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HETEROGENEITY AND THE VOLUNTARY PROVISION OF PUBLIC GOODS*

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Abstract

We investigate the effects of heterogeneity and incomplete information on aggregate contributions to a public good using the voluntary contribution mechanism in a non-linear laboratory environment, using three-person groups in a partners environment under varying conditions of information and communication. Bergstrom, Blum and Varian predict that increasing heterogeneity will have no effect on aggregate contributions in a no-communication environment. Ledyard conjectures a negative effect of heterogeneity, a positive effect of incomplete information, and a positive interaction of heterogeneity and incomplete information. We find that incomplete information has a small but significant *negative* effect. Heterogeneity has a *positive* effect on aggregate contributions, but its effects interact unexpectedly with communication. In a no-communication environment, heterogeneity in two dimensions (income and preferences) increases contributions substantially while heterogeneity in a single dimension (income or preferences) has little effect. In the communication environment we find the reverse. We also find a positive interaction between heterogeneity and incomplete information. Thus we reject the Bergstrom, Blume and Varian invariance result and provide mixed evidence on Ledyard's conjectures.

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I. INTRODUCTION

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. In particular, one might ask whether the heterogeneity in the size and payoff structures of the agents will promote or hinder achieving a co-operative outcome.

Unfortunately, neither theory nor laboratory investigation has led to clear-cut results in this area. We know, of course, that in linear public goods environments the dominant strategy is usually to contribute none of one's endowment to the public good, that in laboratory environments subjects begin by making substantial excess contributions which decline over time but which are not utterly eliminated, and that communication among subjects strongly increases contributions among relatively small groups of individuals (Ledyard, 1995, 141-43). However, there is some evidence that these conclusions should be modified when the payoff functions are not linear in individual contributions. In these environments, the non-cooperative equilibrium is in the interior of the decision set and complete free riding is no longer a dominant strategy. The few laboratory studies that have been carried out in this type of environment have generally found much reduced evidence of excess contributions (Andreoni, 1993; Chan, Mestelman, Moir and Muller, 1996, and Chan, Godby, Mestelman, and Muller, 1997, 1998). Similarly, Walker, Gardner and Ostrom (1990) found Nash equilibrium outcomes in a no-communication common pool resource environment with an interior equilibrium (see also Ledyard, pp. 171-72) . Communication, however, continues to have a strong pro-cooperative effect in the non-linear common pool resource environment (Hackett, Schlager, and Walker, 1994; Muller and Vickers, 1996).

The effects of heterogeneity and incomplete information are far less certain. *A priori* arguments can be made in favour of neutral, positive or negative effects of heterogeneity. In a linear environment, of course, heterogeneity will make no difference to the non-cooperative equilibrium as long as the MPCR is less than 1. In a non-linear environment, Bergstrom, Blume and Varian (1986) demonstrate that the non-cooperative equilibrium level of aggregate contributions is independent of reallocation of endowments among contributors. This implies that limited heterogeneity should not affect aggregate contributions in no-communication environments.

Once tacit or explicit co-ordination is admitted, theorizing becomes less precise. On the negative side, asymmetries in endowments or payoff structures frequently lead to disproportionate contributions and unequal payoffs at the group optimum, leading to the need for negotiation and side payments to ensure that cooperative equilibrium is a pareto improvement. These difficulties may raise the cost of achieving the group optimum. Bardhan (1993), Kanbur (1992), Hackett (1992), Ostrom (1992) and Olson (1983) all make arguments consistent with this position. A contrary view is presented in the sociology literature by Oliver, Marwell, and Teixeira (1985), Marwell, Oliver, and Prahl (1988) and Heckathorn (1993), who argue that in heterogeneous environments there is a greater probability of finding a "critical mass" of individuals willing to contribute to the public good. This may have positive effects in that the motivated individuals will devote resources to persuading or compelling less interested individuals to contribute or negative effects in breaking up previously well entrenched groups. The models used in this literature are highly complex and rely on numerical simulation for their conclusions.

The experimental evidence is very slim. 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.[1] Brookshire, Coursey and Redington (1993) provide a controlled test of the influence of both heterogeneity and information in a linear environment. Working with groups of ten they considered three heterogeneity conditions (a baseline with common preferences for the public good, a "majority 1" condition in which one individual had 50% of the group demand for the good, and a "majority 2" condition in which two individuals shared 60% of the group demand) and two information conditions (complete vs. no information about others' payoffs). They found that the majority 1 condition reduced contributions while the majority 2 condition increased them, relative to the baseline. Incomplete information generally increased contributions.[2] On the basis of this survey, but warning that more research is needed, Ledyard (p. 160) conjectures that heterogeneity will reduce contributions (except, perhaps with incomplete information) while incomplete information will increase them (except, perhaps, with homogenous groups). That is, he expects a negative effect of heterogeneity, a positive effect of incomplete information and a positive interaction between heterogeneity and incomplete information.

Other experiments suggest that Ledyard's conjecture may be applicable only to linear public goods environments. The second design of Isaac's and Walker's (1988) study of

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[1] They found that mean aggregate contributions from four-person groups with mixed MPCRs of 0.30 and 0.75 lay between the aggregate contributions in four-person groups with uniform MPCRs of 0.30 and 0.75 respectively.

[2] This summary is based on the discussion in Brookshire *et al*. and on a re-analysis of mean contributions over all periods and over the last four periods, by treatment. The data reported were insufficient to conduct statistical tests. Ledyard reports that Brookshire *et al.* found no effect of information in the baseline case, but that is not evident from examination of mean contributions, which increase in both the entire session and the latter half.

communication effects in linear public goods was a 2x2 factorial with heterogeneity and incomplete information as treatment variables. A re-analysis of their data shows that when communication is allowed, heterogeneity of endowments significantly lowers aggregate contributions by about 24% ($p = 0.088$). The information condition is insignificant, however, either alone or in interaction with heterogeneity.[3] Several experiments conducted in non-linear public goods or related environments suggest that heterogeneity may have a neutral or positive effect on contributions. Hackett *et al*. (1994) study appropriations from a common pool resource under various conditions of communication, heterogeneity of endowments, and completeness of information. A re-analysis of their data shows that when information is complete heterogeneity significantly improves efficiency when there is no communication and does not affect it when there is communication, while for heterogeneous groups, incomplete information increases efficiency in the no-communication condition while reducing it the communication condition. Similarly, Chan *et al*. (1996) find evidence that sufficiently large dispersion in endowments results in increased contributions in a no-communication, complete-information environment.[4] Both of these experiments study contributions in a non-linear environment with interior equilibrium.

Our research problem, therefore, is to establish the effects of *heterogeneity* in endowments

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[3] Based on analysis of variance of mean contributions for the last half (five periods) of the no-communication phase of Design II.

