Incremental Commitment and Reciprocity in a Real-Time Public Goods Game

Robert Kurzban
Kevin McCabe
Vernon L. Smith
Bart J. Wilson
University of Arizona

Allowing players in public goods games to make small incremental commitments to contributing to the good might facilitate cooperation because it helps to prevent players from being "free ridden," contributing more to the public good than other group members. Two experiments using a real-time version of the voluntary contribution mechanism were conducted to investigate the hypothesis that players are generally willing to contribute public goods conditional on beliefs that others are doing so at similar levels. Experiment 1 provided evidence that affording a strategy of commitment can increase the production of public goods. Experiment 2 provided evidence that most players are willing to contribute to the public good at a level at or slightly above the contribution of the lowest contributor in the group. Both experiments point to inequity aversion as an important element of play in public goods games.

Public goods have the property that once they are produced, any individual in a group can consume them, regardless of whether he or she contributed to the production of the good. A strictly rational agent should, in general, refuse to provision a public good because the agent can enjoy the benefit of the good without bearing the cost of provisioning it (Olson, 1965).[1] When public goods have large aggregate benefits relative to their costs, their production constitutes a social dilemma—a situation in which individually rational choices lead to socially deficient outcomes (e.g., Dawes, 1980)—because group members would be better off in aggregate if the good were produced but each individual member would prefer not to pay to produce it. However, public goods are produced both in the real world, as in contributions to public radio, and in the laboratory (see below).

Willingness to provision public goods has frequently been assessed experimentally with the voluntary contribution mechanism (VCM) (e.g., Isaac & Walker, 1988a). Typically, in these experiments, groups of between four and eight participants are faced with a decision to invest money provided to them by the experimenter into two accounts: a private account and a public (or group) account. Money placed in the private account is kept by the investing individual, whereas money placed in the public account is increased at some interest rate (> 1) and divided among all group members equally. This creates a social dilemma because each individual player maximizes earnings by investing everything in his or her private account, but everyone would be better off if all group members contributed to the public account (i.e., the public good).

In the large number of experiments using the VCM, participants are partially able to overcome the social dilemma, routinely contributing to the public good, much as they do in the real world (see Ledyard, 1995, for a review). Why people voluntarily contribute is an important and heavily debated issue. It is important because knowing why and how social dilemmas are solved can inform both our understanding of human social motives

Authors' Note: The writing of this article was supported by a fellowship from the International Foundation for Research in Experimental Economics and a grant from the Russell Sage Behavioral Economics Roundtable, both to the first author. We would like to thank Mark Dincecco for his valuable assistance with this project. Correspondence concerning this article should be addressed to Robert Kurzban, Department of Anthropology, 341 Haines Hall, University of California, Box 951553, Los Angeles, CA 90095-1553; e-mail: rkurzban@ucla.edu.

PSPB, Vol. 27 No. 12, December 2001 1662-1673

as well as how to structure social policy to facilitate the production of public goods.

An important clue to why people contribute in public goods games comes from the very consistent finding that in multiround games, players' contributions begin at moderate levels but then decrease over time (e.g., Davis & Holt, 1993). Although some of this decrease in contributions can be attributed to participants' learning the incentive structure of the game, it is clear that learning alone does not account for this decline (Andreoni, 1988, 1995; Houser & Kurzban, in press; Isaac & Walker, 1988a).

Instead, Andreoni (1995), among others, has suggested that this decrease might be due to "frustrated attempts at kindness." This argument supposes that players are generally willing to contribute to the public good only if others are doing so at similar levels. Thus, participants who contributed more than the average amount that others did in one round will want to decrease contributions in subsequent rounds, whereas players contributing at or below the average will not change their contribution rates. If, in each round, some participants roll back their contributions while others keep their contributions constant, the inevitable result is a downward spiral to zero.

This argument, then, is that players do not want to contribute significantly more than others do, on average, which we refer to as "being free ridden." This explanation is similar to claims that participants are reluctant to contribute to public goods due to fear that others are not doing so as well (Chen, 1996; Chen & Komorita, 1994; Komorita & Parks, 1995; Yamagishi & Sato, 1986), although fear has been used in other senses, including the motivation not to have one's resources wasted (Rapoport & Eshed-Levy, 1989). One hypothesis, then, to explain the pattern of results in public goods games is that players would like to achieve the group-efficient outcome but are unwilling to risk contributing significantly more than others in their group to do so (Sugden, 1984). Thus, players may begin the game contributing at moderate levels, willing to risk a small amount of inequity in the hope that their contributions will be reciprocated, but decrease these contributions when they are not.

There is some evidence in favor of this view. First, players' reported expectations about other group members' contributions correlate well with their own actual contribution decisions across a number of experiments (Bornstein & Ben-Yossef, 1994; Braver & Barnett, 1974; Croson, 1998; Dawes, McTavish, & Shaklee, 1977; Komorita, Parks, & Hulbert, 1992; Messick et al., 1983; Wit & Wilke, 1992; Yamagishi & Sato, 1986), although the direction of causality of this relationship can of course be questioned. This suggests that players want to contribute at the same level as others in their group, preferring neither to free ride nor to be free ridden.

Additional evidence comes from experiments investigating the impact of commitment[2] in public goods games. Chen and Komorita (1994) ran a series of studies in which participants submitted a pledge to contribute some fraction of their endowment during the subsequent phase of the game. In one condition, these pledges bound not only the player making the pledge, but also all other players in the player's group to the same amount. Making a pledge did not expose the player to being free ridden in this condition, and both pledges and contributions were quite high, up to 73% of players' endowments (see also Chen, 1996). In another condition, players' pledges applied only to themselves, meaning that an individual making a large pledge ran the risk of obligating himself or herself to a contribution greater than that of other players. In this condition, pledges and contributions were much smaller, 36% of players' endowments.

Taken together, these results suggest that commitment can facilitate public good production, but only when the mechanism of commitment does not expose players to being free ridden by the other members of the group. Thus, commitment is a means by which players can assure one another that they are not going to free ride on others' contributions, so that group members can contribute without fearing that they will be free ridden. However, people seem unwilling to use a commitment mechanism if doing so exposes them to being free ridden. This presents an interesting problem from the standpoint of eliciting contributions to public goods: People might be willing to match committed contributions of others but not to commit before others have done so.

