HETEROGENEITY AND THE VOLUNTARY PROVISION OF PUBLIC GOODS*

Kenneth S. Chan, McMaster University
Stuart Mestelman, McMaster University
Rob Moir, University of New Brunswick at Saint John
R. Andrew Muller, McMaster University

June 1998

Abstract

We investigate the effects of heterogeneity, incomplete information and communication on aggregate contributions to a public good using the voluntary contribution mechanism in a non-linear laboratory environment. One-dimensional heterogeneity (heterogeneity in income *or* preferences) and two-dimensional heterogeneity (heterogeneity in income *and* preferences) both increase voluntary contributions. The effect is greatest when information is incomplete in the sense that subjects do not know each other's payoffs. Incomplete information also reduces contributions in the homogeneous case. Communication reverses the relative importance of one- and two-dimensional heterogeneity in promoting cooperation.

Paper to be presented at the meetings of Economic Science Association, Mannheim, Germany, June 10-13, 1998. A new revision will be forthcoming by early July.

E-mail: mullera@mcmaster.ca
Full text at http://socserv2.socsci.mcmaster.ca/~econ/faculty/mullera/recentpapers.htm

* The authors acknowledge the financial support of Environment Canada (through a grant to the McMaster University Eco-Research Program for Hamilton Harbour) and the comments from various readers of earlier drafts of this work.

HETEROGENEITY AND THE VOLUNTARY PROVISION OF PUBLIC GOODS

I. INTRODUCTION

Bardhan (1993) suggests that "cooperation works better in small groups with similarity of needs..." but that "an increase in the disparity in private benefits from [the public good] can lead to a situation in which some parties may lose from cooperation..." This view is supported by Kanbur (1992) who argues that cooperation in the management of common property resources is less likely to come about when agents are highly heterogeneous. In his formal analysis heterogeneity is introduced in agents' benefit functions.

In a different model of common property resource management, Hackett (1992) finds that heterogeneity in costs of appropriation complicates efficient governance structures, and leads to less coordination than when costs are more homogeneous or when side-payments between agents are permitted. Ostrom (1992) comments on the importance of homogeneity of social and individual capital for people to succeed in crafting governance institutions and Olson (1983) suggests that homogeneity in preferences and income may "increase welfare and reduce conflict" within the context of the formation of jurisdictions or clubs which provide public goods.

A contrary view is presented in work by Oliver, Marwell, and Teixeira (1985), Marwell, Oliver, and Prahl (1988) and Heckathorn (1993), who study heterogeneity and public good provision in complex environments. They provide scenarios in which the impact of heterogeneity in preferences and incomes may lead to increases in collective action. Generally the intuition behind these results is that in many situations heterogeneous groups increase the likelihood of a critical mass of individuals who will contribute to the public good. With an increased likelihood of the good being provided, more individuals will contribute. The models used are complex and numerical simulation is used to generate results for alternative parameter specifications.

It is possible to study the impact of different incomes and different returns to public good consumption when public goods are provided through voluntary contributions in a laboratory environment. Isaac and Walker (1988) and Hackett, Schlager, and Walker (1994) show that heterogeneity in income reduces voluntary contributions to public goods when agents can communicate prior to making contribution decisions. When communication is not permitted, Hackett, Schlager and Walker find a positive and significant influence of heterogeneity. Similarly, Chan, Mestelman, Moir, and Muller (1996) find evidence that sufficiently large dispersion in income results in increased contributions.[1] The Chan *et al.* outcomes are predicted by the conventional public goods model (unlike the heterogeneity effects observed by Isaac and Walker and Hackett, Schlager, and Walker which are not consistent with the conventional theory). The effect of heterogeneity in preferences (payoff to public good provision) has not been studied in the laboratory.