[4] The cases in which heterogeneity leads to increased contributions are consistent with a notion of critical mass. In these environments income distribution is so skewed that one individual has sufficient resources and incentive to invest in the public good and the equilibrium contributions are greater than the equilibrium contributions in the environment in which each individual has the same income and each individual contributes a small amount to public good provision. In this case, the increases in public good provision is predicted by Bergstrom *et al*.

and preferences on *aggregate voluntary contributions* to a public good in a *non-linear environment*, under alternative conditions of information and communication. To address it we conduct a laboratory experiment with three-person groups in a partners environment.[5] In general we discover that 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 (income and preferences) increases contributions substantially while heterogeneity in a single dimension (income or preferences) has little effect. In the communication environment we find the reverse. We also find a positive interaction between heterogeneity and incomplete information. Thus we reject the Bergstrom *et al*. non-cooperative equilibrium model and provide mixed evidence on Ledyard's conjectures.

II. THE LABORATORY ENVIRONMENT

In our laboratory environment individuals in each group of three repeatedly allocated their laboratory dollar (L$) endowments to Market 1 (a private good market) or to Market 2 (a public good market). All instructions were framed in neutral language. Allocations were restricted to integer values. Subjects were given tables 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.[6]

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[5] 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.

[6] Instructions are included in Appendix A.

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.

Two information conditions were used. In the incomplete information condition subjects had no information about the incomes and payoff tables of other group members. In the complete information condition they knew both the incomes and payoff tables (preferences) of the other people in their group. In all cases subjects knew their own incomes, 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 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 α_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 income, W, was L$60 per period and the aggregate preference parameter $\alpha = \Sigma_i \alpha_i$ was 27. The two heterogeneity factors were combined with the information factor in a complete 2x2x2 factorial design replicated 3 times (Table 2).

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.

IV. 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, α. Given our experimental parameterization this is 21 tokens in all conditions. The group optimum contribution is easily computed to be 43 tokens.

In a full-information, non-communication environment, the Bergstrom *et al*. prediction is that the non-cooperative equilibrium will prevail in all four heterogeneity conditions.[7] The effect of communication and incomplete information is not obvious. We have seen that a case 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.

IV. 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).

Figure 1 shows the general pattern of the results. Several treatments show a rapid decline of contributions in the initial two periods but in most cases the behaviour over the last four non-communication periods is reasonably stable with mean contributions near and frequently below the Nash equilibrium. In the communication condition mean contributions generally increase until Phase 4. There is clear evidence of end-game effects in the last phase. This motivated our decision to focus on the last four periods of Phase 1 and on Phase 4 when analysing the data.

Table 3 reports mean contributions by treatment and phase. Inspection of Table 3 shows

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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]In ten of the sessions there were two groups of 3 subjects; in the remaining four there was only one group.

that mean contributions for the two single homogeneity conditions (SE/DP and DE/SP) generally move together relative to the remaining conditions. This impression is strengthened by visual inspection (Figure 2). We tested the equivalence of the SE/DP and DE/SP conditions by conducting an analysis of variance of mean contributions with respect to the four heterogeneity conditions (SE/SP, SE/DP, DE/SP and DE/DP), information, communication and all their interactions. An F-test on the underlying regression retained the null hypothesis that the coefficients of all terms involving SE/DP were equal to the corresponding coefficients involving DE/SP (p=0.573) .[9] 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). Table 4 summarizes the mean group contribution by these new categories of treatment.

The pooled data constitute a 3x2x2 factorial design in heterogeneity, communication and information. The main effect of information was very weakly significant (p=0.155). The interaction of information with communication and the three-way interaction of information, communication and heterogeneity were completely insignificant (p= 0.470 and 0.746, respectively). Dropping the last two interactions we conducted the analysis of variance reported in Table 5.[10] In addition, we conducted non-parametric randomization tests (Moir, 1998) on selected hypotheses. These tests, coupled with inspection of Figure 1 and Table 4 lead to the following observations.

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[9] 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. See Table 3.

[10] The remaining ANOVAs are reported in Appendix B.

Observation 1: *Communication increases coordination.*

Figures 1 and 2 provide visual evidence of the impact of communication on voluntary contributions to the public good. For each of the eight heterogeneity/information treatments there is a clear tendency for contributions to be greater during the last four phases than in the first phase. Table 4 shows that the mean contribution per period in the twenty-four communication sessions (34.99) exceeds the mean contribution in the twenty-four no-communication sessions (22.23) by 12.76 tokens or 57%. This main effect of communication is significant at less than the 0.001 level (Table 5 and randomization tests). There is a significant interaction between communication and heterogeneity (p=0.002). However Table 4 shows that mean contributions with communication exceed mean contributions without communication under each of the three heterogeneity categories. This effect is significant for the homogeneity and single heterogeneity categories (F-test, p= 0.019 and p= 0.000 respectively) but not for the double heterogeneity category (p = 0.348).[11] ■

Observation 2: *Heterogeneity generally increases coordination but communication reverses the effects of single and double heterogeneity.*

Mean contributions in the singly and doubly heterogeneous environments (30.04 and 28.52 respectively) exceed mean contributions in the homogeneous environment (25.86) by 4.1 and 2.7 tokens respectively. The three-way classification is weakly significant (F-test, p= 0.093). As noted in Observation 1, the interaction of communication and heterogeneity is strongly significant (analysis of variance, p = 0.002). Separate analyses

[11] See ANOVA tables in Appendix B.

of variance by communication category show significant effects of the heterogeneity classification (p= 0.077 and 0.008 for no-communication and communication respectively). With no communication, mean contributions in the doubly homogeneous case (26.6) exceed the homogenous contributions (20.5) by 6.1 tokens, while mean contributions in the singly homogeneous case (20.9) are only 0.4 tokens higher than in the homogeneous condition. The difference between the two-dimensional heterogeneity treatment and the pooled data from the other two treatments is significant (randomization test, p = 0.010). However, with communication, the mean contributions in the doubly heterogeneous condition (30.5) are actually 0.7 tokens *less* than in homogeneous environments (31.2) while mean contributions in the singly heterogenous condition (39.1) exceed the contributions in the homogeneous condition by 7.9 tokens. The difference between the means of the one-dimensional heterogeneous contributions and the remaining contributions is significant (randomization test, p = 0.001). ■

We note that Observation 2 clearly refutes both the Bergstrom *et al.* prediction that income redistribution will not affect aggregate contributions for the provision of a public good and the Ledyard conjecture that heterogeneity will reduce contributions.