This problem was described by Schelling (1960) in his discussion of two hypothetical parties who both want to contribute a large amount of money to the Red Cross, but only if the other does so as well. The solution Schelling suggested was to allow sequential commitments of small amounts by each individual, thus keeping a tight reign on inequality of contributions. So, in this scenario, one person contributes a small amount, which is then matched by the second person, and so on, allowing each person to risk only the amount of the incremental contributions rather than the whole sum (see also Admati & Perry, 1991; Osgood, 1962; Roberts & Sherratt, 1998).

The same problem applies when players in public goods environments are willing to cooperate only to the extent that everyone else is willing to do so. In turn, a similar solution is possible. What is needed is a mechanism by which players can commit to cooperating to some small degree and observe other players' reciprocal contributions. This allows players to signal their commitment to provisioning the public good without exposing themselves to being free ridden by other group members who do not match their committed contributions.

To instantiate a mechanism that allows players to make "consecutive small contributions" (Schelling, 1960), we used the real-time VCM first developed by Dorsey (1992). In the real-time VCM, participants have some short amount of time in each round in which to update their contributions to the public good. Their actual contribution in a given round is equal to their contribution when the countdown clock reaches zero.

When players can adjust their contributions upward and downward during the round, information about others' contributions amounts to little more than cheap talk.[3] However, similar to Dorsey (1992), we modified the mechanism by which contributions could be updated such that in some groups, players could increase their contribution to the public account in single token increments but were not allowed to decrease their contributions to the public account during the course of the round. This increase only (IO) mechanism can be construed as affording a commitment strategy—once a player has raised his or her contribution to the public good to a particular level, they are unable to reverse this decision, committing them to that level. This mechanism allows players to make small commitments to the public good while allowing them simultaneously to limit their commitments so that they can control the extent to which they expose themselves to being free ridden.

If the hypothesis is correct that players' willingness to provision public goods is a positive function of their ability to prevent themselves from being free ridden, then providing a mechanism of incremental commitment should increase contributions to a public good relative to the case in which incremental commitment is not possible. In Experiment 1, we used the IO mechanism to test this hypothesis, predicting that contributions in a condition in which players could only increase their contributions (commitment) would be higher than in a condition in which players could increase or decrease their contribution (cheap talk).

EXPERIMENT 1

Method

PARTICIPANTS

Fifty participants were recruited from the University of Arizona undergraduate community using the electronic recruitment system maintained by the Economic Science Laboratory. Each participant was told that he or she would earn $5 for showing up to the experimental session and could earn additional money depending on the decisions that he or she and other people in the experiment made during the experiment.

DESIGN

There were two conditions: one with the increase/decrease pledge mechanism, and one with the increase-only mechanism. Five groups of five participants were run in each condition.

PROCEDURE

The procedure was a standard public goods game that largely duplicated that used by Marwell and Ames (1979) with the real-time contribution mechanism developed by Dorsey (1992). Participants were given a time to report to the laboratory and either one or two groups of five were run in a given session, depending on the number of people available for that session.

After arriving, participants received their $5 show-up payment and were assigned to one of the computers in the main laboratory area. Computers in this laboratory are separated by partitions so that players cannot see one another or any other player's computer screen. The entire experiment was conducted by computer.

Once all participants had arrived and were seated at a computer terminal, they read the instructions for playing the public goods game (Andreoni, 1995). These instructions appeared on players' computer screens and participants were allowed to proceed through them at their own pace. Any questions that arose were answered privately by the experimenter. The instructions indicated that the public goods game would continue for 10 rounds. Participants were informed that at the beginning of each round, they would be given an endowment of 50 tokens, that tokens could be invested in accounts that earned points which would be converted to cash and paid at the conclusion of the experimental session, and that they would receive the average amount that they earned over the course of the 10 rounds. The instructions informed them that they could divide their endowment (in units of whole tokens) any way they chose between the two accounts during each round and that they would earn the full value of each token that they put in their personal account as well as one third of the value of each token they and the other participants put in the group account. As part of the instructions, participants were given an opportunity to familiarize themselves with the interface they would be using to update their contributions during the round. The countdown clock, the information that they would see during the round, and the mechanism for updating their contribution (IO or ID) also were explained.

At the beginning of each round, the players' entire endowments were placed in the private account. In the IO condition, players could increase their contribution to the group account one unit at a time by clicking on a small button provided for this purpose. In the ID condition, two buttons were visible, one for increasing the contribution to the group account and one for increasing the contribution to the private account. Across conditions, players could see the current contribution levels of all five members of their group during the round, updated five times per second. The placement of the boxes was constant across all 10 rounds, although there was no way to know which information corresponded to which player in the room.

When all players indicated that they were ready, Round 1 began. The countdown clock was set to 90 seconds and counted down in increments of 1 second. Players could modify their contributions during the entire 90-second countdown. When the time for the round had elapsed, players were informed of the aggregate contribution to the group account and their total earnings in tokens for that round (the number of tokens in the personal account and one third of the tokens in the group account). When all players had indicated that they were ready to begin the next round, the countdown clock returned to 90 seconds and Round 2 began. Subsequent rounds proceeded similarly.

When Round 10 was complete, participants were asked to fill out a short questionnaire, which included a free-response section that asked participants to indicate how they had made their contribution decisions. After filling out the questionnaires, each participant was given a sealed envelope with his or her earnings and dismissed.

Results

We conducted a mixed-effects analysis for repeated measures (e.g., Longford, 1993). The two factors (pledge mechanism [ID, IO] and round) are modeled as (dichotomous zero-one) fixed effects, whereas the groups and the participants within each group are modeled as random effects. Because there could be substantial variation of the contributions across groups, and because contribution decisions are likely to be autocorrelated as participants learn over rounds, we generalized the error structure to include groupwise heteroskedastic variances and a first-order autoregressive (AR[1]) process for residuals by participant and estimated the model via maximum likelihood.[4]

This analysis revealed a main effect of round, $LR(9) = 59.47$, $p < .0001$, but no significant effect of pledge mechanism, $t(8) = 1.18$, $p = .27$.[5] Of more interest is the two-way interaction of pledge mechanism and round, $LR(9) = 17.43$, $p < .05$. This interaction was driven by the drop-off in contributions in the ID condition compared with the relatively stable contributions in the IO condition (see Figure 1).

