The Impact of Information Disclosure and Decentralized E-mail Communication on Common Pool Resource Users' Behaviour

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Abstract:
Face-to-face communication in the extraction of common pool resources has proven to be a powerful instrument in significantly improving efficiency in resource extraction. We evaluate the impact of communication when it is in the form of anonymous web-based E-mail rather than face-to-face communication. We also vary the amount of information subjects receive about each other (our information disclosure treatment). Our results indicate that full disclosure about individual decisions and payoffs leads to significantly larger extraction rates (well above standard Nash predictions) when subjects cannot communicate, but reduces income inequality in a given decision round. Individual payoffs in the full disclosure treatments are, however, lower than the lowest payoffs in the other treatments. Decentralized E-mail communication leads to significantly more efficient outcomes with information disclosure. Without information disclosure it is only more efficient than a baseline treatment if participants choose to communicate before the start of the paid rounds. E-mail communication slightly reduces average payoff inequality in a given round, but causes a bimodal individual total payoff distribution, while the no-communication rounds have single peak payoff distributions. Information disclosure leads to more frequent use of communication, but crowds out the efficiency enhancing impacts of communication use.

JEL classification: C72;C92;C91;D83;Q20

Keywords: Common pool resources; Experiments; Communication; Information; Income inequality.
I. Introduction

Laboratory research on group behavior in common pool resource and public good environments shows that regulatory and economic instruments are not necessary to achieve high levels of collective action. Numerous experiments suggest that repeated interaction and face-to-face communication allow groups to overcome a range of social dilemmas in which individual and collective interests are distinct (e.g. Isaak and Walker (1988), Ostrom et al. (1992, 1994), Ostrom (2006)). There are limitations to the power of communication, of course. Ostrom et al. (1994) find that experimental groups rarely communicate repeatedly when communication is costly. Instead, they report that in the majority of sessions with costly communication groups communicate only once and efficiency is lower than with repeated communication. The obvious conclusion is that it is communication and not the option to communicate that promotes cooperative outcomes. This is a problem for plans to incorporate experimental findings into the design and implementation of environmental and resource management policy because in reality communication is apt to be very costly, especially for large groups of resource users and polluters. In some cases face-to-face meetings are simply not feasible. Online institutional frameworks that disseminate information about the status of the resource and facilitate communication via e-mail or web discussion boards are plausible alternatives, but such instruments are very different from the communication treatments tested in laboratory settings.

In existing experiments communication treatments usually take the form of designated communication periods that occur between decision periods, either in the form of face-to-face communication, E-mail communication (see for example Frohlich & Oppenheimer (1998), Rocco and Warglien (1996), Rocco (1998)), audio communication or videoconferencing (Brosig et al. (2003) or by chat room communication (Bochet et al. (2006)). Communication between users via email or web discussion boards in reality would be less structured than implied by these experiments. A communication or message might involve subsets or even single members of the
full set of users, and communications would be sent and read at times considered desirable or convenient to each individual user. This sort of complexity is not present in standard communication and cooperation experiments in the literature.

Our study is distinct from previous experiments because we do not facilitate or organize communication between group members, and because we more formally evaluate the effect of information disclosure on resource use and communication use. Ostrom et al. (1992) evaluate information disclosure in the first 10 periods of a 32 period sanctioning treatment and find no difference in comparison to a baseline experiment in which participants only received aggregate information about total contribution levels and average payoffs. Information disclosure as a separate treatment variable has been further explored in public goods games (e.g. by Sell and Wilson (1991), Weimann (1994) and Croson (2001)). All of the latter studies also find no significant difference in average contributions to the public good, when either aggregate or individual contribution behaviour is disclosed. Croson (2001) finds, however, that group contributions under individual information disclosure have a significantly higher variance than under the aggregate information treatment. None of the experimental studies on public goods and common pool resources, to our knowledge, evaluate the combined effects of information disclosure and any form of communication on individual cooperation behaviour.

In this paper we study behavior in a common pool resource environment under treatment conditions designed to capture some of the complexity implied by employing online communication and information instruments. We, therefore, designed a web-based experiment where subjects in groups of six were assigned to one of four treatments: an email communication treatment, an information disclosure treatment, an email communication and information treatment, 1

1 Anderhub et al. (2001) have evaluated the difference between identical experiments in the laboratory and on the internet. They did not find a significant difference in the results between the two environments. They also highlighted the opportunities of web-based experiments, particularly the fact that they enable "double blindness" between experimenter and subject. Decisions in a web-based environment can be done asynchronously which provides subjects and experimenter flexibility and sufficient time to understand the experimental environment and the behaviour of subjects.
disclosure treatment, and a baseline treatment that provided neither access to email communication nor information disclosure. By designing a web-based experiment we hope to contribute not only to the limited literature on Internet experiments. The online methodology has, however, a more pragmatic purpose. In most experimental designs, communication takes place in a sequential fashion with predetermined communication breaks between particular rounds. In our paper we impose no restrictions on communication. It allows us insight into the endogenous communication patterns that might be a part of modern communication behaviour, and it enables us to evaluate anonymous, decentralized E-mail communication.

We develop a simple theory of behavior in the presence of information disclosure based on the notion that knowledge of the specific actions and payoffs of other group members might lead agents to pursue relative payoff maximizing strategies. We test several empirical implications of the theory using the experimental data.

We find that information disclosure significantly increases extraction effort from the common pool, and decreases average payoffs for group members. However, we also observe that payoff inequality – measured by the distribution of individual payoffs - is lower in the information disclosure treatments and also in the email communication treatments. This result is consistent with our model of relative payoff maximization behavior. Information disclosure furthermore increases the frequency of communication use.

Our results indicate that the presence of an email communication option does not significantly affect cooperative behaviour. Instead, we find that email communication use does increase cooperation, but that communication does not always emerge in groups that have the option to communicate. The effectiveness of communication depends on the frequency and timing (e.g. before or after decision rounds start) of communication. E-mail communication before the start of the paid periods has a very strong effect on increasing cooperation similar to an initial face-to-face meeting. Communication before each paid round has a smaller but still significant cooperative effect. When information disclosure of individual decisions is paired with
E-mail communication it partially offsets the positive effect of communication. E-mail communication furthermore resulted in a bimodal total individual payoff distribution, while payoffs in the no-communication rounds were characterized by a single peak distribution.

