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## VERY PRELIMINARY VERSION II
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# Heterogeneity, Communication, Coordination and Voluntary Provision of a Public Good

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**Abstract**

The results of twenty-four laboratory sessions are evaluated with respect to the role of alternative definitions of equity when communication is introduced into an environment in which voluntary contributions determine the level of public good provision to small groups of individuals. Individuals experience both non-communication and communication treatments. Additional treatments include the extent to which subjects have information about others' payoffs from (preferences for) the consumption of public goods and about others' incomes and payoff functions (preferences). With communication, participants in incomplete information environments are less able to coordinate their contributions while those in complete information environments succeed more often. Under complex heterogeneity payoff distributions widen with the introduction of communication. The data do not support the emergence of a particular pattern of coordination across all treatments.

**Keywords:** Public goods, voluntary provision, heterogeneous agents, communication, coordination, information

**JEL Classification:** H41, C92

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# Heterogeneity, Communication, Equity, and the Voluntary Provision of a Public Good

## 1. Introduction

Chan *et al.* (1999) report data from an experiment designed to capture aspects of a common property environment contained within the regions of Halton and Hamilton-Wentworth in southern Ontario, Canada. The City of Hamilton, in Canada, borders on a large harbour which is subject to heavy industrial use but which is now increasingly viewed as a recreational and ecological resource. Under a Remedial Action Plan, two large firms, many smaller firms, two municipalities, provincial and federal authorities are expected to undertake expenditures for remediation and prevention of pollution in the harbour. All parties have different sizes, different interests, and different abatement cost structures. This leads to payoff structures which are imperfectly known to one another and almost certainly non-linear. Although all agents are viewed as *stakeholders* in the health of the harbour, they face no binding regulation or external economic motivation to undertake these expenditures. Rather they discuss and co-ordinate their plans through membership in a *restoration council* and an *implementation team*.

The key aspects of this field environment are that the agents differ in at least two dimensions (size and cost structure), that they are incompletely informed about each others' payoff structures, that they can and do communicate with each other before making voluntary contributions to a public good, and that the problem is non-linear in the sense that the optimal allocation of resources almost certainly lies in the interior of the choice set. The voluntary contribution mechanism for the provision of public goods seems to be an appropriate model of the field environment. This suggests that the theoretical and empirical literature on the voluntary contribution mechanism should give some insight into the problems faced in the field. This literature is reviewed by Chan *et al.* (1999) who study the effects of *heterogeneity* in endowments and preferences on *aggregate voluntary contributions* to a public good in a *non-linear environment*, under alternative conditions of information and communication.[1] The laboratory experiment consists of three-person groups in a partners environment.[2] In general incomplete information has a small but significant *negative* impact on aggregate contributions. Heterogeneity has a *positive* impact on aggregate contributions, but its effects interact unexpectedly with communication. In a no-communication environment, heterogeneity in two dimensions (endowment and preferences) increases contributions substantially while heterogeneity in a single dimension (endowment or preferences) has little effect. The reverse holds in the communication environment. There is a positive interaction between heterogeneity and incomplete information. Thus the predictions of the Bergstrom, Blume and Varian (1986) non-cooperative equilibrium model are rejected and mixed evidence is presented on the conjectures by Ledyard (1995).[3]

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[1] Heterogeneity in firm size is captured by giving subjects different endowments and heterogeneity in payoff structure by differences in the induced preference functions. Chan *et al.* (1999) also find that with incomplete information, heterogeneous agents are more cooperative than homogeneous agents.

[2] We chose a three-person environment for consistency with our earlier experiments. Bardhan's (1993) suggestion that small groups are more likely to coordinate successfully implies that using three-person groups allowing communication should increase the likelihood of optimal voluntary contributions regardless of the heterogeneity characteristics of the groups. Any heterogeneity effect will have to be strong if it is to be observed.

[3] Ledyard (1995, 159-60) surveyed five linear public goods experiments that have directly addressed the heterogeneity issue. Three of these (Marwell and Ames, 1979,1980, Bagnoli and McKee, 1991, and Rapoport and Suleiman, 1993) studied threshold public goods environments, the first finding no effect of heterogeneity while the other two found some negative effects. Of the remaining two, Fisher, Isaac, Schatzberg, and Walker (1994) provides only tangential evidence. Brookshire, Coursey and Redington (1993) provide a controlled test of the

While Chan *et al*. (1999) reported the aggregate effects of heterogeneity, communication, and information on voluntary contributions to a public good in small groups, this paper studies the individual effects of these variables. Of particular interest is the pattern of contributions made by different subjects before and after communication is permitted, the character of the coordination that is realized, and the ultimate effect on the distribution of payoffs realized by the members of the groups. The results suggest that communication and a little bit of heterogeneity may improve the payoffs of all members of small groups whether information is complete or not, but that an increase in heterogeneity may lead to reductions in the payoffs of some group members regardless of the completeness of information. Finally, incomplete information may lead to a widening of the distribution of payoffs regardless of the extent of heterogeneity.

## 2. The Laboratory Environment[4]

In our laboratory environment individuals in each group of three repeatedly allocated their token endowments to Market 1 (a private good market) or to Market 2 (a public good market). Subjects received written instructions which were also read aloud.[5] All instructions were framed in neutral language. Allocations were restricted to integer values. Subjects were given tables

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influence of both heterogeneity and information in a linear environment and found that incomplete information generally increased contributions. On the basis of this survey, but warning that more research is needed, Ledyard (p. 160) conjectures that, with respect to contributions, he expects a negative effect of heterogeneity, a positive effect of incomplete information and a positive interaction between heterogeneity and incomplete information. More details with regard to this conjecture are presented by Chan *et al*. (1999).

[4] This section is reproduced from Chan *et al*. (1999).

[5] Instructions are reproduced in Chan *et al*. (1999). The payoff tables are available from the authors and are forthcoming at http://www.socsci.mcmaster.ca/econ/mceel/index.html in *unpublished work in progress* under *publications*.

showing their payoffs according to their own allocation and the allocation of the remaining subjects in the group. They reported their decisions and were informed of the results through a network of personal computers.

There were 22 decision rounds in each session, divided into five phases. The first phase consisted of six decision rounds, during which there was no communication among the subjects. The first two rounds were treated as practice periods and the data from them were discarded. The remaining four phases consisted of four decision rounds each, preceded by limited face-to-face communication (see Table 1). At the end of 22 periods, subjects were paid their accumulated payoffs, converted from laboratory dollars to Canadian dollars at a rate common to all participants that was announced at the beginning of the session.

[Insert Table 1 Here]

Two information conditions were used. In the incomplete information condition subjects had no information about the endowments and payoff tables of other group members. In the complete information condition they knew both the endowments and payoff tables (preferences) of the other people in their group. In all cases subjects knew their own endowments, payoff tables, the identity of the other individuals in their group and when the session would end.

Each individual $i$ had an endowment of $w_i$ tokens. The lab dollar payoff to individual $i$ , $u_i$, was derived from the function

$$u_i = x_i + \alpha_i G + x_i G \qquad \textbf{(1)}$$

where $x_i$ is the allocation to the private good, $G = \sum_i g_i$, is the aggregate allocation to the public good, $g_i = w_i - x_i$ is the individual's allocation to the public good, and $\alpha_i$ is a parameter which characterizes individual preferences for the public good.

There were two levels of heterogeneity in endowments: same endowment (SE) with $w_i = 20 \ \forall i$, and different endowment (DE) with $w_1 = w_2 = 18$, $w_3 = 24$, and two levels of heterogeneity in preferences: same preferences (SP) with $\alpha_i = 9 \ \forall i$ and different preferences (DP) with $\alpha_1 = \alpha_2 = 6$, $\alpha_3 = 15$. In all treatments, the group endowment, $W$, was 60 tokens per period and the aggregate preference parameter $\alpha = \sum_i \alpha_i$ was 27. The two heterogeneity factors were combined with the information factor in a complete 2x2x2 factorial design replicated 3 times (Table 2 ).

[Insert Table 2 Here]

When communication was permitted, subjects with complete information were told that they were permitted to discuss anything they wished, other than physical threats or side-payments, for four minutes. Subjects were also reminded that they had each others payoff tables, which they could bring to discuss during the communication phases of the session. They were also told that any agreements they reached during their discussion would not be enforced by the session monitor or by the computers. Subjects with incomplete information were only permitted to share qualitative information about their own payoffs. They could state that a contribution pattern increased or decreased their payoff, but could not state the quantitative change. Recall that in these sessions subjects had only their own payoff tables. An invigilator attended each session to monitor the discussion and enforce the rules governing communication. No attempts to make side payments or threats occurred in any of the sessions.