In naturally occurring environments, public goods frequently are provided by groups of individuals who are able to communicate. The provision of resources to an irrigation project by farmers in a region, the provision of resources for the construction of a marina by sailors in a

[1] 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.

community, and the provision of resources for the purchase of airplanes by members of a flying club are examples of this kind of activity. In these environments, however, it is impossible to determine if provision is optimal or if the participants have simply found their way to a sub-optimal equilibrium. Non-cooperative game theory predicts that non-binding communication will have no effect on voluntary contributions.[2] Nevertheless, laboratory experiments have demonstrated that communication improves coordination and leads to increases in voluntary contributions *even if the agreements made through communication are not enforced by the experimenters.* Naturally occurring environments are also characterized by incomplete information across participants regarding intensity of preference and income. Although information concerning income can be revealed and perhaps verified through communication, information concerning preferences is neither easily transmitted nor verified. Consequently, studies of the effect of heterogeneity on voluntary contributions to public goods ought carefully to account for communication and information effects.

This paper presents the results of a laboratory experiment into the direction and nature of the effect of heterogeneity on voluntary contributions to a public good under alternative conditions of information and communication. It distinguishes heterogeneity in incomes from heterogeneity in preferences. It finds that heterogeneity in a single dimension (income *or* preferences) has a strong *positive* impact on public good provision in environments characterized by incomplete information and communication among agents. Simultaneous heterogeneity in two dimensions has a smaller but still statistically significant effect. When information is common

[2] Within the context of the conventional model, without side-payments or costly coercion and regardless of the information condition, communication should have no effect on voluntary contributions.

across agents, communication leads to significant increases in public good provision, but heterogeneity has no significant impact. These results suggest that small differences among individuals may aid cooperation and coordination in the voluntary provision of public goods, but that coordination may be reduced as differences become larger and more complex.

II. THE THEORETICAL MODEL

The public goods environment is similar to that introduced in Chan *et al.* (1996). Resources for the provision of public goods are voluntarily contributed by individuals who have a specific endowment of resources at the start of each decision period. Individuals can allocate resources to activities which provide returns directly related to their own investment of resources or they can allocate resources to activities which provide returns dependent upon the resources allocated by the community. Bergstrom, Blume, and Varian (1986) provide a rigorous development of this environment in which public goods will be provided at sub-optimal levels.

Following Bergstrom, Blume, and Varian (**BBV**), individuals allocate their income to a private consumption good and a collective consumption good. On **BBV**'s assumption of zero conjectural variations, the individual must solve the problem

$$\max_{x_i, g_i} \quad u_i(x_i, G) \tag{1}$$

subject to the budget constraint $x_i + g_i = w_i$, the public goods identity $G = G_{-i} + g_i$, and the non-negativity constraint $g_i \geq 0$. Private good allocations are denoted by x_i and allocations to the collective good by g_i. G denotes group allocations to the collective good by all individuals, G_{-i} denotes the allocations of all individuals except i, and w_i is the individual's income.

If the payoff to individual i, u_i, is given by

$$u_i = x_i + \alpha_i G + x_i G \quad \textbf{(2)}$$

where α_i is a parameter which characterizes individual preferences for the public good, the best response function for individual i is

$$g_i = \max\left(\frac{w_i - G_{-i} + \alpha_i - 1}{2}, 0\right) \quad \textbf{(3)}$$

In this environment **BBV** prove that there is a unique Nash equilibrium with following properties: given tastes, richer individuals contribute more to the provision of the public good than do poorer individuals; if the distribution of income is sufficiently unequal, very poor individuals contribute nothing; redistribution of income among individuals who contribute a positive amount both before and after the redistribution has no effect on the aggregate quantity of the public good; redistribution of income from non-contributing individuals to contributing individuals increases the aggregate quantity of the public good.[3]

[3] See Theorems 3, 4, and 5 in Bergstrom, Blume, and Varian (1986, 34-38).

In this environment, heterogeneity in preferences and income will have no effect on the Nash equilibrium value of G if $\sum_{i=1}^{I} \alpha_i = \alpha$ and $\sum_{i=1}^{I} w_i = W$, where I is the number of individuals in the group and W is the income of the group. Heterogeneity in preferences and income is introduced by setting some α_is and w_is different to others.

The parameterization of this model and the resulting equilibrium predictions are presented in the next two sections. Of particular note is that this model permits parameterizations in which income distribution may be changed and the distribution of preferences may be changed without affecting the equilibrium predictions for group voluntary contributions or group optimal contributions, although individual contributions may vary. This permits comparisons of the impact of different treatments from a common base. The introduction of this specific model can guarantee that the introduction of heterogeneity does not lead to an environment in which contributions will increase independent of communication and information treatments (as in two of the cases presented in Chan *et al*., 1996). This eliminates notions of critical mass as an explanation of any positive effects of heterogeneity which may arise.