The paper proceeds as follows. In section II, we explore the theoretical implications of information disclosure in a common pool resource environment. We argue that information about the specific activities and payoffs of other group members might lead agents to pursue a relative income maximizing strategy rather than a pure payoff maximizing strategy. We think of this as an effort to win the game rather than to maximize income. Accordingly, we derive theoretical predictions about two possible Nash equilibriums. The first is a standard income maximizing Nash equilibrium; the second is a relative payoff maximizing equilibrium. We discuss some of the empirical patterns suggested with these two theories. In section III, we explain the parameters used for our experiment, state predictions and hypotheses for each treatment and describe the experimental design. In section IV. we present results associated with each treatment and hypothesis. Finally, in section V, we interpret the results, compare it with other results and explanations in the literature and discuss avenues for future research.

II. Experimental Theory and Previous Findings in Controlled Laboratory Experiments

The experiment examines a standard limited access common pool resource (CPR) problem with a fixed number of appropriators (n) who have a fixed endowment of tokens (e) each period. We can think of this environment in the context of two markets: Market 1 is the CPR with a return that depends on the decisions of all resource users, while market 2 has a constant fixed return (w) that is independent of the actions of other group members. Market 2 represents the opportunity cost of investing into the extraction from the CPR. Participants, face the following payoff (\( \pi_i \)):

\[
\pi_i = (e - x_i)w + \frac{x_i}{\sum x_i} F(\sum x_i)
\]  

(1)
where $x_i$ is individual $i$’s contribution to market 1 (representing extraction effort in the CPR), and $F(\sum x_i)$ represents a harvest, yield-effort or production function, where the price of output is set equal to 1. The socially optimal aggregate contribution to market 1 ($X^*$) is reached when the group payoff function ($\pi$) is maximized:

$$\pi = nw - w \sum x_i + F(\sum x_i)$$

(2)

As long as $F$ is a concave function we can derive a unique socially optimal solution:

$$\frac{\partial F}{\partial nx_i} = w.$$  

(3)

**Behavioral Predictions in a Standard CPR**

The standard assumption about people’s behavior without communication is that they follow a non-cooperative payoff maximization strategy, which means they would try to maximize the payoff function (equation (1)) with respect to $x_i$. This results in the following first-order condition:

$$\frac{\partial \pi_i}{\partial x_i} = -w + \frac{\sum x_i - x_i}{\sum x_i} F(\sum x_i) + \frac{x_i}{\sum x_i} \frac{\partial F(\sum x_i)}{\partial x_i} = 0$$

(4)

We denote $\frac{F(\sum x_i)}{\sum x_i} = AP_i$ and $\frac{\partial F(\sum x_i)}{\partial x_i} = MP_i$ as the average product and marginal product of an additional unit of effort (or contribution to the CPR) respectively. A symmetric Nash equilibrium then results in:

$$\frac{n-1}{n} AP_i + \frac{1}{n} MP_i = w$$

(5)

**Behavioral Predictions in a CPR with Communication**

The theory is less clear in the context of communication, but existing experimental evidence on face-to-face communication shows that groups can achieve very close to the socially optimal

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2 We assume a homogenous environment in which every individual has the same endowment and receives the same benefit from CPR extraction.
solution as long as endowments are not too large (Ostrom et al. 1994, Ostrom 2006).

Accordingly, we expect that email communication will result in a more efficient outcome than predicted by our non-cooperative Nash equilibrium. Rocco and Warglien (1996) have contrasted structured face-to-face communication rounds with E-mail communication in a CPR game and found that E-mail communication increased cooperation but cooperation increased less, was more fragile and cyclical than in the face-to-face communication rounds. A laboratory experiment by Frohlich and Oppenheimer (1998) also shows that e-mail communication stimulates cooperation in a computer-based Prisoner’s Dilemma game, but that it is not as effective as face-to-face communication. Brosig et al. (2003) compared audio communication in which subjects were isolated and could not see each other with no communication and found that the former only slightly increased cooperation.

If these results also apply to decentralized E-mail communication in a CPR game, individuals will be less cooperative than with the face-to-face communication employed in other common pool resource experiments. We, therefore, expect E-mail communication to improve efficiency, but not as much as observed in structured and externally imposed face-to-face communication rounds where subjects are in the same room or see each other.

Behavioral Predictions in a CPR with Information Disclosure

Without individual information disclosure subjects do not know the distribution of individual payoffs and contributions to the CPR. They are, therefore, more likely to use the group average as a reference point for gauging their performance relative to other participants, and/or to pursue the general payoff maximizing strategy outlined above. With individual information disclosure, on the other hand, subjects can track how they are performing relative to every other individual group member. Under these circumstances individuals could try to maximize their profit relative to the profit of the individual with the largest profit ($\pi_{j}^{\text{max}}$). A plausible objective function for
such a relative profit-maximizer would be to maximize $\frac{\pi_i}{\pi_j}$ with respect to $x_i$, which requires the following necessary condition to hold:

$$\frac{\partial \pi_i}{\partial x_i} \cdot \pi_j^{\max} - \pi_i \frac{\partial \pi_j^{\max}}{\partial x_i} = 0,$$

where $\pi_j^{\max} = (e - x_j^{\max})w + \frac{x_j^{\max}}{\sum x_i} F(\sum x_i)$. 

We can solve the necessary condition by setting the numerator equal to 0 and substituting for $\frac{\partial \pi_i}{\partial x_i}$ from equation (4)⁴:

$$[-w + \frac{\sum x_j - x_i}{\sum x_i} AP_i + \frac{x_j}{\sum x_i} MP_i] \pi_j^{\max} - \pi_i [\frac{x_j}{\sum x_i} AP_i + \frac{x_j}{\sum x_i} MP_i] = 0. \quad (7)$$

In a symmetric Nash equilibrium (SNE) it must be true that $x_i = x_j$ and $\pi_j^{\max} = \pi_i = \pi$, and equation (7), therefore, simplifies to:

$$AP_i = w. \quad (8)$$

The latter equation determines the symmetric relative payoff maximizing Nash equilibrium, which coincides with the open access condition, in which all rents are completely dissipated.