## 3. Predictions

In a non-cooperative environment the best response function for individual *i* is given by

$$g_i = \max\left(\frac{w_i - G_{-i} + \alpha_i - 1}{2}, 0\right) \qquad \textbf{(2)}$$

This function is bounded below by the constraint that contributions cannot be negative. Assuming the constraint is not binding on any subject, setting n = 3 and summing over *i* we obtain

$$G = \frac{W + \alpha - 3}{4} \qquad \textbf{(3)}$$

Aggregate contributions in equilibrium depend only on the aggregate group endowment, W, and the aggregate preference parameter, $\alpha$. Given our experimental parameterization this is 21 tokens in all conditions. The group optimum contribution is easily computed to be 43 tokens. Using the equations from **(2)** for each of the three subjects, the individual Nash equilibrium contributions may be calculated for each type of subject in each of the four treatments. These are reported in Table 2. Any combination of contributions totally 43 will yield the same aggregate optimal payoff, but none of these combinations will be a Nash equilibrium.[6]

In a full-information, non-communication environment, the Bergstrom *et al*. prediction is

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[6] If each subject expected both of the others in his group to increase their contributions by one token each in response to his one token increase ( $\partial G_{-i} / \partial g_i = 2$ ), the resulting Nash equilibrium will maximize the aggregate payoff. Each subject's contribution will be 7.33 tokens more than in the Nash equilibrium with zero conjectural variations if subjects could make contributions in fractions of a token. Because contributions are restricted to integer values, the Nash equilibrium contribution will be 7 tokens more than in the zero conjectural variation equilibrium.

that the non-cooperative equilibrium will prevail in all four heterogeneity conditions.[7] The effect of communication and incomplete information is not obvious. Chan *et al*. (1999) describe cases that can be made for and against a negative effect of heterogeneity. We adopt as a working hypothesis Ledyard's conjecture that heterogeneity in either or both dimensions will reduce aggregate contributions and that there will be a positive interaction between incomplete information and heterogeneity.

**4. Results**

Seventy-two subjects in 24 groups of three participated in a total of 14 sessions.[8] Sessions were completed in less than ninety minutes. The average compensation for participating was $27.75 (the range was $19.00 to $43.50; standard deviation was $5.37).

[Insert Table 3 Here]

Table 3 shows the general pattern of the results based on aggregated data. Prior to Phase 1 there was no communication among the subjects. Prior to Phase 4 subjects had two rounds of communication followed by four private decision rounds. The third round of communication preceded Phase 4.[9] The data in Table 3 show that communication resulted in increases in

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[7] These are homogeneity (SE/SP), two variants of heterogeneity in a single dimension (SE/DP and DE/SP), and one variety of heterogeneity in two dimensions (DE/DP).

[8] The subjects in these sessions were recruited through notices posted across the McMaster University campus. Respondents became members of a pool of potential subjects who were invited to participate in different sessions conducted in the McMaster Experimental Economics Laboratory. By inviting members of the pool in alphabetical order we tend to control the inclusion of *good friends* as participants in the same group. In ten of the sessions there were two groups of 3 subjects; in the remaining four there was only one group. In the two-group sessions, the groups met in separate rooms and there was no interaction across the groups.

[9] Chan *et al*. (1999) shows clear evidence of end-game effects in the fifth, and last, phase. This motivates the decision to focus on the last four periods of Phase 1 and on Phase 4 when

aggregate contributions, communication in the presence of simple heterogeneity led to greater increases in contributions than communication among homogeneous subjects. Finally, complex heterogeneity resulted in lower contributions under complete information and communication than did homogeneity while the reverse was true under incomplete information.[10]

[Insert Tables 4 and 5 Here]

We are particularly interested in investigating the affect of subject type on contributions, payoffs, and the coefficients of variation of contributions and payoffs and on the interactions of subject type with heterogeneity, communication and information. Tables 4 and 5 report mean per period contributions and payoffs respectively by heterogeneity treatment, subject type, information condition and phase. S identifies the mean contribution for the pair of subjects who are the same within a group and D identifies the mean contribution for the subject who is different from the others in a group. Finally, we report the mean coefficients of variation of mean individual contributions and payoffs by phase, heterogeneity treatment, information condition in Table 6. The coefficient of variation of mean individual contributions in a group in a phase provides a measure of the distribution of contributions across individuals in the group during a phase. If this value falls across phases for a group, we can argue that the distribution of

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analysing the data.

[10] We analyse the variance in 48 observations: the mean contribution for each of the 24 groups in each of Phase 1 (periods 3-6) and Phase 4 (periods 15-18). This allows us to examine concisely all interactions in our design. The aggregate behaviour of groups of subjects under the different simple heterogeneity treatments (SE/DP and DE/SP) did not differ and were pooled into a single simple heterogeneity category. When analysing the 48 observations we have not allowed for the possible statistical dependence of the Phase 4 observations on the Phase 1 observations. Supplementary tests on completely independent observations, which confirm our results, are reported in Chan *et al*. (1999).

contributions is becoming more equitable within the group. The average across groups in a treatment provides an aggregate measure of equity for the treatment. An analogous comparison may be made with payoffs. Equity in contributions does not imply equity in payoffs.

[Insert Table 6 Here]

Following Chan *et al*. (1999), we will analyse data from Phase 1 (periods 3 - 6) and Phase 4 (periods 15 - 18). Because the data in Tables 4 and 5 reflect more similarities across the SE/DP and DE/SP conditions than across all heterogeneity treatments, we first test the equivalence of the SE/DP and DE/SP conditions.[11]

We conduct the analysis as follows. First, we specify a fully saturated analysis of variance model to explain each dependent variable as a function of type, communication, information, the heterogeneity condition (SE/SP, DE/SP, SE/DP, and DE/DP), and all their interactions. In addition, we allowed for possible fixed subject effects by including a subject identifier as an explanatory variable for mean contribution in a phase and mean payoff in a phase. We allowed for possible fixed group effects by including a group identifier for mean coefficients of variation in contributions and in payoffs.

We tested the equality of the DE/SP and SE/DP effects by estimating a restricted analysis of variance for the four dependent variables in which we specified three levels of heterogeneity: none (SE/SP), simple heterogeneity (SE/DP or DE/SP) and complex heterogeneity (DE/DP). In

[11] The heterogeneity conditions are represented as combinations of SE (same endowments), DE (different endowments), SP (same preferences) and DP (different preferences). SE/SP identifies a condition in which all subjects have the same preferences and endowments. This is the homogeneity condition.

no case was the restriction significant.[12]

This led us to pool the single heterogeneity conditions, leading to a three-way categorization of homogeneity, one-dimensional or *single* heterogeneity (in endowments *or* preferences) and two-dimensional or *double* heterogeneity (in endowments *and* preferences). Tables 7 and 8 summarize the mean group contributions and payoffs by these new categories of treatment for Phase 1 (no communication decision periods) and Phase 4 (the four decision periods following the third round of communication). Tables 9 and 10 contain the coefficients of variation.

[Insert Tables 7 - 10 Here]

The pooled data constitute a 3x2x2x2 factorial design in heterogeneity, communication, subject type, and information. The main effect of communication on contributions was strongly significant (F-test; p = 0.000) while the main effects of communication and subject type on payoffs were strongly significant (F-test; p = 0.000 and p = 0.019 respectively). Dropping two-, three- and four-way interactions with p-values greater than 0.500, we conducted the analyses of variance reported in Tables 11 and 12.[13] Tables 13 and 14 report the analyses of variance of coefficients of variation.

[Insert Tables 11 - 14 Here]

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[12] For contributions and payoffs the F-statistics were 0.443 and 0.604 respectively. The critical value of the F-statistic at the 5% level of significance with 4 and 58 degrees of freedom is 2.53. For the coefficients of variation of contributions and payoffs the F-statistics were 1.28 and 2.24 respectively. The critical value of the F-statistic at the 5% level of significance with 2 and 16 degrees of freedom is 3.63.

[13] The remaining ANOVA tables are available from the authors and are forthcoming at http://www.socsci.mcmaster.ca/econ/mceel/index.html in *unpublished work in progress* under *publications*.

Several observations with regard to individual contributions follow from Tables 2, 7, 9, 11 and 13.

Observation 1: *In the absence of communication, individuals who are predicted to make large contributions under-contribute while those who are predicted to make small contributions over-contribute.*

Table 2 presents the conventional Nash equilibrium contributions by treatment and subject type. Table 4 presents the mean contributions by treatment and subject type and phase (Table 7 summarizes these results for the first and fourth phases and the trichotomous heterogeneity measure). Referring to Table 4, contributions by the high-endowment or high-preference individuals consistently fall short of the predicted values of 13, 11, and 17 tokens in the SE/DP, DE/SP, and DE/DP treatments. For the complete information and incomplete information conditions these values are 9.00, 7.08, 13.25 and 7.92, 9.25, 13.50 respectively. Similarly, the other individuals contributions exceed the conventional Nash equilibrium contribution of 4, 5, and 2 tokens. Their mean values are 6.17, 6.33, 6.88 and 4.88, 7.88, 6.33 respectively for the complete and incomplete information conditions. These results are consistent with the predictions of the equity theory model presented in Chan *et al*. (1997) rather than those of the conventional public good model presented by Bergstrom *et al*. (1986).

Observation 2: *Information conditions have no effect on contributions by subject type, communication condition or heterogeneity treatment.*

The data presented in Table 7 in the first two subtotal lines suggest that contributions by subject type across information treatments match each other closely. This is supported by the analysis of variance presented in Table 11, which shows that the main effect of information on contributions is not significant (F-test, $p = 0.640$).

