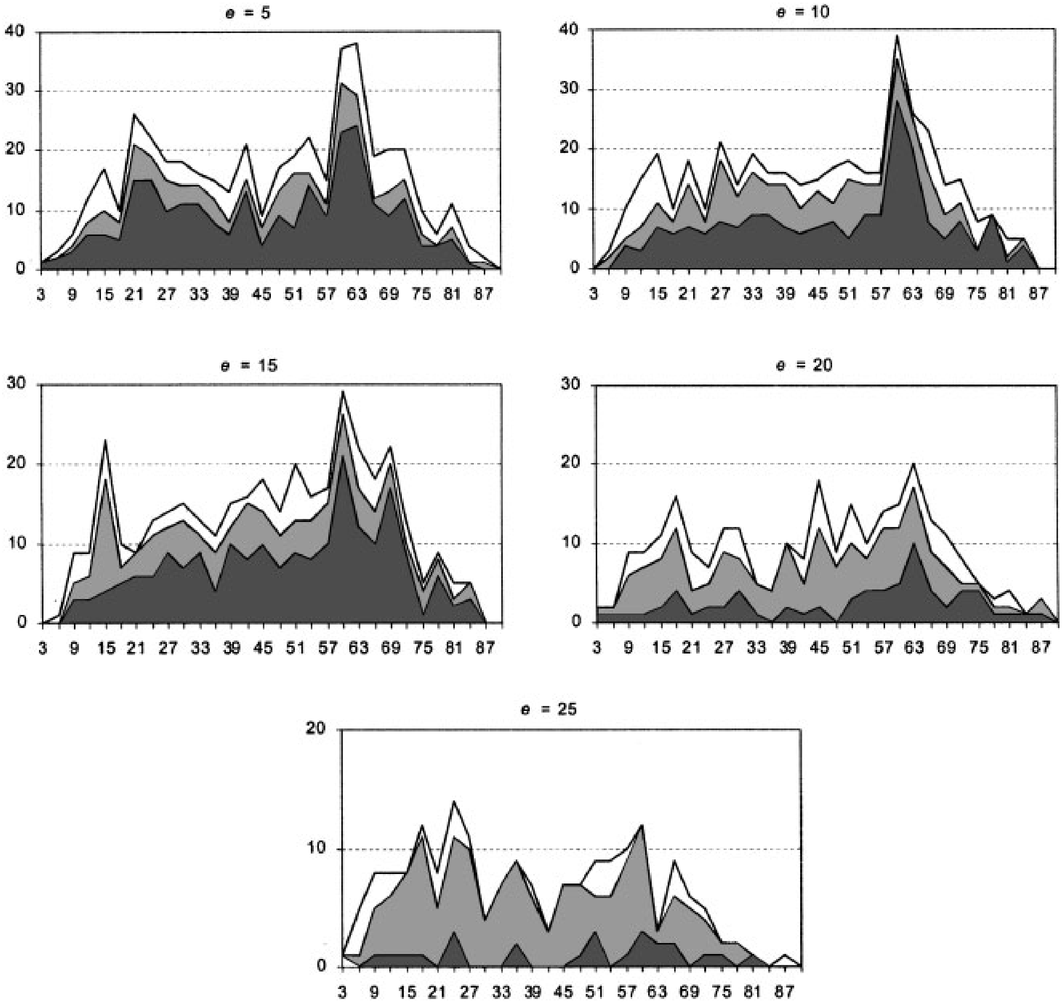

Figure 5. Frequencies of insufficient exits (black area), critical exits (gray area) and superfluous exits (white area) by time and player type. (Vertical axes, frequencies; horizontal axes, time in seconds)

and 5, who had 72.3% and 67.4% of their critical exits following critical entry, respectively. The corresponding percentages for player types 1, 2, and 3 were 61.2, 45.8, and 47.1, respectively. These frequency differences were statistically significant ($\chi^2_{(4)} = 28.17$, $p = 0.001$). Thus, many critical exit decisions actually followed critical entries and this 'deceitful' pattern was more pronounced for player types 4 and 5.

Critical entries include first entries and reentries that followed exit decisions. Our interest here is only in critical reentries—critical contribution decisions following exits. These were categorized as follows: 'reconsider' critical reentry—a decision to contribute when critical that followed a decision to withdraw contribution when critical (the opposite pattern of 'deceitful' exits); other critical reentries—decisions to contribute when critical that followed exit decisions made when not critical for provisioning.

Across all player types, critical 'reconsider' reentries were only slightly more frequent (51%) than other critical reentries (49%). These 'reconsider' reentries were relatively more frequent for player types 4 and 5 (60% and 79%, respectively) than for players 1–3 (50%, 41% and 36%, respectively; $\chi^2_{(4)} = 42.19$,

Table 6. Percentage of rounds in which exit decisions were taken, by player type* and game outcome: present study

Player type	Good is provided	Good is not provided
1 ($e_1 = 5$)	47.4	62.8
2 ($e_2 = 10$)	44.1	67.8
3 ($e_3 = 15$)	40.1	58.7
4 ($e_4 = 20$)	28.6	34.7
5 ($e_5 = 25$)	23.7	28.9
	$N = 329$	$N = 121$

*'Type' refers to the player's endowment at a particular round.