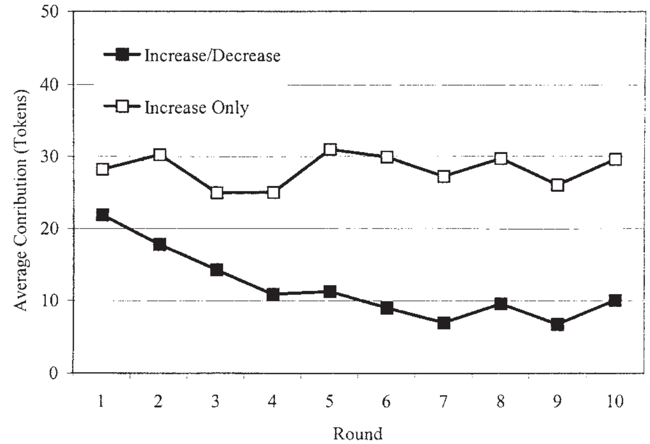

Figure 1 Contributions by condition in Experiment 1.

EXPERIMENT 2

Experiment 1 suggests that the IO mechanism, which affords commitment, is effective in facilitating cooperation when participants have access to full information about others' current contributions. This is consistent with the idea that affording a strategy of commitment that allows players to limit their exposure to being free ridden can facilitate cooperation.

Nonetheless, even with the commitment mechanism, groups in Experiment 1 attained only moderate rates of contribution to the public good. There may be a number of reasons for this, but one possibility is that the environment allowed players to exploit those participants that overcommitted, contributing to the public good in substantial amounts during the round even when others did not. Some evidence exists that whereas conditional cooperation is generally reciprocated, unconditional cooperation tends to be exploited (e.g., Komorita, Hilty, & Parks, 1991). Thus, it is possible that participants who observed other group members making unilateral large contributions chose to free ride on these contributions, keeping their own allocation to the public account low because their fellow group members were generous without needing the incentive of reciprocal cooperation.

This suggests that a mechanism that simultaneously allows incremental commitment but prevents players from seeing others as exploitable might further increase contribution levels. One way to implement such a mechanism is to provide players within a group only the lowest current contribution to the public good. By providing players with only the lowest current contribution, they are prevented from observing the potential for free riding on overly cooperative players in a given round, thus hiding potential exploitative opportunities.

We make two assumptions in Experiment 2. First, we assume, as in Experiment 1, that players have a preference for achieving the group-level optimum outcome provided that they do not expose themselves to being free ridden in the process. Second, we assume that players are "sophisticated" (after Milgrom & Roberts, 1991) and know that others similarly do not want to be free ridden (see also Keser & van Winden, in press). This idea goes back at least as far as Pruitt and Kimmel (1977), whose "goal expectation" model held that cooperation was due to "*an expectation that the other will cooperate* either immediately or in response to the actor's cooperation" (p. 375).[6]

Given these two assumptions, consider players who receive only information about the lowest current contribution to the group account. These players know that everyone in their group is currently contributing at least the value of the information that they observe. Furthermore, players using the IO mechanism will know that the other players are committed to these contributions. If players are sophisticated, they will know that keeping their contribution at this level will freeze this value and, importantly, dissuade others from contributions significantly above this value because they will not want to be free ridden by the player currently at the minimum. However, players will not know how much above this level others are currently contributing, obscuring opportunities for free riding.

In this condition, players can incur the relatively low cost of contributing one unit to ensure that the minimum information does not get stuck at its current level, inhibiting additional group cooperation. Note that raising one's contribution above the minimum in this condition also reveals to a player whether others are tied with him or her; therefore, these marginal increases also can be construed as relatively inexpensive information gathering (Ward, 1989). If all players in a group increase their contribution gradually, just above the minimum value, this will lead to a kind of "ratchet effect," with contributions increasing incrementally by small amounts over time.

As a comparison class for the low information condition, we also included a condition in which players receive only information about the highest current contribution. This condition has the same amount of information (one player's contribution) but does allow players to observe the possibility of free riding off of another's contribution and, critically, does not assure players that others are not free riding off of their own. If the hypothesis is correct that players withhold contributions out of fear that other group members are free riding, providing the highest information should lead to less cooperation than when the lowest contribution information is provided.

To summarize, receiving the value of the lowest contribution means that participants can be sure that all members of the group are committed to at least the level of cooperation indicated by the current value. The IO mechanism combined with the lowest information treatment (IOL[7]) allows one to contribute small amounts, keeping a tether on the extent to which one can be free ridden. Thus, the IOL condition should be effective in eliciting contributions from players because it allows players to make small incremental contributions to the public good while monitoring whether other players are reciprocating, in much the way described by Schelling (1960). Thus, in Experiment 2, we predict that cooperation (contributions) in the IOL information condition will be high and sustainable compared to those in all other cells. A second prediction is that because it is relatively easy in the IOL condition to ensure that one's contribution never strays far from that of others, there will be a close correspondence between players' contributions and the information they receive.

Method

PARTICIPANTS

One hundred participants who had not taken part in Experiment 1 were recruited from the University of Arizona undergraduate community. Each participant was told that he or she would earn $5 for showing up to the experimental session and could earn additional money depending on the course of the experiment. The amount that each participant actually earned depended on the decisions that he or she and the other participants in their group made during the experiment.

DESIGN

The experiment employed a 2 (contribution information: highest, lowest) × 2 (pledge mechanism: ID, IO) factorial design. Five groups of five participants were run in each of the resulting four conditions.

PROCEDURE

The procedure was identical to that used in Experiment 1 with the following exception: Participants in half of the groups in this experiment could see the current contribution level of the highest current contributor to the group account, whereas participants in the other half of the groups could see the current contribution level of the lowest current contributor to the group account. Of course, in both cases, the determination of the highest or lowest contribution included the focal participant.