<u>Observation 3</u>: *Incomplete information decreases coordination in homogeneous environments.*

Mean contributions in the incomplete information condition (27.51) are 2.20 tokens (7.4%) less than mean contributions in the complete information condition (29.71). This main effect is significant (p = 0.073). The interaction between incomplete information and communication is not significant (p = 0.434). The interaction between incomplete information and hetereogeneity is very weakly significant (p = 0.106). Inspection of Table 4 shows that mean contributions in homogeneous environments with incomplete information (21.92) are much less than mean contributions in homogeneous environments with complete information (29.80). A randomization test shows this difference is significant (p = 0.071) as does analysis of variance (p = 0.065). Mean contributions in heterogeneous environments do not differ much across information conditions (means of 30.00 and 30.07 for one-dimensional heterogeneity and 29.04 and 28.00 for two-dimensional heterogeneity). Neither difference is significant on a randomization test (p = 0.506 and p = 0.399 respectively) nor on F-tests.[12] Consequently, while we reject the null of no effect of information in favour of the alternative of some effect, the strength of the result is based on the impact of incomplete information in homogeneous environments. ■

We note that Observation 3 rejects the Ledyard conjecture that incomplete information will increase voluntary contributions generally. However the finding of a *negative* impact of incomplete information in the homogeneous environment is consistent with his conjecture of a *positive* interaction between heterogeneity and incomplete information. This finding is strengthened by the next observation.

Observation 4: *Heterogeneity increases coordination when information is incomplete.*

There is a weakly significant interaction between heterogeneity and incomplete information (p = 0.106). With complete information, there is little difference in average voluntary contributions (29.80, 30.00, and 29.04 for homogeneous, one-dimensional

[12] Analysis of variance on communication, information and their interaction, by individual heterogeneity class (p= 0.972 and 0.795 for single and double heterogeneity respectively).

heterogeneous, two-dimensional heterogeneous environments respectively). The heterogeneity classification is not significant (p=0.953). Under incomplete information, contributions are 21.9, 30.0 and 28.5 for the homogeneity, singly heterogeneous and doubly heterogeneous conditions respectively. The three-way classification is significant (p=0.063). Mean contributions exceed the homogeneous contributions by 8.2 tokens in the singly heterogeneous condition and 6.9 tokens in the homogeneous condition. Both differences are statistically significant (randomization tests, p=0.045 and p=0.019 respectively). ■

We note that Observation 4 is consistent with Ledyard's conjecture.

VI. DISCUSSION AND CONCLUSIONS

We have investigated the effect of heterogeneity on public goods provision in a non-linear environment under alternative conditions of communication and information. Briefly, we found that heterogeneity increases voluntary contributions but that communication unexpectedly reverses the relative importance of single and double heterogeneity. The no-communication portion of this result refutes the Bergstrom *et al.* proposition that aggregate contributions to a public good will be unaffected by redistributing income among contributors. We also found that incomplete information reduces contributions overall because of its strong negative effect in the homogeneous environment. This refuted Ledyard's conjecture of a positive effect of incomplete information. Finally, we found a positive interaction between heterogeneity and incomplete information. This supports Ledyard's (1995) conjecture.

Our study seems to confirm that there are important differences between the linear and non-linear public goods environments. Our hetereogeneity results are inconsistent with those in the linear public goods cases cited by Ledyard and with the Isaac and Walker (1988) study, which was also conducted in a linear environment, but our results are consistent with the Hackett *et al.* study of a non-linear common pool resource environment. Table 6 compares some of our results to the latter two papers. Besides their differences with respect to linearity and formulation of the dilemma (common property versus public goods) the laboratory designs differed in several respects. We used groups of three subjects while Isaac and Walker (IW) used groups of four and Hackett *et al.* (HSW) used groups of eight. Communication in the IW and HSW sessions was allowed before each decision period while we allowed subjects the opportunity to communicate before each block of four decision periods. Nevertheless, it is possible that the key differences in finding are driven by the distinction between linear and non-linear environments.

Why should heterogeneity lead to higher aggregate contributions? The sociological literature, cited above, argues that heterogeneity may generate environments with a critical mass of contributors who may devote resources to convincing others to contribute. Since there are no opportunities for persuasion in our no-communication environment, some other factor may be at work. The positive interaction with incomplete information may provide a clue. In a 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 findings suggest several directions for future research. First, questions remain about the pattern of giving by the individuals with lower incomes and the individuals who did not value the public good as intensely as others. The evolution of patterns of coordination and allocation have yet to be studied.   Second, it would be useful to examine whether our results are robust to changes in the size of group.   Third, and perhaps most pressing, is the need is investigate whether the non-linearity of our environment resloves the apparent discrepancy between the results of our study and Hackett's *et al.* on the one hand and the Isaac and Walker study on the other.

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Table 1. Structure of Sessions

Phase Type	Phase Number[1]	Action
No Communication	1	Play 6 rounds
Communication	2	Communicate Play 4 rounds
	3	Communicate Play 4 rounds
	4	Communicate Play 4 rounds
	5	Communicate 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 Income (w_i = 20 for i = 1, 2, 3)		**Different Income (w_i = 18 for i = 1 and 2, w_3 = 24)**	
	Same Preferences (α_i = 9 for i = 1, 2, 3)	**Different Preferences (α_i = 6 for i = 1 and 2, α_3 = 15)**	**Same Preferences (α_i = 9 for i = 1, 2, 3)**	**Different Preferences (α_i = 6 for i = 1 and 2, α_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
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, α_i, and the subject's endowment of income 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. Mean Group Contributions Per Period by Treatment and Phase[1]

Income, Preference and Information Conditions	No Communication	Communication			
	Phase 1	**Phase 2**	**Phase 3**	**Phase 4**	**Phase 5**
Complete Information					
SE/SP	22.92	34.33	35.08	36.67	35.00
SE/DP	21.33	32.92	32.75	40.25	41.58
DE/SP	19.75	28.75	35.08	38.67	37.42
DE/DP	27.00	34.83	26.33	31.08	25.83
Incomplete Information					
SE/SP	18.00	27.08	24.58	25.83	24.50
SE/DP	17.67	27.58	30.42	39.08	32.67
DE/SP	25.00	29.42	37.00	38.50	35.50
DE/DP	26.17	23.67	30.42	29.83	28.75

[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 group contribution across four periods in three sessions. Data for periods 1 and 2 were dropped to allow for learning.

Table 4. Mean Group Contributions by Communication, Information and Revised Heterogeneity Categorization[1]

Information and Heterogeneity Condition	**No Communication (Periods 3 - 6)**	**Communication (Periods 15 - 18)**	**Totals**
Complete Information			
Homogeneous	22.92	36.67	29.80
Single	20.54	39.46	30.00
Double	27.00	31.08	29.04
Sub-Totals	22.75	36.67	29.71
Incomplete Information			
Homogeneous	18.00	25.83	21.92
Single	21.34	38.79	30.07
Double	26.17	29.83	28.00
Sub-Totals	21.71	33.31	27.51
Combined Information			
Conditions	20.46	31.25	25.86
Homogeneous	20.94	39.13	30.04
Single	26.58	30.44	28.52
Double			
	22.23	34.99	28.61
Sub-Totals			

[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.