This is similar to results for the specific behavioral principles identified by Ito et al. (1995), when appropriators compete for shares and differences. In our case individuals dissipate rents completely when they try to maximize their relative payoffs. In the experimental analysis we test if information disclosure causes behavior more consistent with the complete dissipation of rents, and how communication interacts with this effect. The underlying intuition for the relative payoff-maximizing model is that information disclosure encourages more rivalry or envy, and, therefore, more emphasis on relative rather than absolute payoff maximization.

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⁴ We make the standard assumption that $\frac{dx_j^{\max}}{dx_i} = 0$. 

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Behavioral Predictions in a CPR with Information Disclosure and Communication

In general, we expect email communication to increase cooperation and information disclosure to decrease cooperation because of the pursuit of relative payoff maximizing strategies. The interaction of information disclosure and communication is less obvious. Information disclosure may stimulate communication, and, therefore, could indirectly promote cooperative behavior. This would constrain the use of relative payoff maximizing strategies. Alternatively, it is possible that cooperation cannot be sustained when deviators or relative payoff-maximizers are easily detected due to information disclosure, and no social shaming or sanctioning can take place because decentralized email communication is anonymous and impersonal.

III. Experimental Design, Nash Predictions and Hypotheses of our Paper

The experiment took place on the Internet and consisted of two unpaid practice periods and 15 paid periods. Groups of six participants received endowments of 15 tokens each in every period. They each invested in either market 1 (the CPR) or market 2 with a fixed return independent of the decisions of others. We conducted 12 sessions with a total of 72 different participants (6 new participants for each session). Participants made decentralized anonymous decisions over the internet, and never met each other. Because of the nature of the experiment each session lasted 1-3 months and it took us almost 3 years to complete all 12 sessions. There were 4 different treatments that were repeated three times each:

1. A baseline treatment with neither communication nor information disclosure;
2. Email communication;
3. Information disclosure; and
4. Email communication and information disclosure.

We will refer to the treatments from now on as (1) baseline, (2) communication, (3) information disclosure, (4) communication and disclosure.

The Subject Pool

Participants were recruited from first year and second year undergraduate classes from different disciplines at Carleton University in Ontario, Canada and from the University of Adelaide in
Australia (one session), as well as graduate classes from the School of Public Policy and Administration at Carleton University. Students from the latter programmes typically have a wide variety of undergraduate degrees, and the program is large enough to avoid communication outside of experimental sessions. Participants never met, were randomly allocated to groups and did not know who was playing in their group. Students that signed up were sent a signup sheet with some basic demographic questions about their age range, income range and expected major. They were then randomly allocated to different treatment groups and received an anonymous user name and password, that gave them access to a secure WebCT\textsuperscript{5} website at Carleton University.

Participants used the login information provided via email to enter a website that contained detailed instructions, a payoff matrix, a payoff calculator program, and a results section which provided information about payoffs from each round of the experiment.\textsuperscript{6} Once participants read and understood the instructions, they were directed to an online consent form that they needed to agree with before continuing. The details of the website varied between treatment groups.

Participants in groups that included the communication treatment had access to an internal email system that could be used to send messages to the other participants in the group or to the entire group. Subjects were only identified by their assigned user names and were asked not to disclose their true identity to other members of the group. The email feature was not available to participants in the non-communication treatments. Participants in groups that included the information disclosure treatment had access to a results table that included investment decisions and payoffs of each member of the group for each round of the experiment. Participants in non-information disclosure groups received only information about their own investments and payoffs, as well as aggregate investments and average payoffs.

\textsuperscript{5} WebCT stands for Web Communication Tools and is used for course-specific online interaction in many Universities around the world.

\textsuperscript{6} For details about the experimental website please contact the authors to gain access to the secure WebCT site.
The Payoff function

Every token invested in market 2 received a return of 10 Lab $\text{7}$. The total payoff ($\pi$) in market 1 (the CPR) to the entire group is based on the following quadratic function:

$$\pi = 94 \sum x_i - (\sum x_i)^2 \quad (9)$$

Accordingly, each participant’s total payoff is:

$$\pi_i = (15 - x_i)10 + \frac{x_i}{\sum x_i} \left(94 \sum x_i - (\sum x_i)^2\right) \quad (10)$$

which simplifies to:

$$\pi_i = 150 + 84 x_i - x_i \sum x_i \quad (11)$$

Optimal Outcomes and Nash Predictions

The socially optimal solution is reached when $\frac{\partial \pi}{\partial x_i} = w = 10$. This occurs when $\sum x_i = 42$ or $x_i^* = 7$. A symmetric payoff maximizing Nash equilibrium (SNE) can be derived from equation (5), and equals $x_i^{SNE} = 12$. If subjects maximize relative payoffs according to equation (7) they would contribute more than the SNE of 12. We assume that relative payoff maximizers first wish to have the highest payoff in each round, and secondly that they want to maximize their payoff if there are a number of options that bring the highest relative payoff.

We can, therefore, derive two different reaction functions, which depend on the participant’s objective function (see figure 1).

- -insert figure 1-

These reaction functions can be considered as extreme cases and the true behavior might be a weighted average of both objectives depending on the salience of the disclosed information in each subject’s decision-making process.\textsuperscript{8} The reaction functions plot the decision of a single

\textsuperscript{7} 1 Lab $ is later converted to Can $ 0.005 or Aus $ 0.005.
agent against the average contributions of others in the group. The lighter line in figure 1 is the standard payoff maximizing reaction function with a symmetric Nash equilibrium at $x_i^{SNE} = 12$. The darker line depicts the relative payoff maximizing strategy. In this case, the symmetric Nash equilibrium is 14 and is derived by setting the average product equal to 10.

The reaction functions are equivalent up to the point when the average contribution of the remainder of the group is equal to 10.8 ($\bar{x}_j = 10.8$). At this point, the payoff maximizing reaction function slopes downward. In contrast, for relative payoff maximizers it pays to contribute 15 tokens as long as everyone else contributes less than 12. Once others contribute on average more than the noncooperative payoff-maximizing Nash equilibrium of 12, there is an incentive for relative payoff maximizers to raise their investment by just one token to 13. We reach another symmetric relative payoff maximizing equilibrium at an average investment of 14. At this point it would no longer be in the interest of anyone to raise investment because all rents are dissipated.