Observation 3: *Communication and complex heterogeneity leads to reductions in contributions by individuals who are predicted to be large contributors in the absence of communication.*

Table 7 shows that with no communication, high-endowment or high-preference individuals in heterogeneous groups contribute more than low-endowment and low-preference individuals. The contributions of the same type of individuals in the communication phase conform to a similar pattern, but the difference across heterogeneity treatments is now reversed! High-preference, high-endowment individuals in the complex heterogeneity treatments contribute less than their counterparts in the simple heterogeneity treatments while they contributed more in the no-communication phase. This difference is picked up by the significant three-way interaction HxCxT in Table 11 (F-test, $p = 0.019$).

Observation 4: *Communication increases equity in contributions but given communication, equity declines with heterogeneity.*

Table 9 displays mean coefficients of variation which drop in magnitude from Phase 1 to Phase 4 for each heterogeneity treatment and information condition. The ten of the twelve complete information differences and eleven of the twelve incomplete information differences between Phase 1 and Phase 4 coefficients are positive. Accordingly, using the Wilcoxon matched-pairs signed-rank test we can reject the hypothesis that the contribution distributions are not affected by communication against the alternative that they narrow ($p < 0.010$ and $p < 0.025$ for complete information and incomplete information respectively). Pooling the information conditions we can reject the null that communication has not effect with the same test ($p < 0.005$). Furthermore, if only Phase 4 means are compared, there is a clear decline in these values moving from homogeneous subjects to heterogeneous subjects. Using an exact randomization test, the null hypothesis that there is no difference between the mean coefficient of variation of the homogeneous groups and the heterogeneous groups cannot be supported by the data against the alternative that the mean coefficient of variation for the heterogeneous groups is larger (p = 0.044). Therefore communication increases equality of contributions, but heterogeneity leads to less equitable distributions of contributions than homogeneity.

Several observations with regard to individual payoffs follow from Tables 8, 10 and 12.

<u>Observation 5</u>: *Information conditions have no effect on payoffs by subject type, communication condition or heterogeneity treatment.*

The data presented in Table 8 in the first two subtotal lines suggest that contributions by subject type across information treatments match each other closely. This is supported by the analysis of variance presented in Table 12, which shows that the main effect of information on contributions is not significant (F-test, p = 0.582).

<u>Observation 6</u>: *Communication and complex heterogeneity leads to reductions in payoffs to individuals who are NOT unique in a group. In all other instances communication leads to increased payoffs to all subjects.*

The summary data in Table 8 indicate that in the no-communication periods mean individual payoffs ranges from 694 lab dollars to 416 lab dollars. In communication periods this range is from 820 to 416 lab dollars. In spite of this overlap the main effect of communication is significant (Table 12, F-test, p = 0.000). In addition, given subject type, communication has a significant effect on payoffs (F-test, p = 0.013), and given heterogeneity class, communication has a significant effect on payoffs (F-test, p = 0.011). The anomalous result is the reduction from 454 to 430 lab dollars with the introduction of communication for the individuals who have the low endowments and lesser preference for the public good. The data support the hypothesis that communication does not lead to an increase in payoffs (Wilcoxon matched-pairs signed-rank test on the null that there is no difference between 454 and 430 against the alternative that 454 is greater than 430, p < 0.100). This stands in contrast to the overall result that communication generally increases payoffs.

Observation 7: *Given communication, increasing heterogeneity leads to increasing inequality in payoffs.*

The coefficients of variation displayed in Table 10 show comparable patterns across information conditions and that given communication the mean coefficient of variation across information conditions rises from 0.043 to 0.173 to 0.334 as treatments progress from homogeneity to simple heterogeneity to complex heterogeneity. The significance of these data are reflected in the analysis of variance reported in Table 14 which indicates the heterogeneity and communication interaction is statistically significant (F-test, p = 0.046) while the third-order interaction of heterogeneity, communication and the information condition is not (F-test, p = 0.534).

Observation 8: *Given incomplete information, communication leads to increased inequality in heterogeneous treatments.*

Table 10 shows that communication unambiguously leads to a narrowing of payoff dispersion within homogeneous groups. With incomplete information, however, communication leads to increases in payoff dispersion within heterogeneous groups regardless of the degree of heterogeneity as the mean coefficient of variation rises from 0.183 to 0.262. This difference is significant (Wilcoxon matched-pairs signed-rank test, $p < 0.050$).

## 5. Patterns of Coordination

After the first six decision periods subjects were given an opportunity to meet and discuss the decisions they had made and the results of these decisions. They were permitted, within limits, to share information and discuss strategies for their decisions in subsequent periods. Any agreements with regard to contributions reached by members of a group were not enforceable. Furthermore, subjects never received information with regard to how much any particular individual contributed (even under the complete information condition). Because of the different information conditions and the different heterogeneity treatments, different patterns of coordination of contributions could emerge. Of interest is the effect of the treatment variables on the patterns of coordination.

Generally three patterns of coordination emerged during the communication phases of the sessions. In one pattern, each subject contributed the same number of tokens as each other subject. This is the *equality* or e-pattern. A second pattern is the *clean split* or s-pattern. Under this pattern the subjects clearly make different contributions in such a way that the unique individual in the group consistently contributes a different amount than each of the other two individuals (who have the same endowments and preferences), who make the same contributions. The third pattern is the *cycling* or c-pattern. With this pattern the subjects take turns as the contributor of zero or nearly zero tokens while the other two contribute all or nearly all of their tokens to the public good. This pattern may emerge across the phases of the session or across the periods within a phase. The latter occurs much more often than the former. Because each phase contains four decisions periods, the subjects tend to each contribute nothing in one of the first three periods, while the others contribute a large amount in each of these periods. In the fourth period, the subjects occasionally can agree on a common contribution or they agree to let each individual contribute whatever he wishes to contribute.

Table 15 displays an array of symbols which identify any phases during which coordination of contributions occurred. The letters "c", "e", and "s" identify the instances of coordination. If no coordination is observed an "o" appears in the table. Instances of coordination have not been selected by applying a well defined mechanism to the data, but rather were chosen by examining figures which display the contributions of each subject in each period of each session; this is clearly a subjective process.[14] One cell in Table 15 displays a "d". During the first phase following their first opportunity to communicate the members of this group agreed to each contribute 18, 15, 10 and 7 tokens in the first, second, third and fourth periods of the phase. This pattern was not maintained and the subjects switched to a cycling pattern for the next two phases of their session.

Clear patterns of coordination emerged in only one of six sessions in which subjects were homogeneous. The pattern of contributions and payoffs is shown in Figure 1. Because subjects are homogeneous, this pattern is consistent with both the e- and s-patterns. Two of the subjects contributed slightly more than the Nash equilibrium contribution of seven tokens towards the end of the no-communication phase. After the first round of communication they agreed to each contribute fifteen tokens, and did this consistently through the final four phases. This pattern yielded payoffs of 635 lab dollars to each subject in each period. Lowering their contributions to

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[14] These figures are available from the authors and are forthcoming in *unpublished work in progress* under *publications* at http://www.socsci.mcmaster.ca/econ/mceel/index.html

fourteen tokens a period would have increased their payoffs to 636 lab dollars.[15]

Figure 2 displays the period by period contributions and payoffs for a session in which cycling occurred across the first three communication phases and within the last phase. In this particular example the subjects were able to coordinate on the final contribution of the session, although it is interesting to note that this contribution is well below one third of their aggregate contributions in the previous periods. Note that the individual with the greater preference for the public good (subject identified with the open squares) is clearly realizing greater payoffs than the other subjects. Because this is a incomplete information session, none of the subjects know with certainty what each subject earns from their decisions. It appears as if they are focussing on equalizing contributions.[16] The dashed horizontal lines in Panel 1 identify the conventional Nash equilibrium contributions during the first phase and the symmetric optimal contributions for the subsequent phases. The high preference individual is always *under-contributing* while the other individuals are *over-contributing* relative to these benchmarks.

Figure 3 displays three different patterns of coordination. This is another complete information session. Subjects have different endowments and the same payoff functions. During the first phase following communication the subjects agree on equal contributions identical to those selected by the subjects in the session displayed in Figure 1. After communication prior to

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[15] If one individual contributed fifteen tokens (instead of fourteen) and the other two contributed fourteen tokens the aggregate contribution would rise by one token. However, the payoff of the person whose contribution rises will fall by 29 lab dollars while each of the other's payoffs will rise by 15 lab dollars. It is difficult to coordinate on this outcome, and the net gain is negligible. Fourteen tokens each is effectively a symmetric optimum.

[16] Examining the transcripts from this session may indicate that the high preference subject is a dominant player in forming the strategy for this group. This will be included in a future draft.

phase 3, the high-endowment individual is convinced to increase his contribution to a value which nearly equalizes the payoffs of the three subjects (see Panel 2). After the next round of communication, the high-endowment subject increases his contribution, and slightly reduces his payoff by slightly increasing the payoffs of the others. In the final phase the subjects abandon the equal payoff outcome and enter into a cycling pattern. Each contributes nothing in one period and his total endowment in two periods. In the final period they return the pattern of Phase 4. This is clearly a coordinated strategy. The high endowment subject gains 20 lab dollars over the phase from the previous phase, while the other two each receive 18 lab dollars less.