Table 5. Analysis of Variance Results for Average Per Period Group Contributions[1]

Source	**Partial SS**	**df**	**MS**	**F**	**Prob>F**
Model	2708.17	8	338.52	12.24	0.000
Heterogeneity (H) (homogeneity, single dimensional heterogeneity, or two dimensional heterogeneity)	139.71	2	69.85	2.53	0.093
Communication (C)	1295.28	1	1295.28	46.83	0.000
H*C	425.20	2	212.60	7.69	0.002
Incomplete Information (II)	94.08	1	94.08	3.40	0.073
H*II	131.36	2	65.68	2.37	0.106
Residual	1078.82	39	27.66		
Total	3787.99	47	80.57		

[1] The analysis of variance was conducted with 48 observations. The mean squared error is 5.26. The R-squared is 0.715 and the adjusted R-squared is 0.657. The interaction terms C*II and H*C*II were dropped from the analysis of variance which used the complete set of interactions. The p-values for these two interactions were 0.434 and 0.794 respectively.

Table 6. Comparison with Results of Related Studies

Effect/Other Study/Description	Effect on Co-ordination
Heterogeneity Effect	
Isaac and Walker (1988)[1] Linear Public Goods, communication, pooled incomplete and complete information	
Income heterogeneity	negative, significant 5 periods of 10
Brookshire *et al*. (1993)[4] . Linear Public Good, no communication	
Single high preference individual	negative
Two high preference individuals	positive
Hackett, Schlager and Walker, 1994[2] Non-linear Resource Dilemma.	
Pooled communication and information treatments	positive and non- significant (anova)
Communication, pooled information	negative, not significant (one-way anova)
No communication, pooled information	positive and significant (one-way anova)
Present Study. Non-linear Public Good.	generally positive
Information Effect	
Linear Public Goods (Isaac and Walker, 1988)[3]	
Communication, pooled homogeneous and heterogeneous	negative, never significant
Brookshire *et al*. (1993)[4] . Linear Public Good, no communication	positive
Resource Dilemma (Hackett, Schlager and Walker, 1994)[2]	
Pooled communication and heterogeneity	negative, not significant (one-way anova)
Communication, pooled heterogeneity	negative , significant (one-way anova)
No communication, pooled heterogeneity	positive , not significant (one-way anova)
Present Study. Non-linear Public Good.	Strongly negative in homogeneous case

[1] Observation 6, Isaac and Walker (1988). Four person groups.
[2] Analysis of variance conducted by present authors from data presented in Tables III, IV, and VII of Hackett, Schlager and Walker (1994), excluding the large (25 token) endowment sessions, for which the efficiencies are significantly different from the other treatments. Non-communication results are the means of periods 1 through 5. Communication results are the means of periods 16 through 20. Total endowment for the groups were 80 and 128 in the homogeneous and heterogeneous cases respectively. Dependent variable is efficiency. Eight person groups.
[3] Observation 7, Isaac and Walker (1988). Four person groups.
[4] Based on the discussion in Brookshire *et al*. and on a re-analysis of mean contributions over all periods and over the last four periods, by treatment. The data reported were insufficient to conduct statistical tests.

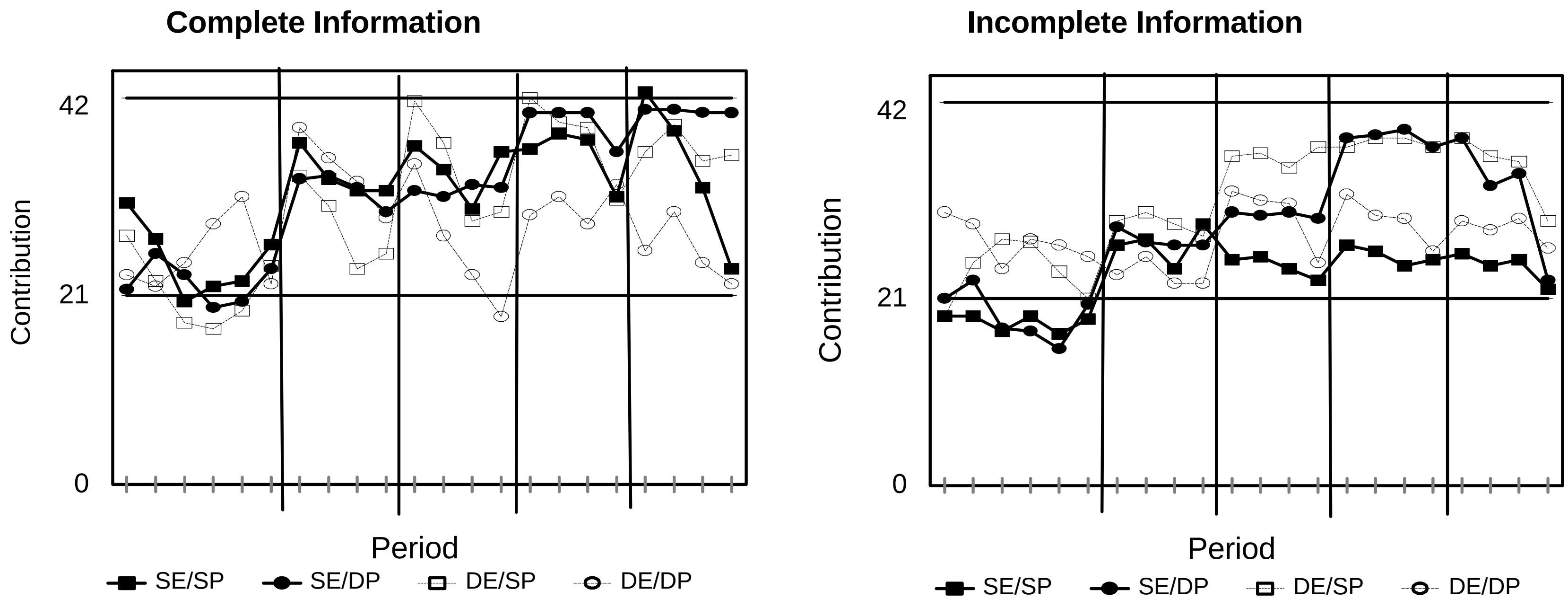

Figure 1. Mean Contributions per Period by Treatment. Data are averaged over three replications of each treatment. Note that non-communication results are generally close to the Nash equilibrium of 21 tokens. Under communication, co-ordination increases until Phase 4. There are frequent end-game effects in Phase 5.