In addition to the respective symmetric Nash equilibriums implied by the two models, the reaction functions also imply some empirical predictions about the distribution of payoffs associated with the two models. In the standard payoff-maximizing model, the reaction function reveals that individual contributions between 4.5 tokens and 15 tokens are consistent with the model under different aggregate conditions. In contrast, the reaction function associated with the relative payoff-maximizing model suggests that individual investments might plausibly range from 10 to 15 tokens. This smaller set of maximizing investments implies that the variance of investments and payoffs will be smaller in the information disclosure treatments where the relative maximizing model is predicted to hold.

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8 See Falk et al. (2002), for example, for an accurate discussion of different combinations of payoff maximization and types of inequity aversion.

9 Note: if everyone else contributes 11 an inequity averse relative payoff maximizer is indifferent between playing 14 or 15 if everyone else contributed 11; both would generate the same payoff.
V. Results

In this section we discuss the results of the experiment at both the aggregate and individual level. Throughout we rely on the theoretical framework presented earlier in the paper to guide the analysis. In each sub-section, we review key theoretical implications and then report evidence related to these implications that can be derived from the experiment.

A. Aggregate Investment By Treatment

In sections II and III we derived theoretical predictions of equilibrium aggregate investments in the CPR for each treatment group under different behavioral models. The classical payoff-maximizing model predicts that groups composed of homogeneous rational actors will invest 72 tokens per round in the CPR. We will refer to the latter as the absolute payoff-maximizing Nash (APN) equilibrium. The relative payoff-maximizing model predicts that information disclosure will inspire relative payoff comparisons that will lead groups to invest 84 tokens per round in the CPR. We will refer to this as the relative payoff-maximizing Nash or RPN. Previous experimental research suggests that groups that communicate face-to-face will make investments that approach the socially optimal investment (SOE) of 42 tokens per round (Ostrom et al. 1994). Other research suggests that email communication is less effective than face-to-face communication, but still yields better outcomes than the classical payoff maximizing predictions. It isn’t clear whether groups assigned to the communication and information treatments will play above or below the APN or even close to the RPN. This is because the relative payoff-maximization model predicts that aggregate investments will increase under information disclosure, while previous experimental results predict investments to fall under communication. From an empirical standpoint these theoretical results suggest that aggregate investment behavior across treatments should approximate the equilibrium predictions of the relevant model. A weak interpretation of these models is that mean aggregate investments in the different treatments
should be ordered according to the order of the equilibrium predictions. A stronger assertion is that mean aggregate investments should equal or converge to the equilibrium predictions.

Table 1 reports mean aggregate investments by treatment over all rounds of the experiment. The ANOVA table allows us to look at the effects of each treatment and at the effects of communication and information disclosure. Information disclosure tends to induce larger investments into the CPR on average than no disclosure of individual investments. The communication treatment results are, however, surprisingly similar to the no communication results. There also seems to be hardly any difference between communication with information disclosure and without disclosure. The variance with no disclosure and communication is, however, significantly larger.

### Table 1:
**Mean Aggregate Contributions per period to the Common Pool by Communication and Information Disclosure Treatments (standard deviations are in parentheses)**

<table>
<thead>
<tr>
<th></th>
<th>Full disclosure</th>
<th>No disclosure</th>
<th>Row Totals</th>
</tr>
</thead>
<tbody>
<tr>
<td>No communication</td>
<td>76.4 (6.91)</td>
<td>65.27 (8.66)</td>
<td>70.83 (9.59)</td>
</tr>
<tr>
<td>Communication</td>
<td>67.58 (8.27)</td>
<td>66.44 (12.19)</td>
<td>67.01 (10.38)</td>
</tr>
<tr>
<td>Column Totals</td>
<td>71.99 (8.78)</td>
<td>65.86 (10.53)</td>
<td></td>
</tr>
</tbody>
</table>

The simple ranking of groups from highest average investment to lowest average investment is: Information Disclosure (76.4 tokens), Communication and Information (67.58 tokens), Communication (66.44 tokens), and Baseline (65.27 tokens). The relative income maximization model predicts that groups assigned to the information disclosure treatment would invest the most in the CPR, and the results in table 1 support that aspect of the hypothesis. On average, groups in the information and communication treatment made the second largest aggregate investments in the CPR. The results provide support for the relative payoff-maximizing model under information disclosure. They also suggest that decentralized email communication is not very effective in promoting cooperation in CPR environments.

Table 2 reports coefficients and standard error estimates from an OLS regression of aggregate investment in each round and session on treatment indicator variables. The baseline group
Table 2: OLS regression of aggregate investment on treatment indicators*

<table>
<thead>
<tr>
<th>Treatment</th>
<th>OLS Coefficients</th>
<th>SE</th>
<th>t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communication</td>
<td>1.18</td>
<td>1.94</td>
<td>0.61</td>
</tr>
<tr>
<td>Information Disclosure</td>
<td>11.13</td>
<td>1.94</td>
<td>5.73</td>
</tr>
<tr>
<td>Information and Communication</td>
<td>2.31</td>
<td>1.94</td>
<td>1.19</td>
</tr>
<tr>
<td>Constant</td>
<td>65.27</td>
<td>1.37</td>
<td>47.48</td>
</tr>
<tr>
<td>N</td>
<td>180</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R Squared</td>
<td>0.188</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F(3,176)</td>
<td>13.63</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*The reference category refers to groups assigned to the baseline treatment.

represents the omitted category in the regression. The coefficients on the communication and information and communication treatments are not statistically different from zero. In contrast, the coefficient on the information disclosure treatment indicator is statistically different from zero (t=5.73). This is evidence that information disclosure is a significant factor and increases aggregate contributions to the CPR.

**Observation 1:** Information disclosure of individual choices and payoffs results in less efficient use of the common pool than the disclosure of aggregate or average contributions.