III. THE LABORATORY ENVIRONMENT

In the laboratory environment individuals were divided into groups of three. 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. In each decision round, individuals in each group allocate their laboratory dollar (L$) endowments to Market 1 (a private good market) or to Market 2 (a public good market). Allocations were restricted to integer values. Subjects reported their decisions through a network of personal computers.

There were two parts to each session. The first part consisted of six decision rounds, during which there was no communication among the subjects. The second part consisted of sixteen decisions rounds in which limited communication was permitted. Before the seventh, eleventh, fifteenth, and nineteenth decision rounds the subjects had an opportunity to have face-to-face communication (see Table 1). Details of the communication that was permitted is discussed below. At the end of each decision round, individuals' payoffs in laboratory dollars were calculated according to the function specified in equation **(2)**[4] and reported via to the subjects via their computer screens. 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 incomplete information environments subjects had no information about the incomes and payoff tables of other group members. In complete information environments they also knew both the incomes and payoff tables (preferences) of the

---

[4] The payoff matrices reported the subjects' payoffs in laboratory dollars as a function of the subjects' allocations to Market 2 (the public good) and the group allocation of the other two subjects to Market 2. Because laboratory dollars had to be allocated to either Market 1 or Market 2, the payoff matrix included the return to the residual which would be invested in Market 1. All subjects had copies of their payoff matrices and the payoff matrices of the other members in their group in complete information environments. The subjects had a copy of their own payoff matrices *only* in incomplete information environments. The information conditions were clearly described in the instructions. Payoff matrices and instructions are available from the authors.

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.

Four heterogeneity treatments were employed: a base line homogeneity treatment in which all subjects had the same endowments and same preferences (SE/SP), heterogeneity in income but not preferences (DE/SP), heterogeneity in preferences but not income (SE/DP), and heterogeneity in both income and preferences (DE/DP) Income heterogeneity was induced by changing the distribution of income from L$20 to each subject to L$18 to two subjects and L$24 to one subject. Heterogeneity in preferences was induced by changing the α_is from {9, 9, 9} to {6, 6, 15}. When heterogeneity was introduced in both income and preferences the subject who was endowed with the high income was also given the stronger preference for the public good. In all treatments, the group income, W, was L$60 per period and the aggregate preference parameter α was 27. The four heterogeneity treatments were replicated 3 times in each of two information conditions. The eight different treatments are summarized in 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.

The communication instructions in the incomplete information treatment were identical with the following exception. Subjects were permitted to share only qualitative information about their own payoffs. They could state that a contribution pattern increased or decreased their payoff, but value amounts could not be shared. Recall that in these sessions subjects had only their own payoff tables.

Seventy-two subjects in 24 groups of three participated in these public goods environments. 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).

IV. PREDICTIONS

If subjects' utilities are fully captured by the induced payoffs described by the payoff function **(2)**, there is a unique single period Nash equilibrium for each treatment. The equilibria are characterized by a unique distribution of non-negative contributions across participants.[5] The theoretical individual and group contributions are presented in Table 2 and are invariant to the information condition. The optimal provision of the public good requires an aggregate contribution of L$43. This also is invariant across treatments.

The public good environment described above would lead self-interested non-cooperative individuals to provide the same aggregate level of voluntary contributions towards public good provision regardless of the heterogeneity characteristics of the environment. This result was supported by data reported in Chan *et al.* (1996) in an environment similar to the environment described here with income heterogeneity, complete information, and no communication.

---

[5] Because individuals may make only integer contributions, the payoff tables associated with the best-response functions derived from the underlying model result in multiple Nash equilibria distributions of contributions. These are eliminated in the payoff tables used in this experiment by adjusting the appropriate cells in the payoff tables to insure that the Nash equilibria distributions of contributions are unique for each of the four heterogeneity treatments.

The effect of communication and incomplete information is not obvious. The theory, as presented in the **BBV** environment, provides no role for communication of the form it is introduced here. Work by Isaac and Walker (1988) and Hackett, Schlager, and Walker (1994), however, strongly suggests that, behaviourally, communication will lead to substantial increases in public good provision with or without complete information. Isaac and Walker (1988) report laboratory results in which income heterogeneity and communication leads to a reduction of public good provision relative to environments with income equality and communication.