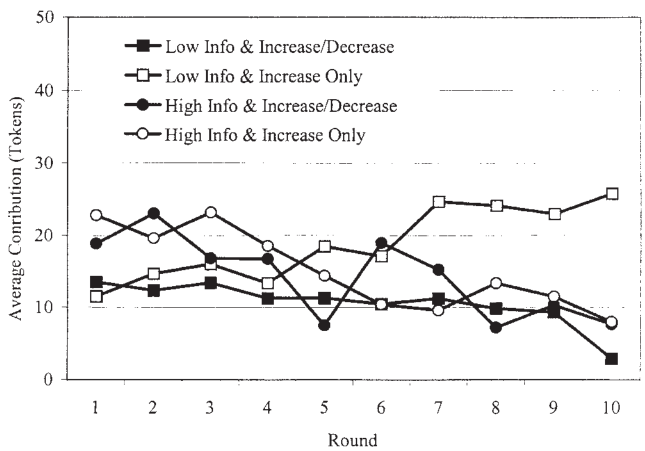

Figure 2 **Contributions by condition in Experiment 2.**

TABLE 1: Results of the Lowest Information Only (IOL) Treatment From the Mixed-Effects Analysis of the Pledge Mechanism and Round Interaction on Contributions, Experiment 2

Variable	*Coefficient*	p
IOL (all rounds)	–2.59	.65
IOL × Round 2	6.77	.0008
IOL × Round 3	8.62	.0005
IOL × Round 4	8.86	.0007
IOL × Round 5	8.80	.0010
IOL × Round 6	12.00	.0001
IOL × Round 7	14.04	< .0001
IOL × Round 8	17.04	< .0001
IOL × Round 9	16.68	< .0001
IOL × Round 10	21.17	< .0001

Results

CONTRIBUTION LEVELS

The primary dependent measure of interest was participants' final contribution at the end of each of the 10 rounds. We employed a mixed-effects model with repeated measures for our analysis. The 2 × 2 treatment effects (contribution information [lowest, highest] and pledge mechanism [ID, IO]) and round are modeled as dichotomous (zero-one) fixed effects, whereas the groups and the participants within each group are modeled as random effects. Because we expected a priori that (a) the variation of the contributions across groups will be heterogeneous and (b) a learning effect across the rounds may manifest itself as autocorrelation in the participants' decisions, we generalized the error structure to include groupwise heteroskedastic variances and a first-order autoregressive (AR[1]) process for residuals by participant.[8]

This analysis from the maximum likelihood estimation yielded no significant effect of contribution information, $t(16) = 1.03$, $p = .32$, and pledge mechanism, $t(16) = -0.46$, $p = .65$. The round effect, however, was significant, $LR(9) = 30.31$, $p < .0005$.

However, these null findings for the main treatment effects are qualified by highly significant two-way interactions between contribution information and round, $LR(9) = 29.42$, $p < .001$, and between pledge mechanism and round, $LR(9) = 41.69$, $p < .0001$. The contribution information and round interaction is driven by the observation that contributions in the low information conditions are, on average, relatively constant over the course of the game, whereas contributions in the highest information condition decrease over time. The final two-way interaction, contribution information and pledge mechanism, was not significant, $t(16) = 3.37$, $p = .70$.

These two-way interactions were themselves qualified by a significant three-way interaction among contribution information, pledge mechanism, and round, $LR(9) = 27.70$, $p < .005$. This interaction is driven by the observation that in the IOL condition, contributions increase over the course of the 10 rounds, whereas in the other three conditions, contributions fall off with time. Figure 2 displays the average contribution across all five groups for each condition over the course of the 10 rounds.

As a joint test for all rounds, a statistical test for the two- and three-way interactions does not reveal the sign or magnitude of the interactions, both of which are relevant to the main hypothesis of this article. The interaction by round in the IOL cell is of particular interest given that the combination of these treatments, by hypothesis, should lead to successful provisioning of the public good. Table 1 reports the coefficients of the specific interaction in this cell by round. Notice that except for the first round, the interaction is highly significant every round and that the magnitude of this effect on the contributions was much larger for Rounds 6 through 10 than for Rounds 2 through 5. With more experience within a session, the total group contributions in the non-IOL treatment are progressively falling, whereas the contributions in the IOL treatment remain relatively high and constant. Hence, the estimates of the IOL treatment effect increase relative to the non-IOL treatment.

The participant and group random effects control for one interesting aspect of the data: between-group variation. Again, the IOL groups are particularly noteworthy. In this condition, two of the groups' contribution levels look similar to those of groups in the other three conditions, with contributions starting off at moderate levels and decreasing toward zero over time. In contrast, in the three other groups in this condition, contributions tended to increase over the course of the game, reaching

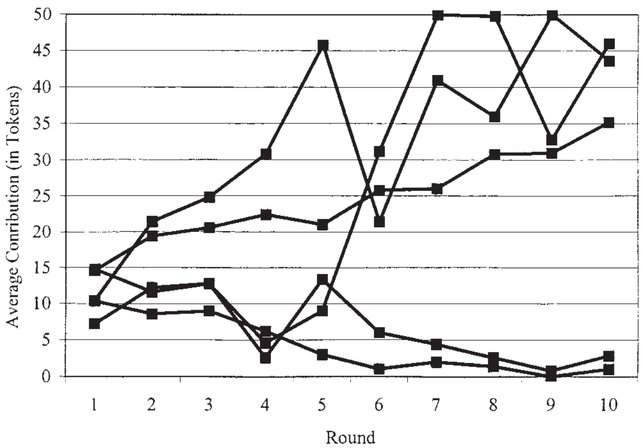

Figure 3 Contributions in the lowest information and increase only conditions in Experiment 2.

levels of more than 75% by the end (see Figure 3). We return to the question of the source of this between-group variation below.