Table 2 also reports F-tests of the joint significance of the three treatment coefficients. The resulting F statistic is sufficient to reject the null hypothesis that aggregate investments did not vary across the treatment groups. In each treatment, we reject the null hypothesis that aggregate investments are equal to the equilibrium predictions of the model. It is worth noting that subjects in all treatments except for information disclosure behaved significantly more cooperative than they are predicted to be under classical models of CPR extraction. It is also evident that we can reject the null hypothesis that aggregate investments are either equal to the relative payoff maximizing SNE or the socially optimal solution.

**B. Aggregate Investment by Treatment and Round**

The theories developed in sections II and III assume that agents have behavioral characteristics, levels of understanding of the strategic game that are stable and constant across all rounds of the experiment. This kind of assertion implies that the same strategy is optimal for agents in every
round of the experiment. Strictly speaking, it rules out the intuitively plausible idea that agents learn and adapt their strategies over the course of the experiment. An analysis that does not somehow account for this unknown process could lead to biased conclusions. Accordingly, in this section we study aggregate investments by treatment and round. We evaluate the extent to which aggregate investments differ over the course of the experiment, and we test these differences against theoretical equilibrium predictions. In general the analysis in this section evaluates the following hypothesis:

Mean aggregate investments should approach the theoretical equilibrium predictions as the game proceeds.

Our hypothesis implies that the equilibrium predictions of the models presented in sections II and III describe the long-term tendency of aggregate investments. We evaluate the hypothesis by studying variation in aggregate investments in the CPR over time in the experiment in several different ways.

-Insert figure 2-

Figure 2 plots mean aggregate investment by treatment and round. The graph also indicates the relative payoff maximizing Nash, the payoff maximizing Nash, and the socially optimal aggregate investment. There is a slight upward trend in aggregate investments in all four treatments. In the information disclosure treatment, mean aggregate investments exceed the classical payoff maximizing Nash of 72 tokens in every single round. Aggregate investments in the information disclosure rounds also exceed mean investment in any of the other treatment rounds in all but the last round of the experiment. It never exceeds or equals the relative payoff maximizing Nash of 84 tokens, but it does move somewhat closer to this equilibrium prediction in the second half of the experiment. This provides some evidence in support of our hypothesis. Mean aggregate investments in the baseline treatment are below the APN in almost every round of the experiment. The gap between the APN and aggregate investments in the baseline treatment
is smaller in the second half of the experiment, which again offers some support for our hypothesis.

In the communication treatment, mean aggregate investment is below the APN in the early rounds of the experiment, above the APN in the middle rounds of the experiment, and below the APN in the later rounds of the experiment. Mean aggregate investments in the communication and information disclosure also start below the APN, but then slowly converge to the APN towards the end of the session.

**Table 3: Mean Aggregate Investment By Treatment In 5-Period Blocks.**

<table>
<thead>
<tr>
<th>Periods</th>
<th>Treatment</th>
<th>1 to 5</th>
<th>6 to 10</th>
<th>11 to 15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communication</td>
<td>62.33</td>
<td>72.20</td>
<td>64.80</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.17</td>
<td>1.89</td>
<td>3.71</td>
<td></td>
</tr>
<tr>
<td>Information Disc</td>
<td>73.53</td>
<td>77.87</td>
<td>77.80</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.04</td>
<td>1.41</td>
<td>1.74</td>
<td></td>
</tr>
<tr>
<td>Communication and Information</td>
<td>64.13</td>
<td>67.40</td>
<td>71.20</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.11</td>
<td>1.87</td>
<td>2.15</td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>62.20</td>
<td>64.20</td>
<td>69.40</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.72</td>
<td>2.27</td>
<td>2.37</td>
<td></td>
</tr>
</tbody>
</table>

*Standard errors are presented under each estimated MAI.

For the most part, the results in table 3 confirm the analysis of figure 2. The groups assigned to the communication treatment invested more during the middle rounds of the experiment than in the first and last five-round periods. The groups assigned to the information disclosure treatment invested less in the first five rounds than in the second and third five round blocks of periods. These results are consistent with the hypothesis that the information disclosure treatment tends toward the RPN. The groups assigned to the communication and information and the baseline treatments also invested more in the last two-thirds of the experiment than in the first third. This indicates that communication is less likely to have a lasting impact on cooperation when information disclosure is present. The results also indicate that convergence is reached quicker in information disclosure treatments.
One strategy for estimating equilibrium tendencies in the presence of a theoretically unknown convergence process is to treat starting values as a session fixed effect that diminishes in importance over the course of the experiment. The Ashenfelter-El Gamel asymptotic convergence model that was originally described in Noussair et al. (1995) provides a convenient parameterization for such a situation. Essentially, in our application the model describes aggregate investments in each session as a set of session fixed effects that converge to a common equilibrium outcome as \( t \) increases. We will use the same asymptotic convergence model as Noussair et al.:

\[
X_{it} = \sum_{j} \beta_{ij}(1/t) + \beta_{2}(t-1)/t + u_{it}; \quad i=1,2,3
\]

Where: \( X_{it} \) is the aggregate investment of session \( i \) in period \( t \), \( \beta_{ij} \) is an estimate of the first period’s aggregate investment in session \( i \), and \( \beta_{2} \) is an estimate of the effort to which session \( i \) would converge over time.

Table 4 presents estimated coefficients and robust standard errors from treatment specific estimates of the Ashenfelter-El Gamel model. There are 45 observations in each regression and we estimate the model by GLS using the Cochrane-Orcutt transformation to address AR(1) serial correlation. Results from the regression indicate that the communication treatment has the lowest asymptotic estimate, while information disclosure has the highest convergence value. The estimates for the information disclosure treatments are more robust with smaller standard errors.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Group 1 Effect</th>
<th>Group 2 Effect</th>
<th>Group 3 Effect</th>
<th>Asymptote</th>
<th>95% CI Around Asymptote</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communication</td>
<td>114.24</td>
<td>-35.79</td>
<td>78.50</td>
<td>69.03</td>
<td>56.15 - 81.90</td>
</tr>
<tr>
<td></td>
<td>54.22</td>
<td>42.93</td>
<td>58.97</td>
<td>6.36</td>
<td></td>
</tr>
<tr>
<td>Information Disclosure</td>
<td>54.37</td>
<td>74.95</td>
<td>65.43</td>
<td>79.06</td>
<td>76.57 - 81.56</td>
</tr>
<tr>
<td></td>
<td>6.35</td>
<td>6.21</td>
<td>5.64</td>
<td>1.23</td>
<td></td>
</tr>
<tr>
<td>Information and Communication</td>
<td>26.53</td>
<td>76.27</td>
<td>49.13</td>
<td>71.77</td>
<td>64.93 - 78.60</td>
</tr>
<tr>
<td></td>
<td>16.04</td>
<td>18.32</td>
<td>28.31</td>
<td>3.38</td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>23.54</td>
<td>-98.12</td>
<td>-23.58</td>
<td>78.26</td>
<td>69.84 - 86.68</td>
</tr>
<tr>
<td></td>
<td>57.19</td>
<td>40.54</td>
<td>39.29</td>
<td>4.16</td>
<td></td>
</tr>
</tbody>
</table>