Our working hypothesis is that, contrary to the predictions of non-cooperative game theory, heterogeneity in income or preferences will affect the level of voluntary contributions, although the direction of the effect is unknown. Moreover, prior experimental work suggests that communication and full information will each increase the level of voluntary contributions. The nature of the interactions among these factors is not known *a priori*; in fact exploring the extent and direction of these interactions is the purpose of our experiment.

V. RESULTS

The data from the experiment are summarized in Table 3, which reports the average per period group contributions by treatment and phase. The first phase of a session consists of the first six periods during which there is no communication. The first two of these periods were treated as practice rounds and dropped while analysing the data. The next four phases each consist of four decision rounds following a round of communication. Each entry in Table 3 represents the average group contribution across four periods in three sessions. Figures 1 and 2 present the times series of group contributions to public good provision for each period of the eight heterogeneity/information treatments.

The statistical results presented to support the observations below are based on randomization tests of differences in means and on analyses of variance which use the average per period group contribution data for each session summarized in the “periods 3-6” column and the “periods 15-18” column in Table 3. This provides two observations from each of the twenty-four sessions. Each observation from a session is collected under a different communication treatment. The third phase of communication rounds is selected because effects of reputation and learning in the communication environment should have stabilized after two rounds of communication and eight decision rounds. The final phase of communication rounds was excluded because of potential end-game effects (the participants knew these were the last four decision rounds).

Data from the SE/DP and DE/SP treatments (heterogeneity in preferences *or* heterogeneity in incomes) reported in Table 3 were pooled after conducting an analysis of variance which indicated that the effects of treatments SE/DP and DE/SP were not significantly different from one another (p = 0.573 for accumulated tests of differences in coefficients corresponding to SE/DP and DE/SP and all relevant interaction terms).[6] The data are further summarized in Table 4 in which the Heterogeneous Income or Preferences treatment pools the SE/DP and DE/SP data and the Heterogeneous Income and Preferences treatment includes the DE/DP data. The results of the analysis of variance which is ultimately used to characterize the data from this experiment are reported in Table 5.

---

[6] 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. These definitions also are included as a note to Table 3.

Observations based on these data are grouped in the same order as the hypotheses are grouped in the previous section.

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. A comparison of the simple means of the twenty-four "no communication" observations (22.23) and the twenty-four "communication" observations (34.99) summarized in Table 4 indicates that they are significantly different (randomization test, p = 0.000). This result is further supported by the analysis of variance result reported in Table 5, which shows that the main effect of communication is significant (p = 0.000). 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 hetereogeneity categories. ■

Observation 2: *Incomplete information decreases coordination in homogeneous environments.*

Mean contributions in the complete information condition (29.71) exceed mean contributions in the incomplete information condition (27.51). Analysis of variance shows that 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 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). 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). 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. ■

Observation 3: *Heterogeneity increases coordination when information is incomplete.*

Mean contributions in the homogenous environment (25.86) are distinctly lower that the mean contributions in either the one-dimensional or the two-dimensional heterogeneity environments (30.04 and 28.52, respectively). Analysis of variance shows this main effect of heterogeneity is marginally significant (p = 0.093). 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 heterogeneous, two-dimensional heterogeneous environments respectively). Under incomplete information, contributions in the one-dimensional heterogeneous environments exceed those in homogeneous environments by more than thirty-five percent (30.07 versus 21.92 respectively). This difference is statistically significant (randomization test, p = 0.045). Mean contributions in the two-dimensional heterogenous environments exceed those in homogeneous environments by more than twenty-five percent (28.00 versus 21.92 respectively). This difference is statistically significant (randomization test, p = 0.019). ■

<u>Observation 4</u>: *Communication reverses the relative importance of one- and two-dimensional hetereogeneity.*