Figure 4 shows an interesting pattern of a group learning to cycle. The amplitude of the cycle widens across phases, but because of incomplete information the high endowment individual is able to conceal the size of his endowment and the cycle swings from zero tokens to 18 (the endowment of the two low-endowment subjects). The high-endowment subject clearly gains the larger share of the payoffs to the group.

The final figure is an example of a group who is unable to form a coordinated contribution strategy. In this session the high-endowment, high preference subject successfully free-rides on the other subjects. Although his payoffs exceed those of the others in the group, they are below those realized in sessions in which subjects are able to coordinate their contributions. In this session the addition of communication to complete information does not appear to improve the ability of a small group of heterogeneous individuals to coordinate their allocation of endowments in such a way as to increase their payoffs.[17]

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[17] Except for Phase 3, the high-endowment individual's payoff very close to or above the equal payoff optimum. The others, however, receive very low payoffs which are frequently half of what the high-endowment individual receives. With complete information and communication

Five of the twelve complete information sessions display repeated coordinated activity by the subjects in these sessions. In three of the twelve incomplete information sessions, coordinated activity arises repeatedly. In one of nine sessions with homogeneous subjects coordination arises, but in seven of twelve sessions in which the subjects are heterogeneous coordination arises. Of the emerging patterns of coordination, splitting contributions near to the split necessary to achieve equal optimal payoffs is more common under complete information, while cycles tend to be more common under incomplete information. Coordination has a impact on the aggregate payoffs received by groups across the periods within a phase. The fourteen percent increase in payoffs per phase realized by coordinating groups relative to those which do not coordinate is significant (t-test, $p = 0.000$) and holds for both information conditions taken separately.

## 6. Discussion and Conclusions

Chan *et al*. (1999) investigated the effect of heterogeneity on public goods provision in a non-linear environment under alternative conditions of communication and information. The major observations were that communication increased coordination (which is well known) and that with incomplete information heterogeneity increased coordination. The character of the coordination that evolved following communication was not discussed . This was the objective of the current paper.

This paper reports impacts on both contributions and payoffs. During the phase in which subjects are unable to communicate, the resulting patterns of contributions resemble those reported in Chan *et al*. (1997). The individuals who are expected to make high contributions,

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it should be possible for everyone to be made better off. Of course, if simple payoff maximization does not characterize this subject's objectives, he may be pleased with this outcome!

according to the convention public good model, under-contribute, while those who are expected to make lower contributions, over-contribute. Under the simple heterogeneity treatments, mean aggregate contributions were not different from those made by homogeneous groups. However, under complex heterogeneity, mean aggregate contributions exceeded those in the other treatments. This result is not consistent with the prediction of the conventional public good model, but is possible from the model incorporating the notion of equity theory in Chan *et al*. (1997) taken from the psychology literature. The mean contribution of low-endowment individuals exceeds the 2-token prediction of the conventional model by more than four tokens, while the mean contribution of high-endowment individuals is below the conventional model's 17-token prediction by more than three tokens.

Unlike the aggregate data, which reflect a weakly significant information effect, neither the individual contribution nor payoff data display significant information effects by subject type, communication condition or heterogeneity treatment. Communication, subject type, and heterogeneity do have significant impacts on contributions and payoffs.

Generally, communication leads to a narrowing of the distribution of contributions across subjects. Without an prediction about how communication will effect the contributions made by members of these groups, it is difficult to evaluate this narrowing of the distribution of contributions. In particular, the contributions which lead to equal payoffs in the optimal state will not result in everyone making the same contribution. However, it is not obvious that this is should be the ultimate outcome.

If individuals made contributions in the no communication phase which were consistent with the conventional public goods model, given the parameterization of these sessions, each individual would receive the same payoff if a Nash equilibrium was realized. If the individuals focussed on trying to equalize contributions, high endowment or high preference individuals would earn more than would the other individuals. The data suggest that in the non-communication phase subjects appear to be focussing on contributions. However, the introduction of communication results in the narrowing of the distribution of payoffs for homogeneous groups as their mean per capita payoffs rise by between 25% and 30%. Communication has a similar effect on individuals in the simple heterogeneity treatments, for which high endowment or high preference individuals did not realize as large a percentage increase in payoffs than did the other individuals (approximately 30% for the former and 40% for the latter).

This pattern of payoff increases did not hold for individuals in the complex heterogeneity treatments or for individuals with incomplete information in the simple heterogeneity treatments. For groups with these characteristics communication brought increased inequality in payoffs. In the simple heterogeneity treatments under incomplete information both types of subjects made payoff gains, but equality fell as the payoffs of the high-endowment or high-preference individuals rose by about 45% while the payoffs of the other rose by about 30%. For the complex heterogeneity treatments, the payoffs of the high-endowment individuals rose by about 20% while that of the other individuals *fell* by approximately 7%! Generally, given communication, increases in heterogeneity resulted in increased inequality in payoffs. The anomalous result, however, is the inability of the homogeneous groups with incomplete information to generate total contributions or payoffs which matched or exceeding those of the heterogeneous groups. Their payoffs (and contributions) are more equally distributed, but they are getting more equitable slices of a smaller pie.[18]

No unique pattern of coordination emerges from these sessions. Having complete information does not lead the subjects to the equal payoff optimal, although when instances of coordination are identified by studying the data for each session, payoffs are nearly 97% of the optimal payoffs. In the cases in which coordination does not emerge, payoffs are approximately 85% of optimal payoffs. Both of these compare quite well to the 75% of optimal payoffs accruing in the no-communication phase across all sessions (which is what would be earned if the Nash equilibrium prediction of the conventional model was realized).

Although coordination is important the two which emerge most frequently are patterns of contributions similar to the equal optimal payoff split and a cycling pattern within a phase in which individuals contribute all or nearly all of their endowment for two periods and none or nearly none of their endowment for one period. The cycling pattern is not as effective as the equal optimal payoff split. It does, however, strongly suggest that a pattern that results in equal contributions, rather than equal payoffs plays a strong roll in coordinating contributions. In fact, the cycling pattern is the dominant pattern in the incomplete information cases when it is impossible to evaluate the payoffs of all participants.

Why should heterogeneity lead to higher aggregate contributions? Initially we conjectured

[18] The mean aggregate Phase 4 payoff for the homogeneous groups with incomplete information 6444 tokens. The comparable payoffs for homogeneous, simple, and complex heterogeneity treatments with complete information and for simple and complex heterogeneity treatments with incomplete information are 7224, 7452, 6600, 7536, and 6828 tokens respectively.

in Chan *et al*. (1999, p. 17) that "the positive interaction with incomplete information may provide a clue. In heterogeneous environments the high preference or endowment individual has an individual incentive to contribute more than the other members of the group. When information is incomplete, the other group members might interpret this higher contribution as indicating a desire to co-operate and they might increase their contributions accordingly." Our review of the individual data indicates that generally the high-endowment and high-preference individuals do contribute more than the other individuals, and that with communication in cases of simple heterogeneity their contributions rise. However, with complex heterogeneity, the contributions of these individuals tend to fall with communication, and the contributions of these individuals tend to be much closer to those of the other individuals. This phase of our investigation of heterogeneity in public good provision will not be completed until we review the transcripts of the communication rounds in attempt to discover more about the processes of coordination and the ways in which these processes differed across homogeneous and heterogeneous groups. Of particular interest is the process by which the high-endowment subjects, who contribute most in complex heterogeneity treatments prior to communication, are able get *others* to increase their contributions while the high-endowment individuals contribute little more or even reduce their contributions.

If there is anything for the practical policy maker to take away from this experiment it is that individuals in small groups are remarkably resourceful in their ability to generate processes for coordinating their activities for increasing their surplus *even if they do not have a way for identifying the optimal (surplus maximizing) allocation of resources*. In the incomplete information cases, in which members of each group know only their own potential payoffs, and have no way of sharing this information with others, the homogeneous groups increased their aggregate surpluses on average from 65% to 85% of the potential optimal surplus after three rounds of communication. For heterogeneous groups this increase was from an average of 76% to 96% of the potential surplus.


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*Table 1*. Structure of Sessions

| Phase Type | Phase Number[1] | Action |
|---|---|---|
| No Communication | 1 | Play 6 rounds |
| Communication | 2 | Communicate<br>Play 4 rounds |
| Communication | 3 | Communicate<br>Play 4 rounds |
| Communication | 4 | Communicate<br>Play 4 rounds |
| Communication | 5 | Communicate<br>Play 4 rounds |

[1] Only data from Phases 1 and 4 are used in the analysis. Rounds one and two of Phase 1 were treated as practice periods and these data were discarded.