RECIPROCITY

To try to evaluate the extent to which players' contributions were influenced by the information they were provided, we ran a regression of the players' actual contributions on the value of the information at the end of the round, with treatments entered as independent variables for all groups across all 10 rounds. Note that the information observed at the end of the round is really only a proxy for the players' expectations because the value could, in principle, have changed at the last moment in a round before a player had a chance to react. Also, because one of the five players in each group was the individual who actually set the highest or lowest value, including all players in these regressions would overestimate the strength of the relationship between the final value and players' contributions because 20% of the observations would necessarily be perfectly correlated. For this reason, we removed the player whose contribution matched the final information value in each round in every cell. If more than one player's contribution matched this value, only one of these tying players was removed. We ran the following regression:

$$\begin{aligned} Contribution_{it} = {} & a_o + a_1 I_i + a_2 H_i + a_2 H_i{*}I_i + \beta_o \text{Endvalue}_{it} \\ & + \beta_1 I_i * Endvalue_{it} + \beta_2 H_i{*}Endvalue_{it} \\ & + \beta_3 H_i * I_i * Endvalue_{it} + e_{it}, \end{aligned}$$

where $I = 0$ for the ID condition and $I = 1$ for the IO condition, $H = 0$ for the low information condition and $H = 1$ for the high information condition, and *Endvalue* refers to the value of the information (highest or lowest) at the end of the round. Subscripts refer to player *i*s at time *t*, where *t* refers to Rounds 1 through 10. The results of this regression are summarized in Table 2.

TABLE 2: Results of the Regression of Final Information Value on Contribution by Treatment, Experiment 2

Variable	*Coefficient*	p	η^2
Constant	5.96	< .0001	
Highest	–8.06	< .0001	0.02
Increase only	–0.97	.20	0.03
Highest × Increase Only	1.27	.60	0.01
Endvalue	0.99	< .0001	0.47
Highest × Endvalue	–0.60	< .0001	0.06
Increase Only × Endvalue	–0.09	.06	0.00
Highest × Increase Only × Endvalue	0.20	< .05	0.00

NOTE: Refer to the text for the regression model. Number of observations = 800, $R^2 = .60$, and $s^2 = 83.92$. *p* values are based on the standard errors for a groupwise heteroskedastic model.

Overall, there was a significant relationship between the information observed at the end of a round and players' contributions. This relationship held across conditions but the slope coefficient differed significantly depending on the information condition. In the lowest information condition, an increase of one token in the information the player observed led to an increase of roughly one token in actual contributions. In contrast, under the highest information treatment, the effect of an increase of one token in the information observed was an increase of roughly one half of a token.

Discussion

Experiment 2 provided strong support for the idea that players in public goods games are willing to contribute to the extent that they believe others are similarly willing to do so. Correlations between actual contributions and the information observed were relatively strong, particularly in the lowest information condition. When players could observe the lowest information, they could be certain that every other player was contributing at least the value of the current value that they were seeing. In the IO condition, players were committed to this contribution, encouraging reciprocal contributions.

In general, the establishment of high levels of contribution followed the ratchet pattern described by Schelling (1960). In the three groups in which high rates of cooperation were observed, players increased their contributions systematically over the course of the round to match the lowest information value and kept their contribution at roughly one token above this level. Figure 4 illustrates this pattern for one period of play for one group that achieved complete cooperation in the IO and low information condition.

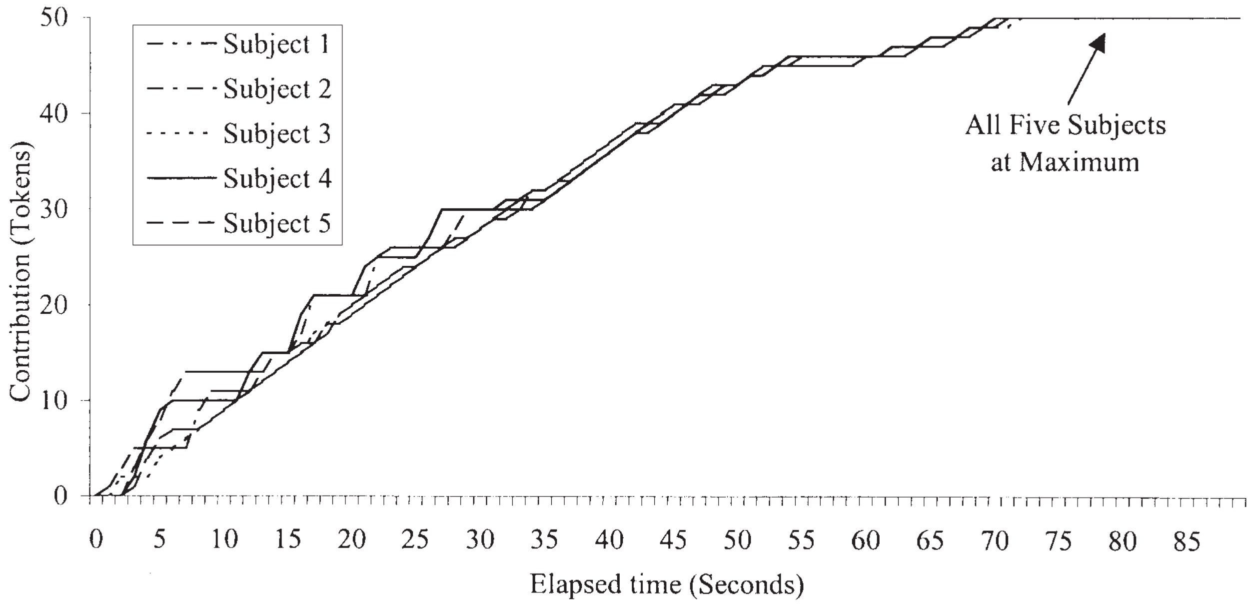

Figure 4 Contributions by all five players over time in a representative round in the lowest information and increase only conditions, Experiment 2.

Groups reached high but not perfect levels of contribution when one player unilaterally refused to increase his or her contribution above the current minimum, keeping the group stuck at that particular level. Why certain players chose to increase their contributions to a seemingly arbitrary point and then stop is not clear, because these players would almost certainly have been better off increasing their contributions because other players in their groups seemed to be using a strategy of keeping their contribution one token above the minimum.

The hypothesis that the low contribution and IO cell would lead to enhanced provisioning of the public good received mixed support. In this cell, three out of the five groups achieved contribution rates of between 60% and 100% during the latter rounds of the game, a respectable amount of within-group cooperation given consistent findings that cooperation rates drop off toward zero in latter rounds of most public goods games with repeated play (Davis & Holt, 1993). However, two of the groups in this cell resoundingly failed to achieve substantial rates of cooperation, with contributions sinking to less than 10% in the final rounds of the game (see Keser & van Winden, in press, for a similar result). Thus, the only statistical evidence for the IOL mechanism's effectiveness emerged in the context of its ability to increase levels of cooperation over time, in contrast to the other three mechanisms.