The interaction of communication and heterogeneity is strongly significant (analysis of variance, p = 0.002). With no communication, mean contributions in homogeneous and one-dimensional heterogeneous environments (20.46 and 20.94, respectively) are noticeably less than mean contributions in two-dimensional heterogeneous environments (26.58). 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 homogeneous environments and *two-dimensional* heterogeneous environments are scarcely distinguishable (31.25 and 30.44, respectively) while mean contributions in the one-dimensional heterogeneous environments are distinctly higher at 39.13. The difference between the means of the one-dimensional heterogenenous contributions and the remaining contributions is significant (randomization test, p = 0.001). ■

VI. DISCUSSION AND CONCLUSIONS

We have investigated the effect of heterogeneity on public goods provision under alternative communication and information conditions. Our work on income heterogeneity is related to that of Isaac and Walker (1988) and Hackett, Schlager, and Walker (1994). Our work on preference heterogeneity is new. We have shown that heterogeneity in income or preferences tends to increase public goods contributions. The effect is greatest when information is incomplete in the sense that subjects do not know each other's payoffs. The nature of the effect is complex. In particular we found that communication reverses the relative importance of one- and two-dimensional heterogeneity in promoting cooperation. It is worth noting, however, that our experimental design is unable to separate the effects of communication from those of learning over the course of the session.

Table 6 compares some of our results to the Isaac and Walker (IW) and Hackett, Schlager and Walker (HSW) papers. Our laboratory environment differs from both of these studies in a number of important respects. We and IW investigate voluntary contributions to a public good while HSW investigate appropriations from an open-access resource. The IW payoffs are linear in individual contributions; ours are decreasing in individual contributions, hence we have an non-cooperative equilibrium in the interior of the contribution space. We used groups of three subjects while IW used groups of four and 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 instructive to compare the results of the three studies.

Table 6 summarizes comparative evidence on heterogeneity and information effects in the three studies. Unreported in Table 6 is the common conclusion of all three studies that non-binding communication is positively related to group contributions. Both IW and HSW find strongly positive and significant effects of communication. Our results confirm these in a related but different environment. Our finding of a positive effect of heterogeneity contrasts strongly with Isaac's and Walker's negative effect. Our finding is consistent, however, with the Hackett *et al*. data which also display a positive effect of heterogeneity, although the authors do not emphasize this finding.

The positive effect of heterogeneity may be interpreted as supporting the sociological literature, cited above, which argues that heterogeneity will increase public goods provision. This literature suggests that heterogeneity may generate environments with a critical mass of contributors who find it in their interest to contribute to the group activity regardless of what others contribute. This leads the group to contribute more than would be contributed if the group was homogeneous. In the laboratory environments created for this experiment there are no such critical masses. Even so, heterogeneous group contributions exceed those of homogeneous groups.

There are many directions to go with these results. 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 patterns of coordination which developed have yet to be studied. Did people choose to contribute equally to the provision of the public good or in proportion to income? What kinds of allocation rules evolved when heterogeneity was in preferences rather than income? Finally, new experiments could be run to study the impact of group size on voluntary contributions to public goods in incomplete information environments. Perhaps the most pressing need is to resolve the apparent discrepancy between the results of the Isaac and Walker study on the one hand and the results of the Hackett *et al*. and present studies on the other.

REFERENCES

Bardhan, Pranab (1993). Symposium on management of local commons. *The Journal of Economic Perspectives* 7, 87-92.

Bergstrom, Theodore C., Lawrence E. Blume, and Hal R. Varian (1986). On the private provision of public goods. *Journal of Public Economics* 29, 25-49

Chan, Kenneth S., Stuart Mestelman, Rob Moir, and R. Andrew Muller (1996). The voluntary provision of public goods under varying income distributions. *Canadian Journal of Economics* 29, 54-69.

Heckathorn, Douglas D. (1993). Collective action and group heterogeneity: voluntary provision versus selective incentives. *American Sociological Review* 58, 329-350.

Hackett, Steven C. (1992). Heterogeneity and the provision of governance for common-pool resources. *Journal of Theoretical Politics* 4, 325-342.

Hackett, Steven C., Edella Schlager, and James Walker (1994). The role of communication in resolving commons dilemmas: experimental evidence with heterogeneous appropriators. *Journal of Environmental Economics and Management* 27, 99-126.

Isaac, R. Mark and James Walker (1988). Communication and free-riding behavior: the voluntary contribution mechanism. *Economic Inquiry* 24, 585-608.