*Table 2*. Experimental Design: Parameterization, Nash Equilibria and Sessions Per Treatment[1]

| | Same Endowment ($w_i$ = 20 for $i$ = 1, 2, 3) | | Different Endowment ($w_i$ = 18 for $i$ = 1 and 2, $w_3$ = 24) | |
|---|---|---|---|---|
| | Same Preferences ($''_i$ = 9 for $i$= 1, 2, 3) | Different Preferences ($''_i$ = 6 for $i$ = 1 and 2, $''_3$ = 15) | Same Preferences ($''_i$ = 9 for $i$ = 1, 2, 3) | Different Preferences ($''_i$ = 6 for $i$ = 1 and 2, $''_3$ = 15) |
| Individual Nash Equilibria Contributions | $g_i$ = 7 for $i$ = 1, 2, 3 | $g_i$ = 4 for $i$ = 1 and 2, $g_3$ = 13 | $g_i$ = 5 for $i$ = 1 and 2, $g_3$ = 11 | $g_i$ = 2 for $i$ = 1 and 2, $g_3$ = 17 |
| Group Nash Equilibria Contributions | 21 | 21 | 21 | 21 |
| Optimal Contributions | 43 | 43 | 43 | 43 |
| Complete Information Sessions | 3 | 3 | 3 | 3 |
| Incomplete Information Sessions | 3 | 3 | 3 | 3 |

[1] The parameters identified above are the subject's preference parameter for the public good, $''_i$, and the subject's endowment for each decision round, $w_i$. If the value of either of these parameters increases, then the subject's return to public good consumption or the subject's endowment in each decision round increases. Also note that the Nash equilibria contributions are independent of the information condition.

*Table 3*. Aggregate Per Period Contributions[1]

| | Homogeneous | | Simple Heterogeneity | | Complex Heterogeneity | |
|---|---|---|---|---|---|---|
| Information | Phase 1 | Phase 4 | Phase 1 | Phase 4 | Phase 1 | Phase 4 |
| Complete | 22.92 | 36.67 | 20.54 | 39.46 | 27.00 | 31.08 |
| Incomplete | 18.00 | 25.83 | 21.34 | 38.75 | 26.17 | 29.83 |
| Nash Equilibria | 21 | 42 | 21 | 42 | 21 | 42 |

[1] This table is based on the data reported on Table 3 in Chan *et al*. (1999)

*Table 4.* Mean Individual Contributions Per Period by Treatment and Phase and Subject Type[1]

| Endowment, Preference, and Information Conditions | No Communication | Communication | | | |
|---|---|---|---|---|---|
| | Phase 1 | Phase 2 | Phase 3 | Phase 4 | Phase 5 |
| Complete Information | | | | | |
| SE/SP | 7.64 | 11.44 | 11.69 | 12.22 | 11.67 |
| SE/DP (S) | 6.17 | 9.96 | 9.54 | 11.83 | 12.58 |
| (D) | 9.00 | 13.00 | 13.33 | 16.58 | 16.42 |
| DE/SP (S) | 6.33 | 9.71 | 10.54 | 11.33 | 11.25 |
| (D) | 7.08 | 9.33 | 14.67 | 16.00 | 14.92 |
| DE/DP (S) | 6.88 | 10.58 | 8.38 | 10.08 | 5.96 |
| (D) | 13.25 | 13.67 | 9.58 | 10.93 | 13.92 |
| Incomplete Information | | | | | |
| SE/SP | 6.00 | 9.03 | 8.19 | 8.60 | 8.17 |
| SE/DP (S) | 4.88 | 10.63 | 9.00 | 11.50 | 9.88 |
| (D) | 7.92 | 6.33 | 12.42 | 16.08 | 12.92 |
| DE/SP (S) | 7.88 | 9.63 | 11.63 | 12.54 | 12.33 |
| (D) | 9.25 | 10.17 | 13.75 | 13.42 | 10.83 |
| DE/DP (S) | 6.33 | 6.33 | 9.29 | 9.00 | 8.71 |
| (D) | 13.50 | 11.00 | 11.83 | 11.83 | 11.33 |

[1] SE indicates endowments are the same across all subjects in a group and DE indicates the endowments are different. SP indicates preferences are the same across all subjects in a group and DP indicates preferences are different. S indicates the mean contribution for the pair of subjects who are the same, D indicates the mean contribution for the subject who is different. The underlying parameters are given in Table 1. Each cell in the table represents the average contribution by subject type across four periods in three sessions. Data for periods 1 and 2 were dropped to allow for learning.

*Table 5*. Mean Individual Payoffs Per Period by Treatment and Phase and Subject Type[1]

| Endowment, Preference, and Information Conditions | No Communication | Communication | | | |
|---|---|---|---|---|---|
| | Phase 1 | Phase 2 | Phase 3 | Phase 4 | Phase 5 |
| Complete Information | | | | | |
| SE/SP | 482 | 570 | 571 | 602 | 559 |
| SE/DP (S) | 426 | 524 | 536 | 572 | 566 |
| (D) | 557 | 707 | 673 | 741 | 773 |
| DE/SP (S) | 409 | 479 | 561 | 598 | 586 |
| (D) | 509 | 660 | 637 | 645 | 648 |
| DE/DP (S) | 453 | 440 | 356 | 416 | 472 |
| (D) | 694 | 868 | 696 | 818 | 617 |
| Incomplete Information | | | | | |
| SE/SP | 416 | 546 | 522 | 537 | 520 |
| SE/DP (S) | 386 | 388 | 514 | 573 | 503 |
| (D) | 482 | 837 | 661 | 745 | 709 |
| DE/SP (S) | 478 | 502 | 577 | 557 | 512 |
| (D) | 555 | 667 | 711 | 762 | 789 |
| DE/DP (S) | 470 | 422 | 443 | 444 | 436 |
| (D) | 672 | 676 | 833 | 820 | 806 |

[1] SE indicates endowments are the same across all subjects in a group and DE indicates the endowments are different. SP indicates preferences are the same across all subjects in a group and DP indicates preferences are different. S indicates the mean payoff for the pair of subjects who are the same, D indicates the mean payoff for the subject who is different. The underlying parameters are given in Table 1. Each cell in the table represents the average payoff by subject type across four periods in three sessions. Data for periods 1 and 2 were dropped to allow for learning.

*Table 6.* Mean Coefficients of Variation of Mean Individual Contributions and Payoffs per Phase by Treatment and Phase[1]

| Endowment, Preference, and Information Conditions | No Communication | Communication | | | |
|---|---|---|---|---|---|
| | Phase 1 | Phase 2 | Phase 3 | Phase 4 | Phase 5 |
| Complete Information | | | | | |
| <u>Contributions</u> | | | | | |
| SE/SP | 0.490 | 0.271 | 0.079 | 0.066 | 0.196 |
| SE/DP | 0.318 | 0.190 | 0.173 | 0.164 | 0.127 |
| DE/SP | 0.244 | 0.083 | 0.141 | 0.195 | 0.141 |
| DE/DP | 0.512 | 0.174 | 0.360 | 0.297 | 0.409 |
| <u>Payoffs</u> | | | | | |
| SE/SP | 0.213 | 0.100 | 0.041 | 0.046 | 0.111 |
| SE/DP | 0.163 | 0.155 | 0.119 | 0.132 | 0.154 |
| DE/SP | 0.141 | 0.155 | 0.072 | 0.083 | 0.051 |
| DE/DP | 0.233 | 0.355 | 0.371 | 0.362 | 0.174 |
| Incomplete Information | | | | | |
| <u>Contributions</u> | | | | | |
| SE/SP | 0.317 | 0.090 | 0.052 | 0.095 | 0.094 |
| SE/DP | 0.363 | 0.373 | 0.281 | 0.323 | 0.169 |
| DE/SP | 0.460 | 0.049 | 0.090 | 0.047 | 0.060 |
| DE/DP | 0.476 | 0.360 | 0.148 | 0.163 | 0.164 |
| <u>Payoffs</u> | | | | | |
| SE/SP | 0.079 | 0.052 | 0.022 | 0.039 | 0.036 |
| SE/DP | 0.141 | 0.355 | 0.289 | 0.319 | 0.186 |
| DE/SP | 0.194 | 0.144 | 0.104 | 0.157 | 0.217 |
| DE/DP | 0.212 | 0.244 | 0.324 | 0.311 | 0.309 |

[1] SE indicates endowments are the same across all subjects in a group and DE indicates the endowments are different. SP indicates preferences are the same across all subjects in a group and DP indicates preferences are different. The underlying parameters are given in Table 1. Each cell in the table represents the average coefficient of variation of three subjects' average contributions or total payoffs across four periods in three sessions. Data for periods 1 and 2 were dropped to allow for learning.

*Table 7*. Mean Individual Contributions by Communication, Information, Subject Type and Revised Heterogeneity Categorization[1]

| Information and Heterogeneity Condition | No Communication (Periods 3 - 6) | | Communication (Periods 15 - 18) | | Totals | |
|---|---|---|---|---|---|---|
| Complete Information | Same | Different | Same | Different | Same | Different |
| Homogeneous | 7.64 | | 12.22 | | 9.93 | |
| Single | 6.25 | 8.04 | 11.58 | 16.29 | 8.92 | 12.17 |
| Double | 6.88 | 13.25 | 10.08 | 10.93 | 8.48 | 12.09 |
| Sub-Totals | 6.76 | 9.78 | 11.37 | 14.50 | 9.06 | 12.14 |
| Incomplete Information | | | | | | |
| Homogeneous | 6.00 | | 8.60 | | 7.30 | |
| Single | 6.38 | 8.59 | 12.03 | 14.75 | 9.21 | 11.67 |
| Double | 6.33 | 13.50 | 9.00 | 11.83 | 7.67 | 12.67 |
| Sub-Totals | 6.27 | 10.23 | 10.42 | 13.78 | 8.35 | 12.00 |
| Combined Information Conditions | | | | | | |
| Homogeneous | 6.82 | | 10.41 | | 8.62 | |
| Single | 6.32 | 8.32 | 11.81 | 15.52 | 9.07 | 11.92 |
| Double | 6.61 | 13.38 | 9.54 | 11.38 | 8.08 | 12.38 |
| Sub-Totals | 6.52 | 10.01 | 10.89 | 14.14 | 8.71 | 12.07 |

[1] Homogeneous sessions have the SE and SP conditions, Single Heterogeneity sessions have either DE or DP but not both, and Double Heterogeneity sessions have both DE and DP conditions. "Same" identifies the mean of the individuals who are the same as another within a group, "Different" identifies the mean of the individuals who are unique within a group. There are none of these individuals in the Homogeneous condition.