We cannot be certain about the source of this between-group variation. It is possible that idiosyncratic differences among experimental sessions could account for some of this variation, but we have no particular reason to believe this is the case. Another possibility is that there is some unmeasured individual difference variable among the players in these groups. If, indeed, players are using a kind of matching strategy, the low contribution information conditions are particularly sensitive to individual differences. Imagine that there is some small fraction of players in the population who simply choose to contribute zero in every round of a public goods game (strong free riders). In the high information conditions, these players are somewhat invisible, their presence indicated only in the end-of-round, aggregate contribution information, which reveals their reticence. In contrast, one of these players in the lowest information condition will be obvious to everyone in their group, because the minimum value will not budge from zero. Even if all players but one keep their contribution slightly above the minimum value, just one "zero player" will prevent the group from establishing mutual cooperation. Small numbers of strong free riders have been observed in other experiments (e.g., Andreoni, 1995; Croson, 1998), suggesting this phenomenon is not simply a function of the design of this particular experiment.

What is the origin of these strong free riders? We can only speculate at this point. Perhaps they are extremely competitive, playing zero to ensure that no one else in their group earns more than they do—it is known that the individual difference variable "social value orientation" can have important effects on cooperation in other games (e.g., Kramer, McClintock, & Messick, 1986; McClintock & Liebrand, 1988; Van Lange & Visser, 1999; but see Parks, 1994). Perhaps they believe they are playing some optimal strategy, trained in game theory, and believing that equilibrium play in these games is zero. Indeed, in the free-response portion of the questionnaire, one player in one of the two groups that was unable to achieve cooperation in the IOL condition indicated that he or she was playing the dominant strategy. This player did contribute zero on 7 of the 10 rounds of the game, dooming the group to extremely low contribution levels. It seems possible that strong free riders were unable to understand what effect their playing zero would have on other players' decisions. Additional work will be required to isolate any individual difference variable that may be at work in these games (for additional work on individual differences, see Kurzban & Houser, in press; Liebrand, 1984; Parks & Hulbert, 1995; Rapoport & Suleiman, 1993; Yamagishi, 1986).

GENERAL DISCUSSION

The results of the experiments reported here yield two primary findings. The first is that providing a mechanism of commitment in the public goods environment can be effective in eliciting cooperation from players, but only under particular conditions. Experiment 1 showed that the commitment mechanism was effective in sustaining cooperation over time when players had access to complete information about others' contributions. The level of cooperation under these conditions did not show the typical pattern of decay over the course of the 10 rounds of play (e.g., Andreoni, 1988; Isaac & Walker, 1988b). In Experiment 2, three groups in the IOL condition were able to achieve extremely high rates of cooperation, particularly in the latter rounds of the game, which contrasted starkly with the other experimental conditions. The IO mechanism seems to be able to facilitate cooperation but also makes groups susceptible to strong free riders, whose presence scuttles attempts to cooperate. In contrast, when players saw only the highest contribution, providing a commitment mechanism had no significant effect on the level of cooperation.

The second finding is that participants in public goods games use reciprocal strategies but that the extent to which they do so depends on the nature of the information they have about other players' contributions. In Experiment 2, there were close relationships between players' actual contributions and the single piece of information that they had available to them about others' contributions. The relationship between the information that players observed and their own contributions was significantly weaker when they had access to the current highest contribution to the public good.

An additional finding is that there is some evidence that players are sophisticated in the sense that they believe others are playing some kind of reciprocal strategy as well. This is clear from the results of the IOL condition. If players played a simple matching strategy by which they set their allocation to the group account to the level that they observed, the minimum value would never change and cooperation could not be established. However, in three of the five groups, players set their allocations to the group account slightly above the level of the current minimum, ensuring that they did not cause the minimum value to get stuck, inhibiting further contributions from reciprocators.

There is evidence from two additional sources suggesting that players are sophisticated. The first is the free-response section of the questionnaires that participants filled out that asked them to indicate how they had made their contribution decisions. Many participants indicated that they themselves were using a reciprocal strategy (e.g., "If others put tokens in the group account, so did I") and that they were contributing to elicit contributions from others (e.g., "I wanted my contributions to be matched"), suggesting that these participants believed others would also use some type of reciprocal strategy.

Second, when participants had the capability of increasing and decreasing their contributions, at least some players put large numbers of tokens in the group account during the course of the round and left them there up until the last few seconds of the game, when they removed them with some haste. This suggests that these players were trying to signal that they were going to contribute a large number of tokens to the group account in an attempt to induce others to do so.

From a theoretical standpoint, these results lend weight to the hypothesis that players in public goods games are motivated by a fear of being free ridden as well as by a desire to achieve high levels of cooperation within one's group. This contrasts with classical economic models that assume that people have preferences over only their own payoffs but is consistent with recently proposed "inequity aversion" models that suggest that people have preferences over their own outcomes as well as the distribution of outcomes among other relevant agents (Dufwenberg & Kirchsteiger, 1998; Rabin, 1993). More specifically, people seem to dislike unequal outcomes but are particularly upset if they are on the short end of the unequal allocation (Fehr & Schmidt, 1999).

More concretely, in the context of public goods games, there seem to be two principles that explain a great deal of contribution behavior. The first is that players do not want to contribute more than other members of their group. The second is that if players believe that everyone is going to contribute in roughly equal amounts, they prefer that amount to be higher rather than lower. On this theory, the incremental IO mechanism allows players to limit their fear of exploitation because they can condition their own play on their observations of others' contributions, ensuring that they will not be the victim of a large and disadvantageous unequal outcome. The low information condition is particularly effective because it essentially allows group members to coordinate on high contribution levels.

If this analysis is correct, it suggests why obtaining cooperation in public goods games in which players make their contributions simultaneously is problematic. In the simultaneous game, in any given round, players do not know how much others are contributing when they make their own decision. Thus, any contribution one makes exposes the player to being free ridden by others who contribute less, leading players to make small contributions to avoid this unpleasant state of affairs. This suggests that moderate levels of contribution toward the beginning of the game are conservative attempts to establish high levels of cooperation but that the spiral downward during the course of multiple round games is the result of the failure of these attempts.