Kanbur, Ravi (1992). Heterogeneity, distribution, and cooperation in common property resource management. Policy Research Working Paper WPS 844. World Bank: Washington, D.C.

Marwell, Gerald, Pamela E. Oliver, and Ralph Prahl (1988). Social networks and collective actions: A theory of the critical mass. III. *American Journal of Sociology* 94, 502-534.

Oliver, Pamela E., Gerald Marwell, and Ruy Teixeira (1985). A theory of the critical mass. I. Interdependence, group heterogeneity, and the production of collective action. *American Journal of Sociology* 91, 522-556.

Olson, Mancur (1983). The political economy of comparative growth rates. In *The Political Economy of Growth*, Dennis Mueller, editor. Yale University Press: New Haven, 7-52.

Ostrom, Elinor (1992). *Crafting Institutions for Self-Governing Irrigation Systems*. ICS Press: San Francisco, California.

TABLE 1

DECISION AND COMMUNICATION ROUNDS

Period Numbers																									
1	2	3	4	5	6		7	8	9	10		11	12	13	14		15	16	17	18		19	20	21	22
x	x	x	x	x	x	C	x	x	x	x	C	x	x	x	x	C	x	x	x	x	C	x	x	x	x

Note: C identifies a round of communication and x identifies a decision round.

TABLE 2

EXPERIMENTAL DESIGN: PARAMETERIZATION, NASH EQUILIBRIA AND SESSIONS PER TREATMENT

	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

Note: 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

AVERAGE PER PERIOD GROUP CONTRIBUTIONS BY TREATMENT AND PHASE

Income, Preference and Information Conditions	**No Commun-ication (Periods 3 - 6)**	**Commun-ication (Periods 7 - 10)**	**Commun-ication (Periods 11-14)**	**Commun-ication (Periods 15-18)**	**Commun-ication (Periods 19-22)**
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

Note: 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.

TABLE 4

AVERAGE PER PERIOD GROUP CONTRIBUTIONS BY DATA USED FOR ANALYSIS OF VARIANCE

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

Note: Homogeneous sessions have the SE and SP conditions, Heterogeneous Income or Preferences sessions have either DE or DP but not both, and Heterogeneous Income and Preferences sessions have both DE and DP conditions.

TABLE 5

ANALYSIS OF VARIANCE RESULTS FOR AVERAGE PER PERIOD GROUP CONTRIBUTIONS

Source	Partial SS	df	MS	F	Prob>F
Model	2708.17	8.212e+09	338.52	12.24	0.000
Heterogeneity (H)	139.71		69.85	2.53	0.093
Homogeneous Income and Preferences Heterogeneous Preferences or Income Heterogeneous Preferences and Income					
Communication (C)	1295.28		1295.28	46.83	0.000
H*C	425.20		212.60	7.69	0.002
Incomplete Information (II)	94.08		94.08	3.40	0.073
H*II	131.36		65.68	2.37	0.106
Residual	1078.82		27.66		
Total	3787.99		80.57		

Notes: 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	Results (direction and significance) Other Study	Present Study
Heterogeneity Effect		
Linear Public Goods (Isaac and Walker, 1988)[a]		
Income heterogeneity, communication, pooled incomplete and complete information	negative, significant 5 periods of 10	positive and significant for one-dimensional heterogeneity
Resource Dilemma (Hackett, Schlager and Walker, 1994)[b]		
Pooled communication and information treatments	positive and non-significant effect on efficiency (anova)	positive and marginally significant
Communication, pooled information	negative, not significant (one-way anova)	negative, not significant
No communication, pooled information	positive and significant (one-way anova)	positive, significant
Information Effect		
Linear Public Goods (Isaac and Walker , 1988)[c]		
Communication, pooled homogeneous and heterogeneous treatments	negative, never significant	negative, significant due to strong effect in homogeneous environment
Resource Dilemma (Hackett, Schlager and Walker, 1994)[b]		
Pooled communication and heterogeneity	negative, not significant (one-way anova)	negative, not significant (one-way anova)
Communication, pooled heterogeneity	negative , significant (one-way anova)	negative, not significant
No communication, pooled heterogeneity	positive , not significant (one-way anova)	negative, not significant