*Table 8.* Mean Individual Payoffs by Communication, Information, Subject Type and Revised Heterogeneity Categorization[1]

| Information and Heterogeneity Condition | No Communication (Periods 3 - 6) | | Communication (Periods 15 - 18) | | Totals | |
|---|---|---|---|---|---|---|
| Complete Information | Same | Different | Same | Different | Same | Different |
| Homogeneous | 482 | | 602 | | 542 | |
| Single | 418 | 533 | 585 | 693 | 502 | 613 |
| Double | 453 | 694 | 416 | 818 | 435 | 756 |
| Sub-Totals | 443 | 587 | 547 | 735 | 495 | 661 |
| Incomplete Information | | | | | | |
| Homogeneous | 416 | | 537 | | 477 | |
| Single | 432 | 519 | 565 | 754 | 499 | 637 |
| Double | 470 | 672 | 444 | 820 | 457 | 746 |
| Sub-Totals | 438 | 570 | 528 | 776 | 483 | 673 |
| Combined Information Conditions | | | | | | |
| Homogeneous | 449 | | 570 | | 510 | |
| Single | 425 | 526 | 575 | 724 | 500 | 625 |
| Double | 462 | 683 | 430 | 819 | 446 | 751 |
| Sub-Totals | 440 | 578 | 538 | 756 | 489 | 667 |

[1] Homogeneous sessions have the SE and SP conditions, Single Heterogeneity sessions have either DE or DP but not both, and Double Heterogeneity sessions have both DE and DP conditions. "Same" identifies the mean of the individuals who are the same as another within a group, "Different" identifies the mean of the individuals who are unique within a group. There are none of these individuals in the Homogeneous condition.

*Table 9*. Coefficient of Variation of Contributions by Phase

| | Homogeneous | | Simple Heterogeneity | | Complex Heterogeneity | |
|---|---|---|---|---|---|---|
| Information | Phase 1 | Phase 4 | Phase 1 | Phase 4 | Phase 1 | Phase 4 |
| Complete | 0.490 | 0.066 | 0.281 | 0.180 | 0.512 | 0.297 |
| Incomplete | 0.317 | 0.095 | 0.412 | 0.185 | 0.476 | 0.163 |

*Table 10*. Coefficient of Variation of Payoffs by Phase

| | Homogeneous | | Simple Heterogeneity | | Complex Heterogeneity | |
|---|---|---|---|---|---|---|
| Information | Phase 1 | Phase 4 | Phase 1 | Phase 4 | Phase 1 | Phase 4 |
| Complete | 0.213 | 0.046 | 0.152 | 0.108 | 0.233 | 0.362 |
| Incomplete | 0.079 | 0.039 | 0.168 | 0.238 | 0.212 | 0.311 |

*Table 11.* Analysis of Variance Results for Average Per Period Individual Contributions[1]

| Source | Partial SS | df | MS | F | Prob>F |
|---|---|---|---|---|---|
| Model | 1927.210 | 76 | 25.358 | 2.49 | 0.000 |
| Heterogeneity (H) (homogeneity, single dimensional heterogeneity, or two dimensional heterogeneity) | 13.203 | 2 | 6.602 | 0.65 | 0.527 |
| Communication (C) | 285.653 | 1 | 285.653 | 28.02 | 0.000 |
| Incomplete Information (II) | 2.250 | 1 | 2.250 | 0.22 | 0.640 |
| Type (T) | 3.063 | 1 | 3.063 | 0.30 | 0.586 |
| H x C | 193.821 | 2 | 96.910 | 9.50 | 0.000 |
| C x T | 13.813 | 1 | 13.813 | 1.35 | 0.249 |
| H x C x T | 59.074 | 1 | 59.074 | 5.79 | 0.019 |
| Subject | 738.296 | 67 | 11.196 | 1.08 | 0.376 |
| Residual | 683.161 | 67 | 10.196 | | |
| Total | 2610.371 | 143 | 18.254 | | |

[1] The analysis of variance was conducted with 144 observations. The root mean squared error is 3.193. The R-squared is 0.738 and the adjusted R-squared is 0.441. The interaction terms HxII, HxT, IIxT, and HxIIxT were dropped from the analysis of variance because of linear dependencies in the model; CxII, HxCxII, CxIIxT, and HxCxIIxT were dropped from the analysis of variance which used the complete set of interactions because their p-values exceeded 0.500 (the p-values for each of these interactions were 0.505, 0.769, 0.835, and 0.528 respectively).

*Table 12*. Analysis of Variance Results for Average Per Period Individual Payoffs[1]

| Source | Partial SS | df | MS | F | Prob>F |
|---|---|---|---|---|---|
| Model | 2464725 | 78 | 31599 | 3.32 | 0.000 |
| Heterogeneity (H) (homogeneity, single dimensional heterogeneity, or two dimensional heterogeneity) | 60530 | 2 | 30265 | 3.18 | 0.048 |
| Communication (C) | 398672 | 1 | 398672 | 41.91 | 0.000 |
| Incomplete Information (II) | 1351 | 1 | 1351 | 0.14 | 0.708 |
| Type (T) | 57780 | 1 | 57780 | 6.07 | 0.016 |
| H x C | 92408 | 2 | 46204 | 4.86 | 0.011 |
| C x T | 61735 | 1 | 61735 | 6.49 | 0.013 |
| H x C x T | 19397 | 1 | 19397 | 2.04 | 0.158 |
| C x II x T | 8738 | 2 | 4369 | 0.46 | 0.6337 |
| Subject | 890569 | 67 | 13292 | 1.40 | 0.089 |
| Residual | 618286 | 65 | 9512 | | |
| Total | 3083012 | 143 | 21560 | | |

[1] The analysis of variance was conducted with 144 observations. The root mean squared error is 97.530. The R-squared is 0.800 and the adjusted R-squared is 0.559. The interaction terms HxII, HxT, IIxT, and HxIIxT were dropped from the analysis of variance because of linear dependencies in the model; CxII, HxCxII, and HxCxIIxT were dropped from the analysis of variance which used the complete set of interactions because their p-values exceeded 0.500 (the p-values for each of these interactions were 0.619, 0.990, and 0.575 respectively).

*Table 13*. Analysis of Variance Results for Coefficients of Variation of Mean Individual Contributions during a Phase by Heterogeneity, Information and Communication Conditions[1]

| Source | Partial SS | df | MS | F | Prob>F |
|---|---|---|---|---|---|
| Model | 1.300 | 29 | 0.045 | 0.92 | 0.590 |
| Heterogeneity (H) (homogeneity, single dimensional heterogeneity, or two dimensional heterogeneity) | 0.073 | 2 | 0.036 | 0.75 | 0.488 |
| Communication (C) | 0.677 | 1 | 0.677 | 13.90 | 0.002 |
| Incomplete Information (II) | 0.002 | 1 | 0.002 | 0.03 | 0.857 |
| H x C | 0.056 | 2 | 0.028 | 0.57 | 0.575 |
| C x II | 0.000 | 1 | 0.000 | 0.00 | 0.959 |
| H x C x II | 0.057 | 2 | 0.029 | 0.59 | 0.565 |
| Group | 0.411 | 20 | 0.201 | 0.42 | 0.968 |
| Residual | 0.877 | 18 | 0.049 | | |
| Total | 2.177 | 47 | 0.046 | | |

[1] The analysis of variance was conducted with 48 observations. The root mean squared error is 0.221. The R-squared is 0.597 and the adjusted R-squared is - 0.052. The interaction term HxII was dropped from the analysis of variance because of linear dependency in the model.