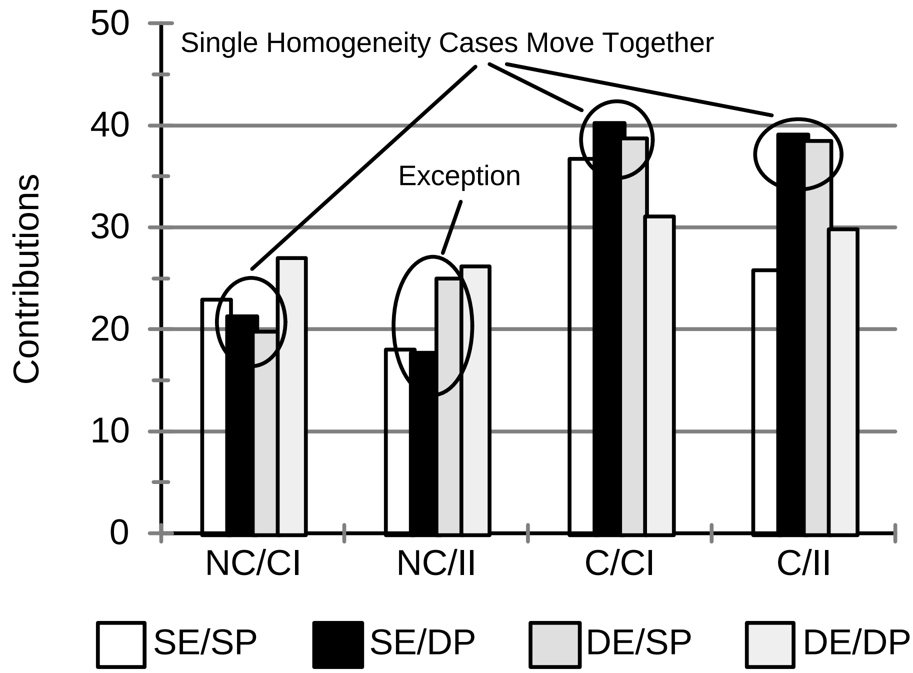

Figure 2. Mean contributions per period by treatment. Treatment keys are NC (no communication), C (communication), CI (complete information), II (incomplete information), SE (same endowment), DE (different endowment), SP (same preferences), DP (different preferences). Note how the single heterogeneity treatments (SE/DP and DE/SP) generally move together. An F-test retains the null hypothesis that the coefficients of SE/DP and DE/SP are equal.

Appendix A

Instructions

1. Instructions for Part 1 (common to both information conditions)

General

You are participating in a study of economic decision-making. This research is funded by several funding agencies. The decisions you make directly influence the money you will earn. At the end of the session, you will be paid in cash. The instructions below describe the environment in which you will participate.

Introduction

The session is divided into periods. At the beginning of each period, you are given some **tokens**. There are two markets to which you may allot your tokens. Your token payoff is determined by how much **you** allot to Market 1, and how much **you and others** allot to Market 2. You need only decide how many tokens to allot to Market 2. Any remaining tokens will allotted to Market 1.

A payoff table has been provided for you to help you decide how much to allot to Market 2. The table describes your payoff in tokens based on your allotment decision to Market 2 and the decisions of others in your group. The numbers on this payoff table include your returns from both your Market 1 and Market 2 allotments. Consider the payoff table on the sheet titled **EXAMPLE**. These numbers are in **no way** meaningful to the session but are only introduced to help you understand how to read a payoff table.

Your **possible** allotment decisions are listed across the top of the table. The **combined possible** allotment decisions of the other members of your group are listed in the left-most column. In order to read this table, you must find your allotment decision in the top row, and move down the column until you reach the combined allotment decision of others in your group.

Consider the case where you allot 3 tokens to Market 2 and the others in the group have a combined allotment to Market 2 of 5 tokens. Find the number 3 in first row. While in this column, read down the column until you reach the row which has 5 in the left-most column. Here you should find the number 10. This is your payoff in tokens for this combination of allotments. Please complete the questions on the **EXAMPLE** sheet. Raise your hand when you have answered the questions and a monitor will review your work and answer any questions you may have about reading the payoff table.

The Market

At this point, please direct all further communication to the session monitor. Information about your decisions is to stay private. Any questions you have will be answered if you raise your hand.

You will be linked, via computer, to two (**2**) other individuals in this room. The three of you form a **group** which will remain together for the session. At the beginning of each period, you will be given some tokens. The computer will prompt you for your allotment decision for Market 2. The session will have two parts. Prior to the start of the second part of the session a new set of instructions will be read aloud. The rules guiding your decision for your allotment to Market 2 during part 2 will be specified at that time. At no time are you permitted to allot either more tokens than your endowment or less than zero. Any remaining tokens will be allotted to Market 1. See **SAMPLE SCREEN**. At the beginning of a period, you will receive a message on your screen concerning your allotment to market 2 for that period. Type a *number* in the square **[ ]** brackets and press **ENTER** when you are ***sure*** you are done. Use the **BACKSPACE** key to make corrections.

When everyone in the room has made an allotment to Market 2 your payoff for the period will be calculated and reported to you. You will also see the combined allotment to Market 2 of all *other* individuals in your group. Using the information on the screen, you can verify the computer's payoff calculation by using your payoff table. At the end of this period, enter your information on the **Record Sheet**. The **Group Total** on the **Record Sheet** should be the sum of your allotment to Market 2 plus the allotment of Others to Market 2. The next period will begin, and the procedure continues as before.

Information Condition

The total token endowment for your group is 60 tokens. Your token endowment is entered on your Record Sheet. Notice that the maximum allotment decision you can make to Market 2 is the token endowment entered on your Record Sheet (in this case you invest no tokens in Market 1). Notice that the maximum combined allotment decisions of the other members in your group is the difference between 60 tokens and your token endowment. The other members of your group may have payoff tables which are different from yours. The other members of your group may have token endowments which are different from yours. Information about payoffs and token endowments is **private** information.

Payoffs

The conversion rate for tokens is **1 token = $0.0023** Canadian throughout the session. For instance, if your payoff in a particular period is 326 tokens, then your Canadian dollar earnings are 75 cents for that period. Again, the value 326 is completely arbitrary, and only used for the purpose of example.

There are two parts to this session, the first part lasts six (**6**) periods. Before the next part, new instructions will be distributed and read.