*Models are corrected for AR(1) serial correlation using the Cochrane-Orcutt transformation.

*Robust standard errors are reported under the coefficient estimates.
We estimate that the groups assigned to the information disclosure treatment converge to an aggregate investment of 79.06 tokens per round. Information disclosure is the only treatment with a 95% confidence interval that does not include the APN. Communication and disclosure, however, converges close to the APN. The baseline treatment has a surprisingly large asymptotic convergence value of 78.26. The range of the 95% confidence interval [69.84-86.68] is, however, very large. From the 5-period block analysis (table 3) it is evident that aggregate investments converged quicker to stable values in the information disclosure treatments, and very slowly in the baseline treatments. It is, therefore, not as obvious that aggregate investments in the baseline treatment would actually converge to the relatively high asymptotic estimate if the experiment continued passed 15 rounds.

The baseline treatment and the communication treatment have very large ranges of aggregate investments, while the information disclosure treatments have relatively narrow ranges (particularly without communication). E-mail communication tends to increase the variance of outcomes. This is consistent with findings by Rocco and Warglien (1996) and Frohlich and Oppenheimer (1998). One of the most cooperative and successful sessions was one with communication and no information disclosure. Another communication session (without information disclosure), however, experienced not a single round of communication. When we group our results not by communication treatment, but by actual use of communication at least once during communication sessions we can observe that communication results in more efficient results in the first 4 periods and in the last third of the experiment, where the communication treatment diverges from the noncooperative payoff maximizing Nash outcome.
C. Aggregate Investments By Rounds, Treatment Effects and Communication Characteristics

Since communication in our experiment is decentralized and endogenous it allows us to track and record specific communication characteristics for each group. The ability to communicate might not be a significant factor by itself, but the way communication is used. In the communication treatments (both with and without information disclosure) we need to examine the ways in which individuals used communication. It is, therefore, important not to just analyze the treatment effect, but to separate different communication characteristics, such as the use of communication before the start of the paid rounds and the frequency of communication use.

There is an average probability of communication use in a given round of 31 % in full disclosure sessions, but only 20 % chance in no disclosure session. Figure 3 displays the frequency of use in a given round by treatment (i.e. full disclosure or no disclosure).

-insert figure 3-

Communication in the full disclosure rounds is far more equally distributed throughout the experiment and particularly strong in paid round 4 or 8. Compared to no disclosure sessions there is also a much greater probability that communication occurs towards the end of the experiment. Communication at the beginning of the experiment is equally likely under both treatments. With information disclosure participants usually are more likely to switch to payoff maximizing behaviour, which means that at some point in the session payoffs become significantly lower. It then becomes more likely that a participant will engage in communication and ask others to reduce contributions to the CPR. Without full disclosure it is impossible to identify or address individuals that behave noncooperatively or selfish, and, therefore, less communication throughout the experiment occurs. We indeed observed a number of E-mail directed at particular individuals in the full disclosure treatments.

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10 This can, however, occur too late in the experiment so that payoffs are often lower than in no disclosure treatments, and sometimes even lower than in the baseline treatment.
In order to understand the effects of all the treatments and the use of communication by round we included two communication variables into a multiple regression analysis (with aggregate investment as a dependent variable): \( \text{CommUse} \) is a dummy variable that indicates if any participants communicated in a given round and \( \text{Precomm} \) is a dummy variable that tracks if participants communicated before the start of the 15 paid rounds. We conjectured that lagged communication would have a negative influence on aggregate contributions to the common pool in the current period.

The estimate of the constant (see table 5) indicates the starting aggregate investment in the baseline treatment. It is considerably lower than the Nash prediction of 72, but there is a positive round effect of 0.5 tokens per period. After 15 rounds investments converge to 68.67, close to the aggregate Nash prediction.

<table>
<thead>
<tr>
<th>Table 5: A Simple OLS Regression with Communication Use Variables (standard errors in parentheses)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Explanatory Variable</strong></td>
</tr>
<tr>
<td>Constant</td>
</tr>
<tr>
<td>Disclosure</td>
</tr>
<tr>
<td>Disclosure&amp;Comm</td>
</tr>
<tr>
<td>Communication</td>
</tr>
<tr>
<td>Precomm</td>
</tr>
<tr>
<td>CommUse (-1)</td>
</tr>
<tr>
<td>Round</td>
</tr>
</tbody>
</table>

*, **, *** indicates significance at the 90 %, 95% and 99 % confidence level respectively.

The information disclosure treatments start off significantly higher at 72.45 and converge toward 79.8. It might at first look surprising that communication has a positive impact on total CPR investment. This is more than neutralized when participants communicate before the start of paid periods and throughout the paid sessions due to the large negative effects of \( \text{PreComm} \) and lagged \( \text{CommUse} \) on aggregate contributions. Groups that do not communicate are worse off than in the baseline on average because they behave particularly noncooperative despite their
communication possibilities. This can have a number of reasons. Participants that do not communicate could, for example, have high opportunity cost of time, have no “natural leader” among them or have a larger proportion of self-interested individuals. The regression results emphasize the importance of communication before the start of the paid rounds. Communication in the paid rounds does not result in significantly different results than a baseline treatment when preplay communication does not occur. It would take a relatively high frequency of communication to make up for the additional 5.84 tokens of contributions that the communication treatment adds. Our results are consistent with Frohlich and Oppenheimer (1998) and Rocco (1998). The latter showed that E-mail communication is ineffective without an initial face-to-face meeting, while the former has a specially designated communication phase before the start of the paid sessions. We confirm their results with decentralized E-mail communication and with endogenously chosen pre-play E-mail communication. Endogenous pre-play communication seems to be more effective in inducing cooperation than centrally structured communication. It might be very useful to further explore this in a specially designed experiment that compares endogenously chosen pre-play communication to imposed pre-play communication.