*Table 14.* Analysis of Variance Results for Coefficients of Variation of Mean Individual Payoffs during a Phase by Heterogeneity, Information and Communication Conditions[1]

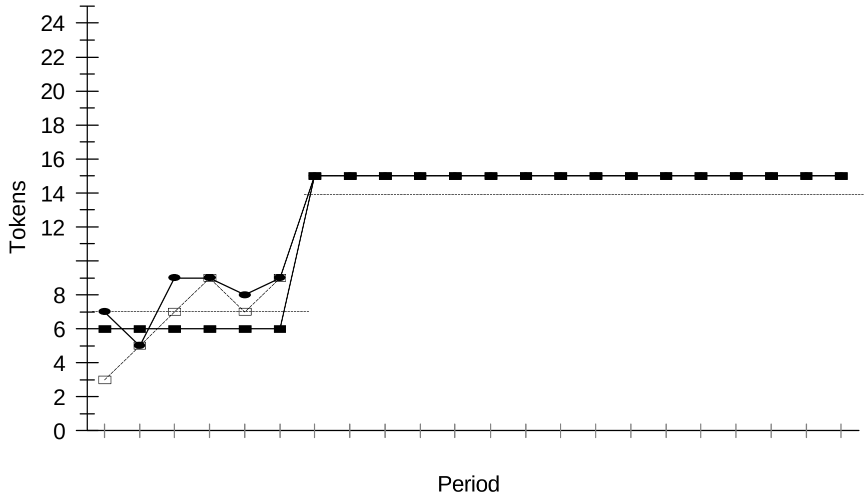
| Source | Partial SS | df | MS | F | Prob>F |
|---|---|---|---|---|---|
| Model | 0.526 | 29 | 0.018 | 1.87 | 0.083 |
| Heterogeneity (H) (homogeneity, single dimensional heterogeneity, or two dimensional heterogeneity) | 0.024 | 2 | 0.012 | 1.24 | 0.314 |
| Communication (C) | 0.001 | 1 | 0.001 | 0.07 | 0.800 |
| Incomplete Information (II) | 0.014 | 1 | 0.014 | 1.46 | 0.243 |
| H x C | 0.071 | 2 | 0.036 | 3.67 | 0.046 |
| C x II | 0.014 | 1 | 0.014 | 1.42 | 0.249 |
| H x C x II | 0.013 | 2 | 0.006 | 0.65 | 0.534 |
| Group | 0.199 | 20 | 0.010 | 1.02 | 0.485 |
| Residual | 0.174 | 18 | 0.010 | | |
| Total | 0.700 | 47 | 0.015 | | |

[1] The analysis of variance was conducted with 48 observations. The root mean squared error is 0.098. The R-squared is 0.751 and the adjusted R-squared is 0.350. The interaction term HxII was dropped from the analysis of variance because of linear dependency in the model.

*Table 15*. Patterns of Cooperation

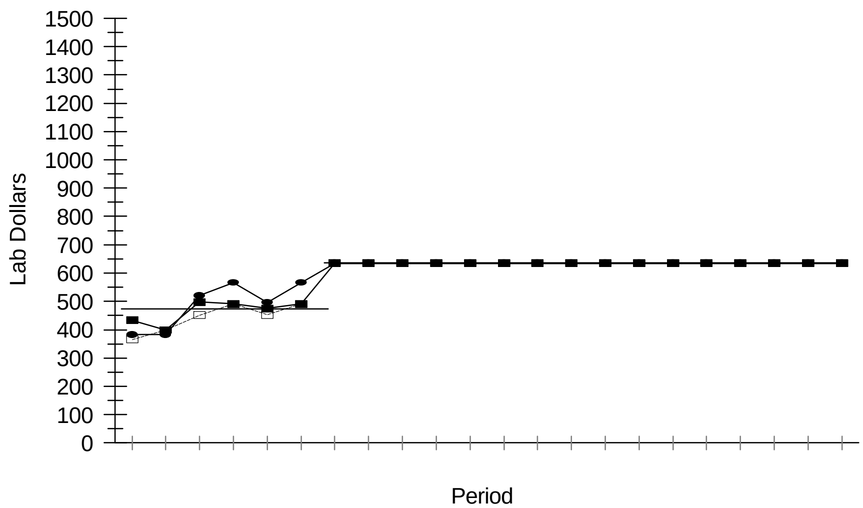
| Treatment | Complete Information (Session and Phase) | | | | | Incomplete Information (Session and Phase) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | S | P2 | P3 | P4 | P5 | S | P2 | P3 | P4 | P5 |
| SE/SP (Homogeneity) | 1 | o | o | o | o | 1 | o | o | o | o |
| | 2 | e,s | e,s | e,s | e,s | 2 | o | o | o | o |
| | 3 | o | o | c | o | 3 | o | o | o | o |
| SE/DP (Simple Heterogeneity) | 1 | o | o | c | c | 1 | o | o | o | o |
| | 2 | s | s | s | s | 2 | o | o | o | o |
| | 3 | c | e | s | s | 3 | c | c | c | c |
| DE/SP (Simple Heterogeneity) | 1 | o | o | o | o | 1 | o | c | e | o |
| | 2 | e | s | s | c | 2 | o | o | o | o |
| | 3 | o | o | o | c | 3 | e | c | o | e |
| DE/DP (Complex Heterogeneity) | 1 | o | o | o | o | 1 | o | o | o | c |
| | 2 | d | c | c | s | 2 | c | c | c | c |
| | 3 | o | o | o | o | 3 | o | o | o | o |

Note: o indicates that there is no evidence of cooperation; e indicates equal contributions; s indicates a distinct split between the unique individual and the other two in the group; c indicates cycling within a phase; the shaded c indicates the cycling is across phases rather than within phases; d indicates a coordinated declining contribution.



Session 2: Same Endowment, Same Preferences, Complete Information

Figure 1 (Panel 1) Token Contributions in an Equal Contribution Case



Session 2: Same Endowment, Same Preferences, Complete Information

Figure 1 (Panel 2) Payoffs in an Equal Contribution Case

the three subjects in the group.

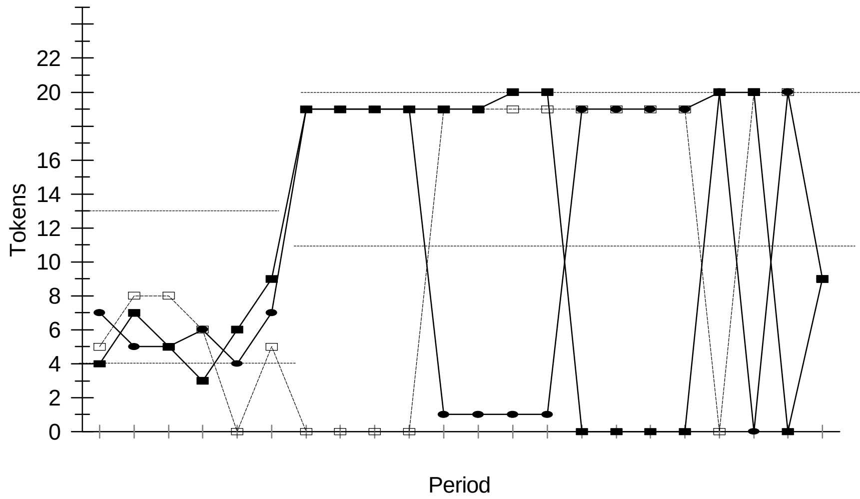



Figure 2 (Panel 1) Token Contributions in a Unique Cycling Case

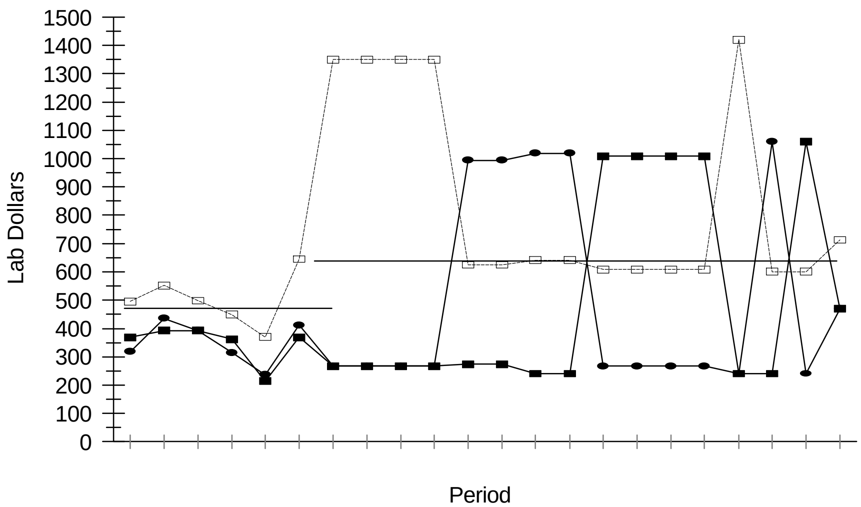
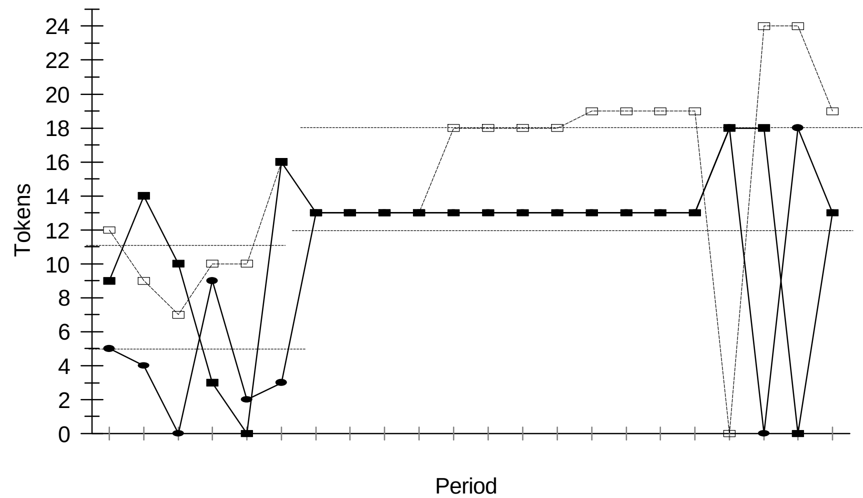