Also, to the extent that this model is correct, doubt is cast on explanations of contribution behavior that make reference to altruism or learning as important factors (e.g., Andreoni, 1990) and suggest instead that reciprocity is a key element (e.g., Croson, 1998; Komorita, Chan, & Parks, 1993; Komorita et al., 1992). Players seem to use their own contributions to elicit contributions from others (Pruitt & Kimmel, 1977) and are willing to expose themselves to small amounts of being free ridden to do so. Thus, reciprocity in public goods games needs to be understood not only in the context of responding in kind to others' contributions but using one's own contributions to elicit cooperation from others.

An important feature of the low information treatment is that it allows players to monitor to some extent every other member of the group. The low information indicates that every single group member is contributing at least at the indicated level. This suggests a role for perceptions of unanimity in group cooperation (Smith, 1991), but because unanimity per se was not manipulated in these experiments, further research will be needed to clarify when and if this is an important factor. For example, it is an open question how results of Experiment 2 would change if information about the second lowest contributor were provided (for computer simulation data that bear on this issue, see de Heus, 2000; Parks & Komorita, 1997). This is a potentially important area of research because it would shed light on the exact nature of the fear of being free ridden; that is, are people reluctant to be free ridden by even one other player, or are they willing to tolerate a certain amount of free riding to establish cooperation among remaining group members?

As always, caution should be exercised in generalizing from these results. There are many different contexts in which individuals must decide how much to cooperate with one another, ranging from small work groups up to large scale phenomena such as provisioning public radio, and many of these contexts obviously differ in important ways from the stylized laboratory environment. Settings outside the lab might differ in the information that one has about what others are doing, the opportunity to signal one's commitment, the degree of interpersonal interaction, and so forth. However, the real-time mechanism does reflect the structure of many types of public goods environments, such as many fundraising drives, which often provide potential donors continuously updated information about how much money has been pledged up to that time (Dorsey, 1992). More generally, many cooperative activities occur in real time and, of course, most actions that we take in the real world cannot be undone or taken back once they are completed.

It is also important to note that it is not clear how specific the effects we observed are to potentially important factors such as group size, the per capita return of the public good, participant population, and so forth. In addition to determining the generality of these findings, an important goal for future research will be to develop techniques that are capable of distinguishing among the different kinds of reciprocal strategies participants might be using in public goods environments.

NOTES

1. We add "in general" because there are situations in which a rational agent will provision a public good, such as when the benefit of the good to the individual exceeds the cost of its production (see Olson, 1965, for a thorough discussion).

2. We will use the term *commitment* strictly to mean an action that is binding on the actor. Others have used the word in the sense of a spoken promise, which might or might not be broken (e.g., Kerr & Kaufman-Gilliland, 1994).

3. Cheap talk is communication that is costless and nonbinding. "Little more" is an important hedge because the talk is more "expensive" as the clock gets closer to zero. Because there are physical limits to how fast a player can remove tokens using our interface, a player with a very high contribution might not be able to decrease his or her contribution all the way to zero if only a few seconds are left, making contributions toward the end of a round more like commitments.

4. Likelihood ratio (LR) tests find that both of these specifications are significant: heteroskedastic group variances, $LR(19) = 131.96$, $p < .0001$, and AR(1) residuals, $LR(1) = 60.83$, $p < .0001$. These specifications improve the efficiency of the estimates. The LR test determines whether the difference in the maximized value of the likelihood function with the restriction is significantly different than the unrestricted maximum value of the likelihood function (see, e.g., Kennedy, 1992, p. 61).

5. To illustrate the improvement in efficiency, the standard error on the main effect of the pledge mechanism, without compensating for groupwise heteroskedasticity and AR(1) error terms, is 6.30, but with the corrections for nonspherical disturbances, the standard error is 6.13.

6. As an aside, it is interesting to note that evolutionary psychologists have predicted that people should be "sophisticated" in this sense across a variety of contexts. This derives from the fact that natural selection builds mechanisms that embody assumptions that reflect the stable, recurrent features of the environment in which a population evolves (Cosmides & Tooby, 1992). Thus, the important elements of human psychology that have been reliably present over evolutionary time should be embodied in people's assumptions about others.

7. For ease of exposition, treatment cells hereafter are referred to by a three-letter combination of the mechanism and the information participants observed (e.g., IOH is the increase only and high information condition).

8. Likelihood ratio tests find that both of these specifications are significant: heteroskedastic group variances, $LR(19) = 384.16$, $p < .0001$, and AR(1) residuals, $LR(1) = 110.12$, $p < .0001$. These specifications improve the efficiency of the estimates in Table 2.

REFERENCES

Admati, A. R., & Perry, M. (1991). Joint projects without commitment. *Review of Economic Studies*, *58*, 259-276.

Andreoni, J. (1988). Why free ride? Strategies and learning in public goods experiments. *Journal of Public Economics*, *37*, 291-304.

Andreoni, J. (1990). Impure altruism and donations to public goods: A theory of warm glow giving. *Economic Journal*, *100*, 464-477.

Andreoni, J. (1995). Cooperation in public goods experiments: Kindness or confusion? *American Economic Review*, *85*, 891-904.

Bornstein, G., & Ben-Yossef, M. (1994). Cooperation in intergroup and single-group social dilemmas. *Journal of Experimental Social Psychology*, *30*, 52-67.

Braver, S. L., & Barnett, B. (1974). Perception of opponent's motives and cooperation in a mixed- motive game. *Journal of Conflict Resolution*, *18*, 686-699.

Chen, X. P. (1996). The group-based binding pledge as a solution to public goods problems. *Organizational Behavior and Human Decision Processes*, *66*, 192-202.

Chen, X. P., & Komorita, S. S. (1994). The effects of communication and commitment in a public goods social dilemma. *Organizational Behavior and Human Decision Processes*, *60*, 367-386.