$p < 0.0001$). We note that the frequency of transition from critical entry to critical exit was greater than the frequency of the opposite transition ('reconsider reentry') for player types 4 and 5 and about equal for players 1–3.

In sum, more than a half of the critical exit and entry decisions followed another critical move by the same player. This event was more pronounced for player types 4 and 5. For these latter player types, critical exits following critical entries were more frequent than the opposite transition.

Exit decisions and rate of provision

In this final subsection we relate the patterns of exit decisions documented above with the rate of the public good provision. An important practical question is whether the decision to exit, if exercised, affected the rate of provision. Table 6 answers this question positively by showing that for each of the player types, an exit decision decreased the rate of provision despite the possibility of reentry. There are two possible explanations for this finding that are complementary. First, an exit decision might have sent the wrong signal of brinkmanship, which caused a reciprocal response. Second, because exit decisions tended to occur towards the end of the round, there might have been insufficient time for other players wishing to compensate for the lost contribution to make their own contribution before the round ended.

REVOCABLE VS. IRREVOCABLE COMMITMENTS

A significant difference was found between the mean payoffs (across all 45 rounds of the session) of the present and previous studies (mean payoff equal to 34.0 and 31.2 in the previous and present study, respectively; $t_{(98)} = 5.81$, $p < 0.0001$). When commitments were irrevocable, players earned more. Similarly, the public good was provided 85.3% of the time in the previous study compared to only 73.1% in the present study. The percentage of rounds ending in equilibrium did not differ significantly between studies (73.3% in the present study, 69.6% in the previous study; $\chi^2_{(1)} = 1.57$, $p = 0.21$; compare both panels of Table 4), supporting Hypothesis 1 in both experiments. Equilibrium outcomes increased slightly with repetition of the stage game in the previous but not in the present study.

The three equilibrium sets that maximize group earnings accounted for 95.5% of all the rounds ending in equilibrium in the previous study compared to only 74.6% in the present study. This difference between the two studies was significant ($\chi^2_{(1)} = 54.74$, $p < 0.001$; see Table 4). Interestingly, of the contributing sets that do not maximize group earnings, the one with the greatest relative increase in the current study was the null set. This was not the result of lack of attempts for good provision but, rather, the result of failed attempts. In 38 of these 39 cases, players contributed their endowments at some point during the round, signaling attempts for cooperation (see above).

Consistent with Hypothesis 3, no contributing set formed with a greater frequency than the set {1,2,3}. The difference between the two studies in the number of rounds this set was formed was statistically significant ($\chi^2_{(1)} = 45.44$, $p < 0.001$). This result also holds when computing the percentage of the set {1,2,3} out of the number of rounds that ended in equilibrium, or when computing it out of the number of rounds ending with group-earning maximizing sets ($\chi^2_{(1)} = 88.5$, $p < 0.001$; $\chi^2_{(1)} = 38.9$, $p < 0.001$ for the two tests, respectively). In both studies, the frequency of forming the set {1, 2, 3} increased as players gained more experience with playing the game. A logistic regression analysis predicting the logit of the {1, 2, 3} outcome (vs. all other outcomes) with study, block, and their interaction as predictors revealed a significant study effect (as previously indicated by the chi-square test), a significant block effect ($\chi^2_{(2)} = 29.38$, $p < 0.001$), and a non-significant interaction ($\chi^2_{(2)} = 0.64$, $p = 0.73$). The rate of convergence to the set {1, 2, 3} was not different between the two studies.

Wealth effects

Wealth effects, an inverse relation between player type and the proportion of contribution, appeared to be stronger in the previous study (compare the two panels of Table 3). To test the interaction effect between study and endowment size, a mixed-design two-way ANOVA with kind of commitment (i.e. study) as a between-subjects factor and endowment size as a within-subjects factor was conducted on the subjects' proportion of contribution of each type. The ANOVA yielded a significant study main effect ($F_{(1,98)} = 21.08$, $p < 0.001$) with higher level of contribution in the previous study, a significant endowment size main effect ($F_{(4,392)} = 254.5$, $p < 0.0001$) of the sort observed before, and a significant interaction effect ($F_{(4,392)} = 19.65$, $p < 0.001$), demonstrating a stronger wealth effect in the previous study.