You will be linked, via computer, to two (**2**) other individuals in this room. The three of you form a **group** which will remain together for the session. At the beginning of each period, you will be given some tokens. The computer will prompt you for your allotment decision for Market 2. The session will have two parts. Prior to the start of the second part of the session a new set of instructions will be read aloud. The rules guiding your decision for your allotment to Market 2 during part 2 will be specified at that time. At no time are you permitted to allot either more tokens than your endowment or less than zero. Any remaining tokens will be allotted to Market 1. See **SAMPLE SCREEN**. At the beginning of a period, you will receive a message on your screen concerning your allotment to market 2 for that period. Type a *number* in the square **[ ]** brackets and press **ENTER** when you are ***sure*** you are done. Use the **BACKSPACE** key to make corrections.

When everyone in the room has made an allotment to Market 2 your payoff for the period will be calculated and reported to you. You will also see the combined allotment to Market 2 of all *other* individuals in your group. Using the information on the screen, you can verify the computer's payoff calculation by using your payoff table. At the end of this period, enter your information on the **Record Sheet**. The **Group Total** on the **Record Sheet** should be the sum of your allotment to Market 2 plus the allotment of Others to Market 2. The next period will begin, and the procedure continues as before.

Information Condition

The total token endowment for your group is 60 tokens. Your token endowment is entered on your Record Sheet. The payoff tables are being distributed now. Each of you will receive three payoff tables, corresponding to the three members of your group. The endowment of each member of your group appears as the right-most number in the first row of each payoff table. This number will be either 18, 20, or 24. Notice that the maximum allotment decision you can make for Market 2 is 18 tokens if you have an 18 token endowment, 20 tokens if you have a 20 token endowment, or 24 tokens if you have a 24 token endowment (in each of these cases you invest no tokens in Market 1). Notice that the maximum combined allotment decisions of the other members of your group is the difference between 60 tokens and your token endowment. Please switch your payoff tables with another person in the room. Notice that the tables you received are exactly the same as the tables you gave up. **<u>Your payoff table has a letter in the top right corner which corresponds to the letter on your folder.</u>**

Payoffs

The conversion rate for tokens is **1 token = $0.0023** Canadian throughout the experiment. For instance, if your payoff in a particular period is 326 tokens, then your Canadian dollar earnings are 75 cents for that period. Again, the value 326 is completely arbitrary, and only used for the purpose of example.

There are two parts to this session, the first part lasts six (**6**) periods. Before the next part, new instructions will be distributed and read.

2. Instructions for Part 2 (Incomplete Information Condition)

Sometimes, in previous sessions, participants have found it useful, when the opportunity arose, to communicate with one another. We are going to allow you this opportunity before some of the remaining periods.

You will have the opportunity to participate in sixteen (**16**) more periods in which you make token allotments to Markets 1 and 2. The environment will be identical to that of the previous six periods **except** you will have an opportunity to **communicate** with the members of your group. Before periods seven (**7**), eleven (**11**), fifteen (**15**), and nineteen (**19**) you will have an opportunity to meet with the members of your group. There will be some restrictions on your communication.

1) You may not discuss any quantitative aspects of the private information you may have on your payoff tables. Information on endowments may be shared but information on specific payoffs under various conditions may not be shared; the direction in which payoffs may move are qualitative aspects of your payoffs and may be shared (for example, you may indicate that a particular pattern of allotments may increase or decrease your payoff, but you may not indicate that your payoff will change by (say) 373 tokens).

2) You may not discuss or make side payments or physical threats.

3) Agreements made during the communication phases of the session will not be enforced by the monitors or the computers.

4) Meeting time will be limited to four (**4**) minutes, but you may return to your computer stations earlier.

Because of these restrictions on communication with one another, one of us will monitor your discussions. To facilitate this, communication will take place away from your computer stations, but in this room.

Remember, after you have returned to your computer stations and the next period has begun, there will be no more communication until four decision-periods have been completed.

3. Instructions for Part 2 (Full Information Condition)

Sometimes, in previous sessions, participants have found it useful, when the opportunity arose, to communicate with one another. We are going to allow you this opportunity before some of the remaining periods.

You will have the opportunity to participate in sixteen (**16**) more periods in which you make token allotments to Markets 1 and 2. The environment will be identical to that of the previous six periods **except** you will have an opportunity to **communicate** with the members of your group. Before periods seven (**7**), eleven (**11**), fifteen (**15**), and nineteen (**19**) you will have an opportunity to meet with the members of your group. There will be some restrictions on your communication.

1) You may not discuss or make side payments or physical threats.

2) Agreements made during the communication phases of the session will not be enforced by the monitors or the computers.

3) Meeting time will be limited to four (**4**) minutes, but you may return to your computer stations earlier.

Because of these restrictions on communication with one another, one of us will monitor your discussions. To facilitate this, communication will take place away from your computer stations, but in this room.

Remember, after you have returned to your computer stations and the next period has begun, there will be no more communication until four decision-periods have been completed.

4. Example Payoff Sheet

EXAMPLE

Sample Payoff

Allotment Decisions to Market 2

		Your Allotment					
		0	**1**	**2**	**3**	**4**	**5**
Combined Allotment of Others	**0**	2	3	4	6	5	2
	1	3	4	6	8	6	4
	2	4	5	8	3	7	8
	3	5	6	10	15	8	11
	4	6	7	12	11	9	7
	5	3	6	9	10	8	6
	6	4	5	8	9	7	5
	7	3	4	6	8	6	4
	8	2	3	3	7	5	3
	9	1	2	1	4	4	2

Questions

1) What is your payoff if you allot 0 tokens to Market 2 and the combined allotment of others to Market 2 is 7 tokens?

Answer:

2) If you allot 3 tokens to Market 2, and one of the other players allots 2 tokens, while the other allots 4, what is your payoff?

Answer:

Appendix B

Analysis of Variance Models

This appendix reports the details of the analyses of variance supporting the observations of the text.

1. Analysis of Variance in Aggregate Contributions, by Four-Way Heterogeneity Condition, Information, Communication and their Interactions

   Source: andy980604.log

   a. Table of Mean Aggregate Contributions

```
. table hetero info comm , c(mean AvgG) f(%9.1f) row col sc
```

hetero	NC CI	NC II	NC Total	C CI	C II	C Total	Total CI	Total II	Total Total
se/sp	22.9	18.0	20.5	36.7	25.8	31.2	29.8	21.9	25.9
se/dp	21.3	17.7	19.5	40.2	39.1	39.7	30.8	28.4	29.6
de/sp	19.8	25.0	22.4	38.7	38.5	38.6	29.2	31.8	30.5
de/dp	27.0	26.2	26.6	31.1	29.8	30.5	29.0	28.0	28.5
Total	22.8	21.7	22.2	36.7	33.3	35.0	29.7	27.5	28.6