**Observation 2:** Decentralized and isolated E-mail communication only leads to significantly more cooperative and efficient outcomes than a baseline treatment (without full information disclosure) if subjects communicate before the start of the paid rounds of the experiment. Decentralized E-mail communication can then have a very strong effect on cooperation and efficiency levels.

The situation is different with information disclosure. Here the treatment alone reduces average aggregate contributions. We also observed more frequent and consistent communication in the information disclosure treatments. This results in approximately 5 less tokens invested into the common pool on average (with a 0.31 probability of communication occurring) even without precommunication. With initial communication before paid rounds start, communication and

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11 The analysis of individual behaviour as a function of socioeconomic variables will be the subject of a different paper. We collected demographic information about participants and conducted a debriefing survey after the experiment.
disclosure results in almost 17 less tokens invested into the common pool than information disclosure without communication.

**Observation 3:** Decentralized E-mail communication is very effective in reducing aggregate investments into a common pool with full information disclosure, even if subjects do not elect to communicate before the start of the experiment.

### D. Average Individual Investments

A more detailed look at average individual contributions by treatment reveals some evidence for the reaction curves derived earlier (see figure 1). Not a single individual in the information disclosure treatment contributed less than 10 tokens on average (see figure 4). This is consistent with the reaction curve predictions for relative payoff maximizers (on average)\(^\text{12}\).

The baseline treatment, on the other hand has participants contributing as little as 5.67 tokens to the CPR on average. In the communication treatment 5% of participants contributed on average as little as 6-7 tokens to the CPR. The baseline treatment and the communication treatment both have almost bimodal distributions with densities and peaks at lower contributions (between 8-10 tokens) and at very high contributions (between 13-15 tokens). The information disclosure treatment has a much narrower range of contributions centered around 12-14 tokens. This furthermore implies that the variance of payoffs is lower in the information disclosure treatments. Finally communication and information disclosure is the only treatment where not a single individual contributed in the 14-15 tokens range, while in all the other treatments a significant number (at least 10%) fell into this category. The range is also narrower than in the no disclosure treatments.

---

\(^{12}\) The reaction curve derived earlier does not consider the effects of dynamic variations in the contributions of others. On a round by round basis every treatment has a large range of contributions, as individuals follow different strategies. We, therefore, consider the average contributions of individual participants throughout a session as an approximation.
Observation 4: Information disclosure results in a much smaller range of average contributions than no disclosure of individual information. This is consistent with theoretical predictions for the range of contributions of relative payoff maximizers that cannot communicate.

E. Distribution of Payoffs

E1. Payoff inequality in a given round

We used the coefficient of variation in individual payoffs to measure income inequality by round. The COV is simply the standard deviation in payoffs in a given round expressed as a percentage of the mean payoff in that round. In this context, the COV is a measure of the similarity in individual payoffs. In a given round and session, the COV, therefore, takes a value of zero when each participant receives the exact same payoff. As payoff inequality increases, the COV increases as well. Table 6 depicts the mean COV over all rounds and sessions by treatment. At first glance one detects hardly any difference between communication and no communication treatments. The communication treatment has a slightly higher mean and, therefore, less equitable outcome, but a smaller standard deviation. A more significant difference is apparent when we compare disclosure and no disclosure treatments. The rounds with information disclosure have a significantly lower mean and lower standard deviation. When we analyze each treatment in more detail we can observe that the information disclosure treatment without communication has by far the lowest COV averaged over session rounds, and the treatment with information disclosure and communication has the lowest standard deviation. No communication and no disclosure, on the other hand, indicate the largest inequality and the largest variation. Information disclosure tends to reduce inequality and communication acts to reduce the variance of inequality.
Table 6: Mean COV over all rounds and sessions by treatment (standard errors are in parentheses)

<table>
<thead>
<tr>
<th></th>
<th>No Disclosure</th>
<th>Information Disclosure</th>
<th>Row Totals</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Communication</strong></td>
<td>13.46 (8.63)</td>
<td>12.85 (6.09)</td>
<td>13.15 (7.4)</td>
</tr>
<tr>
<td><strong>No Communication</strong></td>
<td>17.11 (10)</td>
<td>8.05 (7.67)</td>
<td>12.58 (9.97)</td>
</tr>
<tr>
<td><strong>Column Totals</strong></td>
<td>15.31 (9.47)</td>
<td>10.47 (7.29)</td>
<td></td>
</tr>
</tbody>
</table>

A regression analysis offers a more comprehensive assessment. Table 7 presents the results from a simple pooled OLS procedure. The dependent variable is the COV of payoffs in a given round of a given session. The use of communication and communication before the first paid period are all insignificant in explaining the inequality of payoffs. Estimation results show that communication and particularly information disclosure significantly (at the 95% and 99% confidence interval respectively) reduce income inequality.

Table 7: OLS regression of COV per round

<table>
<thead>
<tr>
<th>Explanatory Variable</th>
<th>Parameter estimate</th>
<th>Std. Error</th>
<th>Significance level (approx.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Constant)</td>
<td>19.44***</td>
<td>1.651</td>
<td>.000</td>
</tr>
<tr>
<td>Disclosure</td>
<td>-9.074***</td>
<td>1.713</td>
<td>.000</td>
</tr>
<tr>
<td>Communication</td>
<td>-3.386**</td>
<td>1.713</td>
<td>.05</td>
</tr>
<tr>
<td>Disclosure&amp;Comm</td>
<td>-4.555***</td>
<td>1.713</td>
<td>.009</td>
</tr>
<tr>
<td>Round</td>
<td>-0.29***</td>
<td>.140</td>
<td>.04</td>
</tr>
<tr>
<td>N</td>
<td>180</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.159</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**, *** indicates significance at the 95% and 99% confidence level respectively.