Notes:
a. Observation 6, Isaac and Walker (1988). Four person groups.
b. Analysis of variance conducted by present authors from data presented in Tables III, IV, and VI 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.
c. Observation 7, Isaac and Walker (1988). Four person groups

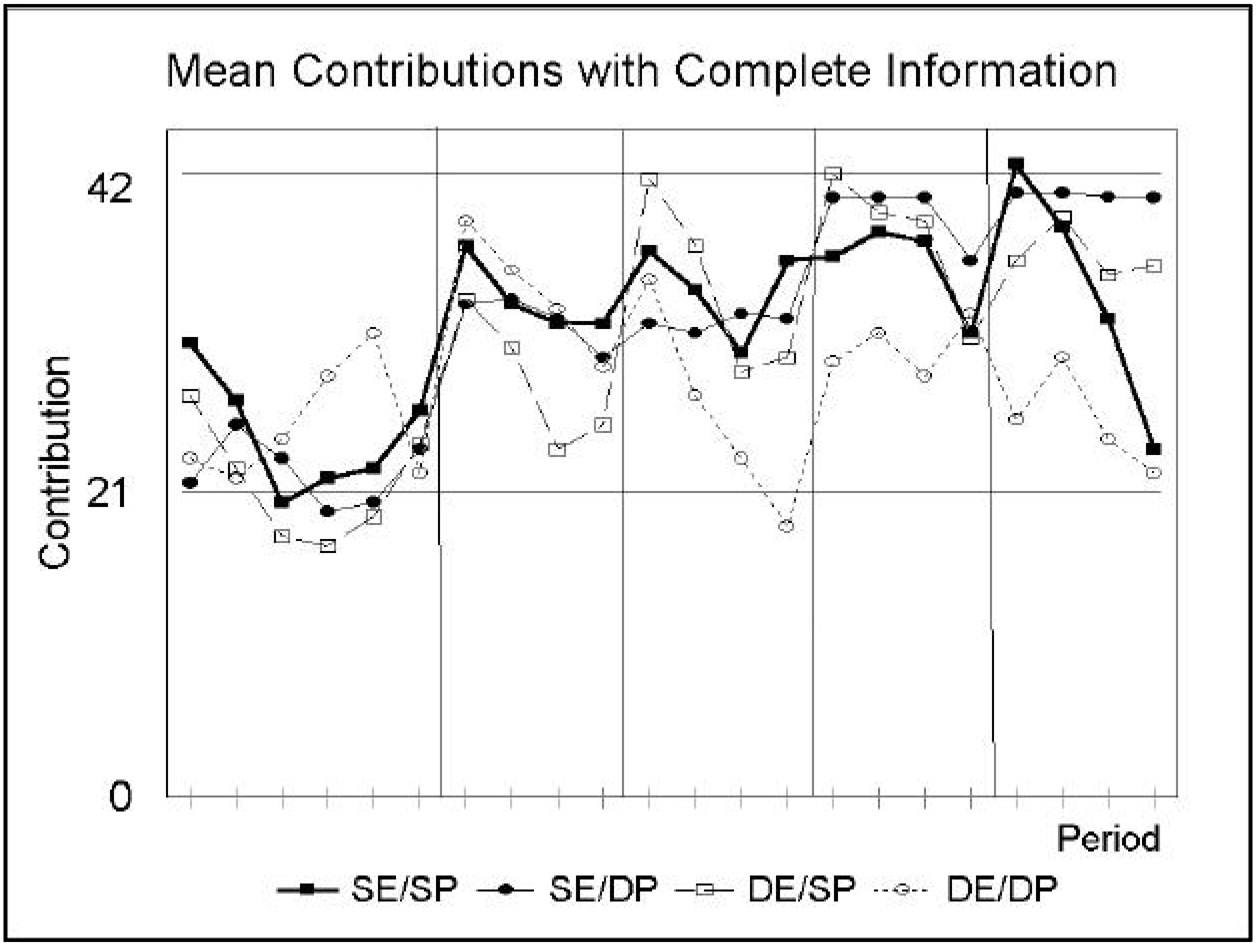
Mean Contributions with Complete Information
42
21
0
Contribution
Period
SE/SP
SE/DP
DE/SP
DE/DP