b. ANOVA - Complete Model

```
. anova AvgG hetero comm info hetero*comm hetero*info comm*info
hetero*comm*info

                           Number of obs =      48     R-squared     =  0.7464
                           Root MSE      = 5.47877     Adj R-squared =  0.6275

                  Source |  Partial SS    df       MS           F     Prob > F
              -----------+----------------------------------------------------
                   Model |  2826.44661    15  188.429774       6.28     0.0000
                         |
                  hetero |   144.52474     3  48.1749132       1.60     0.2076
                    comm |   1953.9388     1   1953.9388      65.09     0.0000
                    info |  57.9700521     1  57.9700521       1.93     0.1742
             hetero*comm |  448.701823     3  149.567274       4.98     0.0060
             hetero*info |  168.233073     3   56.077691       1.87     0.1548
               comm*info |  16.0429687     1  16.0429687       0.53     0.4701
        hetero*comm*info |  37.0351563     3  12.3450521       0.41     0.7460
                         |
                Residual |  960.541667    32  30.0169271
              -----------+----------------------------------------------------
                   Total |  3786.98828    47  80.5742188
```

c. ANOVA - by Communication Condition

```
. by comm: anova AvgG hetero info hetero*info

-> comm=       NC (No Communication)
                           Number of obs =      24     R-squared     =  0.4218
                           Root MSE      = 4.86404     Adj R-squared =  0.1689

                  Source |  Partial SS    df       MS           F     Prob > F
              -----------+----------------------------------------------------
                   Model |  276.197917     7  39.4568452       1.67     0.1875
                         |
                  hetero |  177.385417     3  59.1284722       2.50     0.0966
                    info |  6.51041667     1  6.51041667       0.28     0.6071
             hetero*info |  92.3020833     3  30.7673611       1.30     0.3086
                         |
                Residual |  378.541667    16  23.6588542
              -----------+----------------------------------------------------
                   Total |  654.739583    23  28.4669384
```

```
-> comm=        C (Communication)
                           Number of obs =      24     R-squared     =  0.5061
                           Root MSE      = 6.03117     Adj R-squared =  0.2900

                  Source |  Partial SS    df       MS           F     Prob > F
              -----------+----------------------------------------------------
                   Model |  596.309896     7   85.187128       2.34     0.0752
                         |
                  hetero |  415.841146     3  138.613715       3.81     0.0310
                    info |  67.5026042     1  67.5026042       1.86     0.1920
             hetero*info |  112.966146     3  37.6553819       1.04     0.4036
                         |
                Residual |      582.00    16      36.375
              -----------+----------------------------------------------------
                   Total |   1178.3099    23   51.230865
```

d. Test for Pooling SE/DP and DE/SP

(Source: stuart3.log)

Dummy Variables:

de	different environment
dp	different preferences
ph1	phase 1 (not 4)
ph1de	ph1*de
ph1dp	ph1*dp
ph1dedp	ph1*dp*de
ii	incomplete information
iide	ii*de
iidp	ii*dp
iidedp	ii*de*dp
iiph1	ii*ph1
iiph1de	ii*ph1*de
iiph1dp	ii*ph1*dp
iiph1dep	ii*ph1*dedp

```
. regress AvgG de dp dedp ph1  ph1de ph1dp ph1dedp ii  iide iidp iidedp iiph1
>  iiph1de iiph1dp iiph1dep

  Source |       SS       df       MS                  Number of obs =      48
---------+------------------------------               F( 15,    32) =    6.28
   Model |  2826.44661    15  188.429774               Prob > F      =  0.0000
Residual |  960.541667    32  30.0169271               R-squared     =  0.7464
---------+------------------------------               Adj R-squared =  0.6275
   Total |  3786.98828    47  80.5742188               Root MSE      =  5.4788

------------------------------------------------------------------------------
    AvgG |      Coef.   Std. Err.       t     P>|t|       [95% Conf. Interval]
---------+--------------------------------------------------------------------
      de |          2   4.473397      0.447   0.658      -7.112012    11.11201
      dp |   3.583333   4.473397      0.801   0.429      -5.528679    12.69535
    dedp |  -11.16667   6.326339     -1.765   0.087        -24.053    1.719665
     ph1 |     -13.75   4.473397     -3.074   0.004      -22.86201   -4.637988
   ph1de |  -5.166667   6.326339     -0.817   0.420        -18.053    7.719665
   ph1dp |  -5.166667   6.326339     -0.817   0.420        -18.053    7.719665
 ph1dedp |         20   8.946795      2.235   0.032       1.775975    38.22402
      ii |  -10.83333   4.473397     -2.422   0.021      -19.94535   -1.721321
    iide |   10.66667   6.326339      1.686   0.102      -2.219665      23.553
    iidp |   9.666667   6.326339      1.528   0.136      -3.219665      22.553
  iidedp |     -10.75   8.946795     -1.202   0.238      -28.97402    7.474025
   iiph1 |   5.916667   6.326339      0.935   0.357      -6.969665      18.803
 iiph1de |        -.5   8.946795     -0.056   0.956      -18.72402    17.72402
 iiph1dp |  -8.416667   8.946795     -0.941   0.354      -26.64069    9.807358
iiph1dep |   3.416667   12.65268      0.270   0.789        -22.356    29.18933
   _cons |   36.66667    3.16317     11.592   0.000        30.2235    43.10983
------------------------------------------------------------------------------

<intermediate tests deleted>

. test iiph1de=iiph1dp,acc

 ( 1)  de - dp = 0.0
 ( 2)  ph1de - ph1dp = 0.0
 ( 3)  iide - iidp = 0.0
 ( 4)  iiph1de - iiph1dp = 0.0

       F(  4,    32) =    0.74
            Prob > F =    0.5725
```

2. Analysis of Variance in Aggregate Contributions, by Three-Way Heterogeneity Condition, Information, Communication and their Interactions

Source: andy980604.log

Note that `hetero2` refers to the three-way classification.

a. Table of Mean Contributions

```
. table hetero2 info comm , c(mean AvgG) f(%9.1f) row col sc

----------+---------------------------------------------------------------
Dimension |
ality of  |         Communication Condition and Information Condition
Heterogen | -------- NC -------    -------- C --------    ------ Total ------
eity      |    CI      II  Total       CI      II  Total       CI      II  Total
----------+---------------------------------------------------------------
     none |  22.9    18.0   20.5     36.7    25.8   31.2     29.8    21.9   25.9
   single |  20.5    21.3   20.9     39.5    38.8   39.1     30.0    30.1   30.0
   double |  27.0    26.2   26.6     31.1    29.8   30.5     29.0    28.0   28.5
          |
    Total |  22.8    21.7   22.2     36.7    33.3   35.0     29.7    27.5   28.6
----------+---------------------------------------------------------------
```