DISCUSSION AND CONCLUSION

A major purpose of the experimental literature on public good provision is to assess the magnitude of free riding and the variables that affect it. When the VCM and PPM are implemented in public good experiments with small and fixed groups under the multiround simultaneous protocol of play with no preplay communication, the evidence largely supports free riding. Although subjects typically begin the experiment with moderate levels of contribution, these levels drop steadily across iterations of the stage game. In the VCM this often occurs within ten iterations. These findings have been widely quoted with no attempt to explicitly note that they may only hold under simultaneous play. Consequently, the conclusions drawn from these experiments about the extent of free riding might be overly pessimistic. There is a growing body of experimental evidence suggesting that these results may not generalize to other protocols of play. Using the sequential protocol in one-shot games, Erev and Rapoport (1990) and Rapoport and Erev (1994) reported higher levels of public good provision than those typically observed under the simultaneous protocol. Both the previous study of GKR and the present study also revealed considerably higher levels of provision under the real-time protocol, in this case in iterated rather than single-shot public good games. Moreover, successful provision of the good increased rather than declined over time.

The previous study by GKR and the present study each included two sessions only. As the population, rather than the group, is the independent statistical unit of analysis, the conclusions that we draw above are limited to four observations. However, in support of these conclusions, Dorsey (1992) and Kurzban et al. (2001) reported similar results with linear public goods. Taken together, these studies present converging evidence that the extent of free riding may depend not only on the parameters of the game (e.g. number of players, threshold provision in the PPM, marginal rate of substitution between private and public accounts in the VCM, size of public good) but also on the institutional arrangement that specifies the 'rules of the game.' The real-time protocol is particularly appealing because it provides a closer approximation to real-life public good provision situations, in which order of play is endogenously determined. It also provides a richer environment that allows players to send and receive signals about the intentions of the other group members, induce contributions by controlling the timing of their decision, and use tactics of brinkmanship not possible under other protocols of play. The ability to transmit signals through the decisions to contribute or withdraw contributions during the round of play seems to serve a similar function and have similar effects to the institutional arrangement of preplay communication in simultaneous games.

Yet another advantage of the real-time protocol of play is that it allows the study of the effects of nonverbal commitment to one's contribution decision in a very natural way. Results reported in our previous and present studies show that irrevocable commitments increase the rate of provision in comparison to situations in which commitments are revocable. The dynamic analysis that we conducted shows that this is largely due to the use of the exit option and brinkmanship behavior. Initial levels of contribution in the first seconds of the round were about the same in the present and previous studies (GKR, Figure 1). Apparently, implementation of the exit option towards the end of the round, combined with the stochastic nature of the termination point, resulted in many cases in which the good was not provided in time. In light of this conclusion it is perhaps not surprising that most institutional arrangements that have evolved naturally do not allow for revocable commitments. Our results clearly support these arrangements.

The latter result is by no means self-evident. Playing under the real-time protocol without the option of withdrawing one's contribution, players might decide not to try eliciting others' cooperation by being the first to contribute for fear of wasting their contribution if the good is not eventually provided. In comparison, when contributions are revocable, early signals of cooperation (i.e. entries) carry little risk. In contrast to this reasoning, all comparisons of real-time play with and without the possibility of withdrawing contributions show higher levels of public good provision when contributions are irrevocable (Dorsey, 1992; Kurzban et al., 2001, and the current study). It is possible that under some extreme conditions (e.g. playing one-shot games for large sums of money) the risk of losing one's endowment would loom so large as to prevent irrevocable contributions, thereby reversing the effects documented in Section 5. Searching for the boundary conditions of the apparent advantage of real-time play with irrevocable contributions is a topic for future research.

Symmetry between players is typically assumed in order to gain tractability; it is clearly the exception, not the rule. In both of our studies, we have set up a design in which wealthier players (with relatively higher endowments) are more critical to the good provision than poorer players but have less to gain. Our results are very clear that it is the relative payoff rather than criticality (i.e. the likelihood of being efficacious in providing the public good) that affects contribution. Players who have more to gain from the good contribute more often even though they are less critical to the good provision. Invoking the assumption that the perception of one's efficacy is positively related to one's endowment, these results suggest that efficacy is not an important determinant of play, particularly for the low-endowment players. This contrasts with models that implicate criticality in decisions to contribute (e.g. Au, Chen, & Komorita, 1998). More importantly, this tendency for lower-endowment players to contribute increases over iterations of the stage game in strong support of Hypothesis 3.

The random assignment of players' types might have contributed to obtaining these 'wealth effects'. Note that the most frequently observed equilibrium outcome (the $\{1, 2, 3\}$ contributing set) also results in the largest variation in individual payoffs within the group. Had players' types not been rotated, low-endowment players might have refrained from contributing because of inequity aversion (Fehr & Schmidt, 1999). Knowing that players' types in the experiment are rotated might have weakened the impact of equity considerations on participants' behavior.

Still, we hypothesize that the same qualitative results pertaining to endowment size would hold in short-term interactions (i.e. one-shot games) with the real-time protocol. The dynamic analysis of contribution times suggests that initial attempts to elicit cooperation are more frequent among low-endowment players, who risk less in attempting to do so. Such attempts can be successful due to the signaling opportunities in the real-time protocol. However, in repeated games with fixed player types, players might pursue strategies that aim to equalize the payoffs of players with different 'wealth' in the long run. Additional research is required to answer this question.

ACKNOWLEDGEMENTS

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