Cosmides, L., & Tooby, J. (1992). Cognitive adaptations for social exchange. In J. Barkow, L. Cosmides, & J. Tooby (Eds.), *The adapted mind* (pp. 163-228). New York: Oxford University Press.

Croson, R.T.A. (1998). *Theories of altruism and reciprocity: Evidence from linear public goods games.* Unpublished manuscript, the University of Pennsylvania, Philadelphia.

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. M., McTavish, J., & Shaklee, H. (1977). Behavior, communication, and assumptions about other people's behavior in a commons dilemma situation. *Journal of Personality and Social Psychology*, *35*, 1-11.

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

Dufwenberg, M., & Kirchsteiger, G. (1998). *A theory of sequential reciprocity.* Unpublished manuscript.

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

de Heus, P. (2000). Do reciprocal strategies work in social dilemmas? *Personality and Social Psychology Review*, *4*, 278-288.

Houser, D., & Kurzban, R. (in press). Revisiting kindness in public goods games. *American Economic Review.*

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

Isaac, R. M., & Walker, J. M. (1988b). Group size effects in public goods provision: The voluntary contributions mechanism. *Quarterly Journal of Economics*, *103*, 179-200.

Kennedy, P. (1992). *A guide to econometrics* (3rd ed.). Cambridge, MA: MIT Press.

Kerr, N. L., & Kaufman-Gilliland, C. M. (1994). Communication, commitment, and cooperation in social dilemmas. *Journal of Personality and Social Psychology*, *66*, 513-529.

Keser, C., & van Winden, F. (in press). Conditional cooperation and voluntary contributions to public goods. *Scandinavian Journal of Economics.*

Komorita, S. S., Chan, D. K., & Parks, C. (1993). The effects of reward structure and reciprocity in social dilemmas. *Journal of Experimental Social Psychology*, *29*, 252-267.

Komorita, S. S., Hilty, J. A., & Parks, C. D. (1991). Reciprocity and cooperation in social dilemmas. *Journal of Conflict Resolution*, *35*, 494-518.

Komorita, S. S., & Parks, C. D. (1995). Interpersonal relations: Mixed-motive interaction. *Annual Review of Psychology*, *46*, 183-207.

Komorita, S. S., Parks, C. D., & Hulbert, L. G. (1992). Reciprocity and the induction of cooperation in social dilemmas. *Journal of Personality and Social Psychology*, *62*, 607-617.

Kramer, R. M., McClintock, C. G., & Messick, D. M. (1986). Social values and cooperative response to a simulated resource conservation crisis. *Journal of Personality*, *54*, 576-592.

Kurzban, R., & Houser, D. (in press). Individual differences and cooperation in a circular public goods game. *European Journal of Personality.*

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.

Liebrand, W. B. (1984). The effect of social motives, communication and group size on behaviour in an *N*-person multi-stage mixed-motive game. *European Journal of Social Psychology*, *14*, 239-264.

Longford, N. T. (1993). *Random coefficient models.* New York: Oxford University Press.

Marwell, G., & Ames, R. (1979). Experiments in the provision of public goods, I: Resources, interest, group size and the free rider problem. *American Journal of Sociology*, *84*, 1335-1360.

McClintock, C. G., & Liebrand, W.B.G. (1988). Role of interdependence structure, individual value orientation, and another's strategy in social decision making: A transformational analysis. *Journal of Personality and Social Psychology*, *55*, 396-409.

Messick, D. M., Wilke, H., Brewer, M. B., Kramer, R. M., Zemke, P. E., & Lui, L. (1983). Individual adaptations and structural change as solutions to social dilemmas. *Journal of Personality and Social Psychology*, *44*, 294-309.

Milgrom, P. R., & Roberts, J. (1991). Adaptive and sophisticated learning in normal form games. *Games and Economic Behavior*, *3*, 82-100.

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

Osgood, C. E. (1962). *An alternative to war or surrender.* Urbana: University of Illinois Press.

Parks, C. D. (1994). The predictive ability of social values in resource dilemmas and public goods games. *Personality and Social Psychology Bulletin*, *2*, 431-438.

Parks, C. D., & Hulbert, L. G. (1995). High and low trusters' responses to fear in a payoff matrix. *Journal of Conflict Resolution*, *39*, 718-730.

Parks, C. D., & Komorita, S. S. (1997). Reciprocal strategies for large groups. *Personality and Social Psychology Review*, *4*, 314-322.

Pruitt, D. G., & Kimmel, M. J. (1977). Twenty years of experimental gaming: Critique, synthesis, and suggestions for the future. *Annual Review of Psychology*, *28*, 363-392.

Rabin, M. (1993). Incorporating fairness into game theory and economics. *American Economic Review*, *83*, 1281-1302.

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.

Rapoport, A., & Suleiman, R. (1993). Incremental contribution in step-level public goods games with asymmetric players. *Organizational Behavior and Human Decision Processes*, *55*, 171-194.

Roberts, G., & Sherratt, T. N. (1998). Development of cooperative relationships through increasing investment. *Nature*, *394*, 175.

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

Smith, V. L. (1991). The principle of unanimity and voluntary consent in social choice. In V. L. Smith (Ed.), *Papers in experimental economics* (pp. 377-391). Cambridge, UK: Cambridge University Press.

Sugden, R. (1984). Reciprocity: The supply of public goods through voluntary contributions. *Economic Journal*, *94*, 772-787.

Van Lange, P.A.M., & Visser, K. (1999). Locomotion in social dilemmas: How people adapt to cooperative, tit-for-tat, and noncooperative partners. *Journal of Personality and Social Psychology*, *77*, 762-773.

Ward, H. (1989). Testing the waters: Taking risks to gain reassurance in public goods games. *Journal of Conflict Resolution*, *33*, 274-308.

Wit, A. P., & Wilke, H.A.M. (1992). The effect of social categorization on cooperation in three types of social dilemmas. *Journal of Economic Psychology*, *13*, 135-151.

Yamagishi, T. (1986). The provision of a sanctioning system as a public good. *Journal of Personality and Social Psychology*, *51*, 110-116.

Yamagishi, T., & Sato, K. (1986). Motivational bases of the public goods problem. *Journal of Personality and Social Psychology*, *50*, 67-73.

Received November 15, 2000
Revision accepted January 10, 2001