b. ANOVA - Complete Model

```
. anova AvgG  hetero2 comm info hetero2*comm hetero2*info comm*info
hetero2*comm*info

                           Number of obs =      48     R-squared     =  0.7229
                           Root MSE      = 5.39866     Adj R-squared =  0.6383

                  Source |  Partial SS    df       MS           F     Prob > F
              -----------+----------------------------------------------------
                   Model |   2737.7487    11  248.886245       8.54     0.0000
                         |
                 hetero2 |  139.709635     2  69.8548177       2.40     0.1054
                    comm |  1295.27552     1  1295.27552      44.44     0.0000
                    info |  94.0755208     1  94.0755208       3.23     0.0808
            hetero2*comm |  425.199219     2  212.599609       7.29     0.0022
            hetero2*info |  131.355469     2  65.6777344       2.25     0.1197
               comm*info |  18.2130208     1  18.2130208       0.62     0.4344
       hetero2*comm*info |  13.5325521     2  6.76627604       0.23     0.7940
                         |
                Residual |  1049.23958    36   29.145544
              -----------+----------------------------------------------------
                   Total |  3786.98828    47  80.5742188
```

c. ANOVA - by Communication Condition

```
. anova AvgG  hetero comm info hetero*comm hetero*info comm*info
hetero*comm*info

                           Number of obs =      48     R-squared     =  0.7464
                           Root MSE      = 5.47877     Adj R-squared =  0.6275

                  Source |  Partial SS    df       MS           F     Prob > F
              -----------+----------------------------------------------------
                   Model |  2826.44661    15  188.429774       6.28     0.0000
                         |
                  hetero |   144.52474     3  48.1749132       1.60     0.2076
                    comm |   1953.9388     1   1953.9388      65.09     0.0000
                    info |  57.9700521     1  57.9700521       1.93     0.1742
             hetero*comm |  448.701823     3  149.567274       4.98     0.0060
             hetero*info |  168.233073     3   56.077691       1.87     0.1548
               comm*info |  16.0429687     1  16.0429687       0.53     0.4701
        hetero*comm*info |  37.0351563     3  12.3450521       0.41     0.7460
                         |
                Residual |  960.541667    32  30.0169271
              -----------+----------------------------------------------------
                   Total |  3786.98828    47  80.5742188

. by comm: anova AvgG  hetero  info  hetero*info
-> comm=       NC
                           Number of obs =      24     R-squared     =  0.4218
                           Root MSE      = 4.86404     Adj R-squared =  0.1689

                  Source |  Partial SS    df       MS           F     Prob > F
              -----------+----------------------------------------------------
                   Model |  276.197917     7  39.4568452       1.67     0.1875
                         |
                  hetero |  177.385417     3  59.1284722       2.50     0.0966
                    info |  6.51041667     1  6.51041667       0.28     0.6071
             hetero*info |  92.3020833     3  30.7673611       1.30     0.3086
                         |
                Residual |  378.541667    16  23.6588542
              -----------+----------------------------------------------------
                   Total |  654.739583    23  28.4669384

-> comm=        C
                           Number of obs =      24     R-squared     =  0.5061
                           Root MSE      = 6.03117     Adj R-squared =  0.2900

                  Source |  Partial SS    df       MS           F     Prob > F
              -----------+----------------------------------------------------
                   Model |  596.309896     7   85.187128       2.34     0.0752
                         |
                  hetero |  415.841146     3  138.613715       3.81     0.0310
                    info |  67.5026042     1  67.5026042       1.86     0.1920
             hetero*info |  112.966146     3  37.6553819       1.04     0.4036
                         |
                Residual |      582.00    16      36.375
              -----------+----------------------------------------------------
                   Total |   1178.3099    23   51.230865
```

d. ANOVA by 3-way heterogeneity condition

```
. by hetero2: anova AvgG comm info comm*info

-> hetero2=     none
                           Number of obs =      12     R-squared     =  0.6337
                           Root MSE      =  6.3701     Adj R-squared =  0.4964

                  Source |  Partial SS    df       MS           F     Prob > F
              -----------+----------------------------------------------------
                   Model |  561.682292     3  187.227431       4.61     0.0372
                         |
                    comm |  349.380208     1  349.380208       8.61     0.0189
                    info |  186.046875     1  186.046875       4.58     0.0647
               comm*info |  26.2552083     1  26.2552083       0.65     0.4444
                         |
                Residual |     324.625     8   40.578125
              -----------+----------------------------------------------------
                   Total |  886.307292    11  80.5733902

-> hetero2=   single
                           Number of obs =      24     R-squared     =  0.8456
                           Root MSE      = 4.25949     Adj R-squared =  0.8225

                  Source |  Partial SS    df       MS           F     Prob > F
              -----------+----------------------------------------------------
                   Model |  1987.92448     3  662.641493      36.52     0.0000
                         |
                    comm |  1984.71094     1  1984.71094     109.39     0.0000
                    info |    .0234375     1    .0234375       0.00     0.9717
               comm*info |  3.19010417     1  3.19010417       0.18     0.6795
                         |
                Residual |  362.864583    20  18.1432292
              -----------+----------------------------------------------------
                   Total |  2350.78906    23   102.20822

-> hetero2=   double
                           Number of obs =      12     R-squared     =  0.1181
                           Root MSE      = 6.72449     Adj R-squared = -0.2126

                  Source |  Partial SS    df       MS           F     Prob > F
              -----------+----------------------------------------------------
                   Model |  48.4322917     3  16.1440972       0.36     0.7857
                         |
                    comm |   45.046875     1   45.046875       1.00     0.3475
                    info |  3.25520833     1  3.25520833       0.07     0.7953
               comm*info |  .130208333     1  .130208333       0.00     0.9585
                         |
                Residual |      361.75     8    45.21875
              -----------+----------------------------------------------------
                   Total |  410.182292    11  37.2892992
```

3. Reduced ANOVA after excluding insignificant interactions

Source: stuart3.log

Note: In this subsection, `htreat2` denotes the three-way heterogeneity classification, `phase` denotes communication, and `ii` denotes incomplete information

```
. anova AvgG htreat2 phase htreat2*phase ii htreat2*ii

                    Number of obs =      48     R-squared     =  0.7151
                    Root MSE      = 5.25946     Adj R-squared =  0.6567

         Source |  Partial SS    df       MS           F     Prob > F
    -----------+----------------------------------------------------
          Model |  2708.17318     8  338.521647      12.24     0.0000
                |
        htreat2 |  139.709635     2  69.8548177       2.53     0.0930
          phase |  1295.27552     1  1295.27552      46.83     0.0000
  htreat2*phase |  425.199219     2  212.599609       7.69     0.0015
             ii |  94.0755208     1  94.0755208       3.40     0.0728
     htreat2*ii |  131.355469     2  65.6777344       2.37     0.1064
                |
       Residual |   1078.8151    39  27.6619257
    -----------+----------------------------------------------------
          Total |  3786.98828    47  80.5742188
```