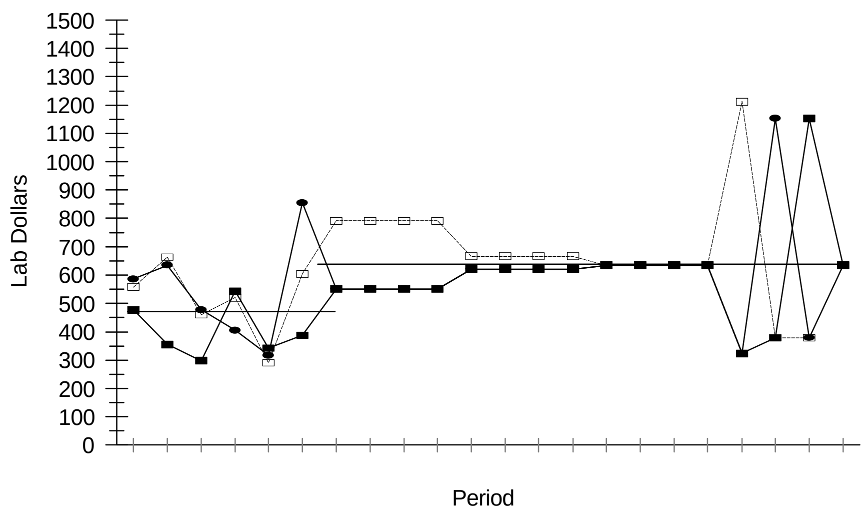

Figure 2 (Panel 2) Payoffs in a Unique Cycling Case

Note: Open squares, solid circles and solid squares identify the contributions or payoffs of each of the three subjects in the group. The open square is the subject with a greater preference for the public good.




Session 2: Different Endowment, Same Preferences, Complete Information

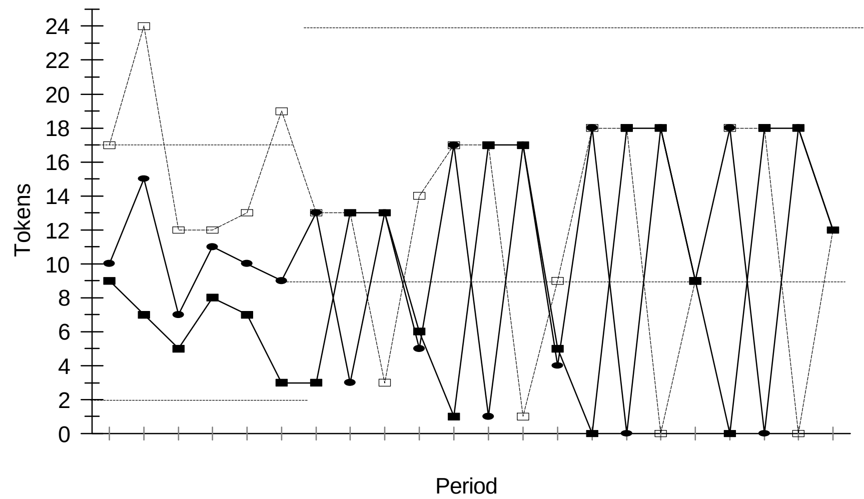
Figure 3 (Panel 1) Token Contributions When Cooperation Takes Different Forms




Session 2: Different Endowment, Same Preferences, Complete Information

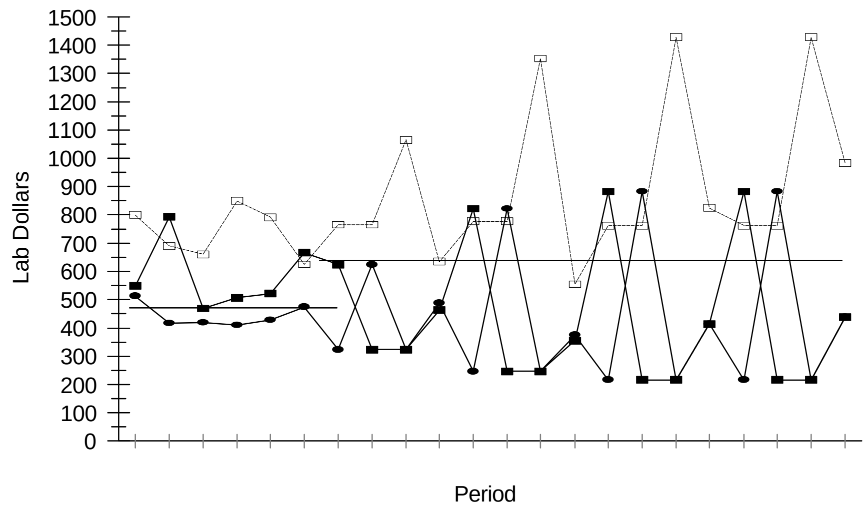
Figure 3 (Panel 2) Payoffs When Cooperation Takes Different Forms

Note: Open squares, solid circles and solid squares identify the contributions or payoffs of each of the three subjects in the group. The open square is the subject with a greater endowment.



Session 2: Different Endowment and Preferences, Incomplete Information

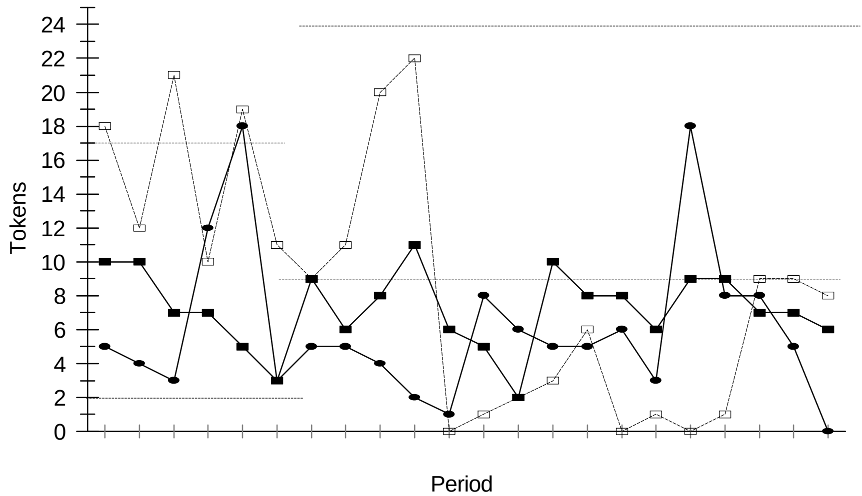
Figure 4 (Panel 1)     Token Contributions in a Typical Cycling Case



Session 2: Different Endowment and Preferences, Incomplete Information

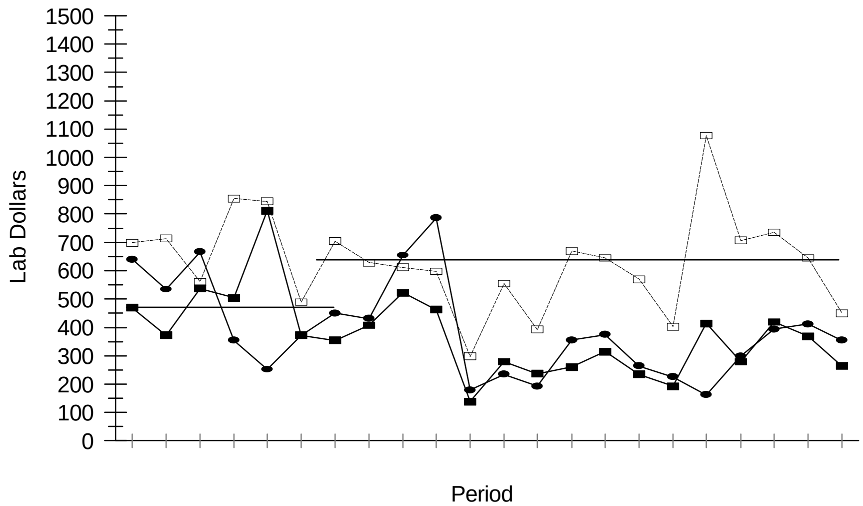
Figure 4 (Panel 2)     Payoffs in a Typical Cycling Case

Note: Open squares, solid circles and solid squares identify the contributions or payoffs of each of the three subjects in the group. The open square is the subject with the greater endowment and greater preference for the public good.



Session 3: Different Endowment and Preferences, Complete Information

Figure 5 (Panel 1) Token Contributions When No Cooperation Emerges



Session 3: Different Endowment and Preferences, Complete Information

Figure 5 (Panel 2) Payoffs When No Cooperation Emerges

Note: Open squares, solid circles and solid squares identify the contributions or payoffs of each of the three subjects in the group. The open square is the subject with the greater endowment and greater preference for the public good.

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