Communication tends to diminish the payoff equity enhancing effect of information disclosure, as information disclosure and communication are more effective than communication alone in equalizing payoffs. There also appears to be a slight time trend towards lower inequality. This trend can be interpreted in at least two ways. The convergence in COV could reflect a learning/emulation process in which participants gravitate towards what they perceive to be a
‘good’ or ‘acceptable’ strategy. The outcome of such a process is a more symmetric distribution of payoffs and a correspondingly lower COV. Alternatively, the convergence in the COV could reflect a more explicit desire for equality as the experiment progresses.

**Observation 5:** The ability to communicate by E-mail and particularly information disclosure significantly reduces the inequality of payoffs in a given round.

### E2. Total individual payoff distribution by treatment

Individuals are likely sensitive to both round-by-round distribution of payoffs as well as aggregate distribution of payoffs (over all rounds), particularly when full information disclosure is involved. We, therefore, organized total individual payoffs aggregated over all 15 periods in Lab $ 400 increments and calculated the frequency of payments in each payoff segment for each treatment (see figure 5). From figure 5 two interesting results emerge. First almost everyone in the full disclosure treatments has lower payoffs than the lowest recipients in any of the other treatments. Secondly no-communication treatments have single peak payoff distributions, while communication treatments have bimodal distributions. A large percentage of individuals in any communication treatments (with and without full disclosure of information) had relatively low payoffs (below average), while another large proportion of individuals had larger than average payoffs. This is because communication resulted in more cooperative behaviour in a subset of individuals. This benefitted everyone on average, but the less cooperative, more opportunistic types benefitted received disproportionally higher payoffs than the more cooperative types.

### VI. Conclusions

Our experimental results have shown that full disclosure of individual contributions and payoffs has a significant impact on group behaviour. It leads to outcomes that are even less efficient than standard payoff maximizing Nash predictions, and to lower payoffs for the large majority of individuals than the lowest payoffs received in any of the other treatments. This is different to
results in other public goods and CPR experiments. One reason could be that we have an anonymous, decentralized environment where participants never met or even gathered in the same room, which could drive individuals to less cooperative behaviour with more rivalry and less other-regarding behaviour. Information disclosure, therefore, needs to be taken more seriously as a treatment variable by itself and not just in combination with sanctioning. In fact it needs to be determined in future research if subjects overcontribute above their best response for payoff maximization in order to punish other people or if it is pure envy which drives this behaviour. The survey information from our experiment might shed more light on this research question.

Decentralized E-mail communication does not lead to significantly more cooperative behaviour compared to a baseline treatment, unless subjects chose to communicate before the start of the paid rounds. As opposed to other experiments using E-mail communication, our subjects were not in the same room and never met. We also did not structure the experiment in a way that there was a designated communication phase before the start of the paid rounds. This was very much up to the participants to initiate. When participants initiated preplay communication our results are very much in line with Frohlich & Oppenheimer (1998) and with Rocco and Warglien (1996), i.e. that E-mail communication enhances cooperation and efficiency but not as much as face-to-face communication or videoconferences (Brosig et al. (2003)) or live chat rooms (Bochet et al. (2006)). This seems to suggest that isolating participants and using a web environment does not explain differences in cooperative behaviour with E-mail communication, as Frohlich and Oppenheimer incorporated a formally designated preplay communication phase in a computer lab environment. Individuals communicate differently when communication stages are formally built into an experiment or institution, rather than left to the initiation of subjects. We observed that endogenously initiated pre-play anonymous E-mail communication can be very effective, as participants seem to create an identity of their own.

Rocco (1998) found that E-mail communication was not effective in encouraging players to be
more cooperative in a social dilemma experiment, but showed that E-mail communication can be effective if subjects meet face-to-face before paid rounds start. We confirm this result in our web-based CPR environment and show that initial endogenously chosen E-mail communication instead of face-to-face communication succeeds in promoting trust and encourages enough players throughout the paid sessions to cooperate. E-mail communication is, however, not effective when it occurs for the first time after individuals have already made decisions in paid rounds and received payoffs. With anonymous E-mail communication participants cannot as easily assess what others are thinking. It is, therefore, important that as many people as possible articulate themselves before the start of the paid sessions, and that communication is regularly refreshed. This is, of course, quite different to face-to-face communication with predetermined patterns where everyone gets an instantaneous verbal and nonverbal feedback about the cooperative mood and approval rate of suggested strategies.

With full information disclosure decentralized E-mail communication is effective in enhancing efficiency even without pre-play communication. The use of E-mail communication is also more frequent throughout the sessions. Information disclosure tends to, however, crowd out the efficiency enhancing effects of communication, but reduces payoff inequality in a given round.

There are a number of policy implications we can potentially derive from this experiment. The use of anonymous E-mail communication could create a challenge for the voluntary regulation of larger CPRs that are used by many stakeholders, which do not naturally interact with each other on a regular basis. Policymakers’ role could be to initiate communication before CPR users make decisions, and to ensure that a critical mass stays engaged in the communication process by asking them to provide regular feedback by E-mail or web postings, ideally in the form of videoconferencing or live chats (shown to be more effective by Brosig et al. (2003) and Bochet et al. (2006) respectively). The disclosure of individual information might be harmful. It could induce CPR users to fully dissipate rents and significantly
reduce payoffs because they are likely to choose the least cooperative users as a reference point. This is less of a concern with E-mail communication; however payoff inequality over the long run could become an issue as cooperators realize that they are carrying an uneven burden. It is much better to stick with average or aggregate information in anonymous social dilemma settings.
REFERENCES


Rocco, E., 1998. Trust breaks down in electronic contexts but can be repaired by some initial face-to-face contact. Proceedings of CHI (April), 496-502.


FIGURES

Figure 1: Reaction Functions for Payoff-maximizing and Relative Payoff-Maximizing Behaviour
Figure 2: Aggregate Contributions to the Common Pool by Treatment and by Round Mean over all the sessions
Figure 3: Communication Frequency by Treatment and Round
Figure 4: Frequency of average individual contributions
Figure 5: Individual Total Payoff (over all 15 rounds) Distribution by Treatment