Figure 1

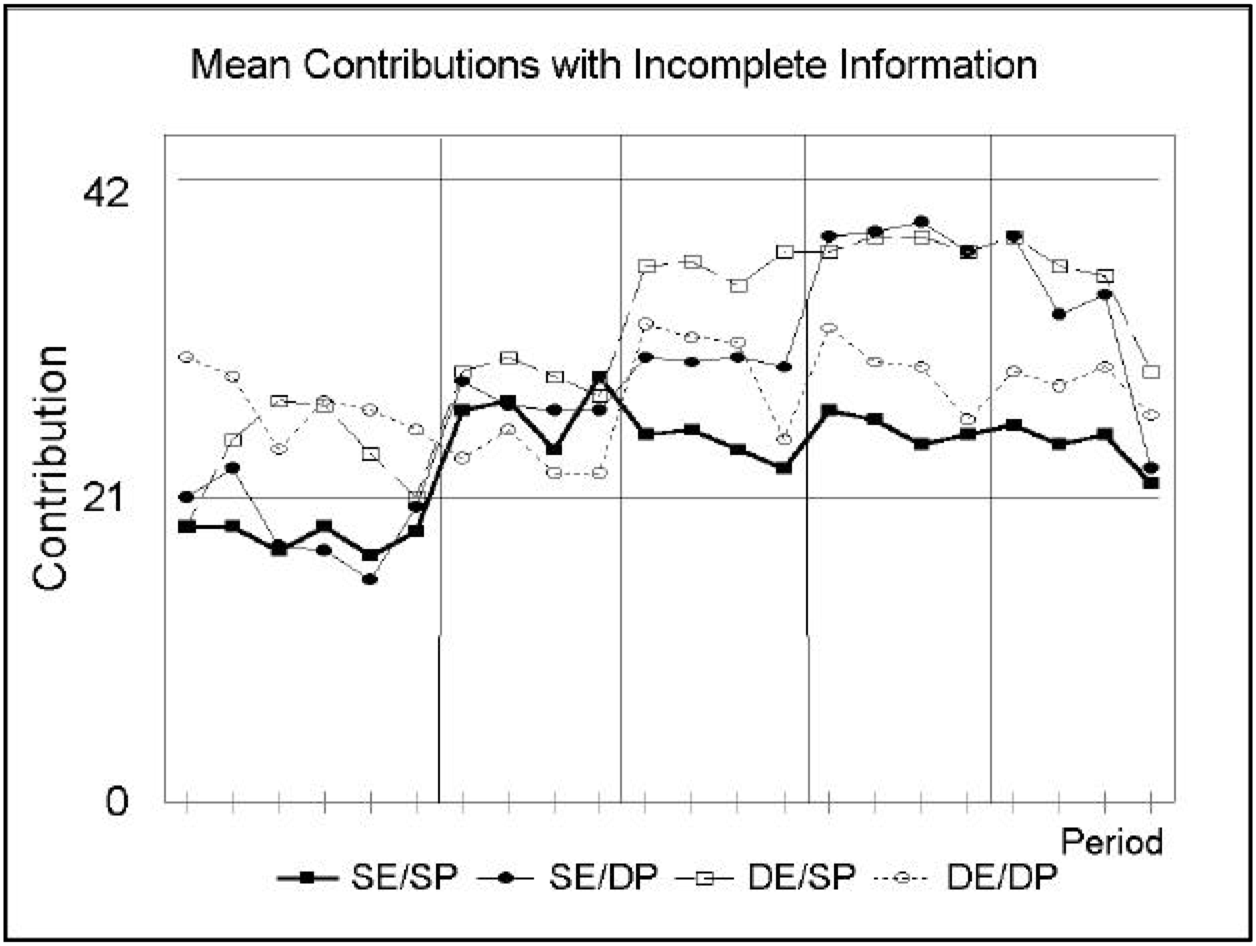
Mean Contributions with Incomplete Information
42
21
0
Contribution
Period
SE/SP
SE/DP
DE/SP
DE/DP

Figure 2

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. **Your payoff table has a letter in the top right corner which corresponds to the letter on your folder.**

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 <u>not</u> 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 <u>not</u> 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**
	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
Combined Allotment of Others	**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: