Join the Leader, Imitate or Follow: Evolutionary Stable Strategies in the Commons

Abstract:
We develop an evolutionary game theory model for a limited access common pool resource. With full disclosure of individual extraction decisions and payoffs we conjecture that subjects will imitate the most successful players' strategy as long as their payoffs increase. We derive a stable asymmetric equilibrium of Stackelberg leaders and followers that predicts larger aggregate extraction than the symmetric Nash equilibrium but less than the complete rent dissipation scenario. We also formally model the effect of electronic communication on individual behaviour and the stability of coalition formation. As opposed to previous findings in the CPR literature we observe that full information disclosure significantly changes individual behaviour and aggregate use of the common property. Groups that had complete information about other subject's behaviour extracted significantly more from the CPR, which is consistent with our evolutionary stable equilibrium predictions. Cooperation with E-mail communication is a function of the number of self-identified cooperators and as predicted reduces aggregate extraction but does not reach full efficiency. Full information and communication leads to the formation of smaller coalitions, and, therefore, larger aggregate extraction from the common pool than communication without full information disclosure.

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

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I. Introduction

Common property has often been blamed for the overexploitation of many common pool resources such as ocean fisheries, groundwater aquifers or oil pools. Open access to the resource will cause entry of harvesters until all rents are dissipated and nobody derives any profit or utility from the common property. Limited access, on the other hand can result in a Nash equilibrium that is inefficient but at least creates rents for common property users. It has, however, been shown that complete rent dissipation is possible with limited access when there is noncompetitive competition (Mason et al. (1988)) or resource users have large capacity endowments (Walker et al. (1990)). Favourable cheap talk conditions, on the other hand, can result in a cooperative solution close to the social optimum (Ostrom et al. (1992), (1994)). Surprisingly none of the paper on common pool resources found that behaviour is affected by the information provided to subjects. Even in the public goods literature only one study (Sell and Wilson, 1991) finds that information provided to subjects has a significant impact on public good provision. Furthermore none of the experimental studies on public goods and common pool resources evaluate the interactive effects of information disclosure and any form of communication on individual behaviour.

The focus and results of the public goods and common pool resource literature is in stark contrast to the literature on competition between oligopolistic firms and their market strategies (e.g. Altavilla et al. (2006), Offerman et al. (2002), Matthey (2006), Apesteguia et al. (2007)) that has consistently shown that behaviour significantly changes with the information provided to subjects in oligopoly experiments. Findings can be explained by dynamic learning games, which distinguish between different learning strategies that are influenced by the information available to subjects. Static symmetric Nash equilibria have proven to be good predictors for belief-learning situations at the aggregate level but they they fail to predict the outcomes of games with full information about the decisions and payoffs of each individual player. In studies of Cournot and Bertrand competition between firms it has been well established that the imitation rule prevails when players have full information on their rivals' choices and payoffs (Offerman et al. (2002), Altavilla et al. (2006)). However, for imitation to be possible, players need to either have information about other players or need to be able to communicate in order to discuss possible group strategies and to get a sense of relative consensus with suggested strategies.

A common pool resource game is similar to an oligopoly game with reverse implications for the players (see Heintzelman et al. (2009)). Excessive competition can lead to complete rent dissipation, while cooperation or collusion between individual resource users is desirable because it will lead to optimal CPR use. It is, therefore, peculiar that theoretical predictions and experimental findings differ substantially between the two environments. The CPR literature has generally assumed that subjects make decisions based on the history of the game and their best response to the decisions of others. This kind of belief learning assumption is reasonable when only aggregate group information or average payoff, production or effort information is given to decision-makers. The imitation of the most successful strategies, on the other hand is only possible when subjects have detailed information about other individual decisions. Imitation can then be an efficient strategy because it could reduce cognitive effort and decision costs. In fact there is more evidence for imitation behaviour when detailed individual information is available to subjects than for belief learning or a static Cournot Nash play conjectures (Apesteguia (2007), Offerman et al. (2002)).

The CPR literature has focused more on explaining the impact of communication on cooperative behaviour and the deviation from the limited access (blockaded entry) Nash equilibrium. Both literature streams have, however, not examined the interplay of communication and information provision on the competition between firms or CPR extraction behaviour respectively. When some players cooperate it becomes very lucrative for other players to act opportunistically and the most successful individual strategy becomes a best response strategy. Without communication detailed information disclosure might lead to very competitive outcomes and full rent dissipation as in Cournot games (Altavilla et al. (2006)). Most experimental studies have, however, shown that subjects do not remain at the rent dissipating Walrasian equilibrium for very long. We, therefore, need to further examine evolutionary stable strategies when imitation and communication or collusion is possible. We know that communication will lead actors to a more cooperative outcome, and detailed information will result in more imitation of the most successful strategies.

In this paper we, therefore, reexamine the CPR game as a dynamic learning game. Our objectives are twofold. First we wish to derive evolutionary stable strategies in CPR environments with detailed individual payoff and effort information and or for environments in which subjects can communicate with each other. Our second objective is to evaluate some of our predictions derived from our model in a controlled web-based experiment and to better understand how subjects learn and update their decision-making in CPR environments. We conjecture that individuals initially experiment with different strategies, and subsequently react to information and or communication messages. With no information and communication we assume that people will react to the average payoff or aggregate decisions of others. Subjects are expected to react to the most successful strategies when they have individual payoff end effort information, and communication will enhance cooperation through coalition formation. We, therefore, conjecture that different information and communication environments trigger different strategies and, therefore, result in different evolutionary stable equilibria.

We model the CPR environment as a Stackelberg leader-follower model with several potential leaders and followers. Without individual information disclosure and communication it is expected that fictitious play or belief learning that depends on the average decision and reactions of others in the past will emerge. With full information disclosure we expect imitation of the most successful players, which by definition are individual Stackelberg leaders. When subjects can communicate they must decide if they want to be part of a coalition that jointly acts as a Stackelberg leader or to follow and respond in the most profitable way to the decision of a *Stackelberg coalition*. Followers have the option to remain followers or to join the group of Stackelberg leaders. We could think of the latter situation as a group of harvesters that tries to avoid the "tragedy of the commons" and who know that some harvesters will not join, but will capitalize on the conservation effort of the cooperative group. The leader group, therefore, might increase their effort level as the number of followers rises in order to limit opportunistic behaviour of followers and to increase the payoffs of the members of the colluding group.

We use the Stackelberg model as a benchmark to evaluate the dynamic decisions of a limited time horizon experimental CPR game. Our communication instrument consists of sequential anonymous E-mail communication in order to eliminate the uncontrollable influence of peer pressure and nonverbal cues that could persuade players to engage in ongoing cooperation. In our environment communication is decentralized and endogenously initiated by the subjects whenever they feel the need for communication.

We proceed as follows. First we derive predictions for different environments in which CPR users operate. We identify evolutionary stable equilibria and then make predictions based on a parameterization of a specific realistic CPR function commonly used in the literature (e.g. by Walker et al. (1990), Ostrom et al.(1994)). We then test our predictions in a controlled web-based experiment where we vary the information provided to subjects and the ability to communicate with other subjects by E-mail. Finally we discuss the implications of our results for behavioral assumptions in dynamic learning environments.

II. Theoretical and Behavioral Predictions

We examine a standard limited access common pool resource (CPR) problem with a fixed number of appropriators (n) who have a fixed endowment of effort (e) each period. The use of effort has an opportunity cost of 'w'. 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. Individual resource users, therefore, have the following payoff function (π_i):

$$\pi_i = (e - x_i)w + \frac{x_i}{\sum x_i} F(\sum x_i) . \qquad (1)$$

where x_i=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.

2.1 Efficient Solution

The socially optimal aggregate contribution to market 1 (X^*) is reached when the group payoff function (π) is maximized[1]:

$$\pi = nwe - w\sum x_i + F(\sum x_i)\ . \qquad (2)$$

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

$$\frac{\partial F}{\partial n x_i} = w\ . \qquad (3)$$

This socially optimal solution can consist of a multitude of different individual effort decisions. Besides a symmetric solution that involves X^*/n, there are a number of asymmetric contributions that add up to X^*.

2.2. Behavioral Predictions

The CPR environment, just like the oligopoly environment, is susceptible to experimentation with alternative strategies because opportunistic behaviour pays off when others cooperate. This makes it very tricky and costly to compute optimal strategies, and some players might find it more economic to mimic successful strategies of other players. Furthermore the sequence and details of communication affect individual responses. Coalitions can form with communication, and the information environment determines to what extent CPR users can track the effectiveness of non-binding agreements. We, therefore, expect that variations in information and

[1] We assume a homogenous environment in which every individual has a relatively small and limited endowment and receives the same benefit from CPR extraction.

communication environments will trigger different strategies by CPR users just as in oligopoly or other similar environments. We conjecture that the type of feedback provided to CPR users either by other CPR users through communication or by the mediator in the form of feedback information from past rounds will cause differences in behaviour. Imitation, for example, is only possible if individual subjects receive information about the behaviour of other individuals. Coalition building and group payoff optimization on the other hand is only possible if players engage in communication and make suggestions about contribution rules. We assume that people experiment with different strategies until it is no longer in anyone's interest to switch his or her strategy. We will, therefore, make predictions of evolutionary stable strategies for different communication and information environments.

2.2.1 The baseline environment

The CPR baseline has been explored several times in different experiments (see Ostrom et al (1992, 1994), Walker et al. (1990)). In the baseline treatment CPR users cannot communicate with other users and only receive feedback about their own payoff and the aggregate effort and average payoff. Subjects consequently cannot imitate the strategies of the most successful or exemplary players and cannot form coalitions or establish agreements with other resource users. The usual assumption is that subjects follow belief learning, i.e. they base investment decisions on the average behaviour of others in the past and engage in some kind of best response, either to last period's decisions of others or they follow fictitious play (based on all past aggregate decisions). There is no clear evidence if subjects will follow belief-learning strategies in limited information environment or if they rather randomly vary decisions around the static Cournot Nash play. Offerman et al. (2002) provide evidence that the latter is more reasonable. In any case the static Cournot Nash equilibrium is a good predictor for the outcome in the baseline treatment. The standard static Nash equilibrium can be derived by maximizing the payoff function (equation (1)) with respect to x_i. This results in the following first-order condition:

$$\frac{\partial \pi_i}{\partial x_i} = -w + \frac{\sum x_i - x_i}{\sum x_i} \frac{F(\sum x_i)}{\sum x_i} + \frac{x_i}{\sum x_i} \frac{\partial F(\sum x_i)}{\partial x_i} = 0 \tag{4}$$

We denote $\frac{F(\sum x_i)}{\sum x_i} = AP$ and $\frac{\partial F(\sum x_i)}{\partial x_i} = MP$ 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[2]:

$$\frac{n-1}{n} AP + \frac{1}{n} MP = w \ . \tag{5}$$

A CPR game most often, however, is a dynamic learning game in which subjects test out the reaction of others to their decision. We rarely end up with a symmetric equilibrium in a dynamic CPR game or experiment. In experiments we often reach a Nash equilibrium at the aggregate level with asymmetric individual decisions. We expect convergence to the group Nash equilibrium with differences in individual contributions and payoffs.

2.2.2 Behavioral predictions with full information disclosure

The information provided to subjects about the behaviour of the group or individual others has been shown to have an impact on the dynamic adjustment of individual strategies in several experimental studies (e.g. Offerman et al. (2002), Matthey (2006), Altavilla et al. (2006) and Apesteguia et al. (2007)). We conjecture that subjects will copy the decisions of the most successful other subjects as long a their payoff after the

[2] See also Dasgupta and Heal (1979).

change of their strategy is larger than before; otherwise they will play a best response strategy. Subjects will switch, however, as long as one strategy generates a higher payoff than the other. Consequently we can derive an equilibrium proportion of best response followers that do not lead or imitate. A leader might first emerge because he or she thinks that others will just follow in a best response fashion, similar to a Stackelberg leader-follower model. If everyone simultaneously behaves as a Stackelberg leader, we would end up with a Stackelberg disequilibrium, which would drive profits to zero and would result in complete CPR rent dissipation. Even if only one Stackelberg leader first emerges and then others imitate the behaviour of the successful leader, rents could quickly be dissipated and resource stocks decimated if effort endowments are large[3]. Rent dissipation is not as easily possible with relatively low individual endowments where Stackelberg leaders quickly reach an upper limit. We assume that the equilibrium number of Stackelberg leaders is reached when no subject can improve his or her payoff by adopting Stackelberg leader behaviour. We can, therefore derive the following equilibrium conditions:

Proposition1. *With full information about the decisions and payoffs of every individual player, subjects will switch strategies as long as:* $\pi_L(n_L) > \pi_F(n_L)$ and $\pi_L(n_L) > \pi_F(n_L - 1)$
A evolutionary stable equilibrium is reached when $\pi^e_L(n_L) \geq \pi^e_F(n_L)$ and $\pi^e_L(n_L) \geq \pi^e_F(n_L - 1)$

> where π^e_L=the equilibrium profit of a Stackelberg leader;π^e_F=the equilibrium profit of a Stackelberg follower; n_F=the number of followers and n_L=the number of Stackelberg leaders.

We know that individual Stackelberg leaders will always have larger profits than Stackelberg followers because they provide more effort and consequently receive a larger share of the CPR output. An evolutionary stable equilibrium can, therefore, only be

[3] Walker et al. (1990) reported negative rents with large endowments and no information disclosure.

reached when the equilibrium profit of the Stackelberg leaders is at least as high as the one of the followers. It also must hold that no single player can be made better off by switching to become a follower. This proposition basically precludes that complete rent dissipation can ever be evolutionary stable with blockaded entry or a limited number of resource users. If everyone acts as a Stackelberg leader and zero profits are made, at least one subject will switch to become a follower, which makes everyone better off. The follower's profit will be lower than the remaining Stackelberg leader's profits but it is higher than if that follower switched back to Stackelberg leader behaviour.

Result 1. *Complete rent dissipation for a limited number of resource users or players engaged in a CPR game is not an evolutionary stable equilibrium. At least one follower will emerge in equilibrium.*

Informal Proof: Rent dissipation and even negative rents can temporally occur in a simultaneous Stackelberg leader-follower model. In a sequential or dynamic setting there is an incentive for individual Stackelberg leaders to change strategies once zero or a negative rent is incurred. In a dynamic sequential Stackelberg game in a CPR environment we, therefore, will reach an asymmetric strategy equilibrium.

2.2.3 Behavioral predictions with communication

Repeated non-binding face-to-face communication in the form of "cheap talk" has proven to steer CPR users to almost full efficiency (e.g. Ostrom et al. (1992), Walker et al. (1994), Ostrom (2006)) when only aggregate or average CPR investment and payoff information is provided to subjects in experiments, and as long as individual endowments are not too large. With online real time chat rooms almost the same results are achieved (Bochet et al. (2006), Brosig et al. (2003)). Subjects tend to cooperate less (Frohlich & Oppenheimer (1998), Rocco (1998)) when communication is not repeated or when communication is sequential as with E-mail communication. In face-to-face communication or real time chat rooms typically all the subjects send at least some form of signal either through nonverbal cues, eye contact or explicit communication messages. With E-mail communication it is not as common that everyone responds. Some subjects might be in "silent" approval or disapproval of certain messages but they don't always share their opinion with everyone. It is also less common to send "small talk" or acknowledgment messages by E-mail. This might explain the difference we observe between regular face-to-face or chat room communication and sequential E-mail communication. In the latter environment there is less pressure to join the coalition of cooperators, whereas face-to-face communication makes it more uncomfortable for deviators not to at least signal approval of joining the coalition. With online E-mail communication people do not always engage in the communication, which could more easily be perceived as nonwillingness to cooperate. We, therefore, conjecture that the coordination of effort depends on the number of identified cooperators and the number of followers that respond opportunistically to the coalition of cooperators. We expect that effort will only be coordinated by a group of people that have responded to E-mails and that have agreed to coordinate effort. New members will join as long as their payoffs increase after they join.

Without full information disclosure, individuals must guess how many people are in their coalition and if coalition members are sticking to their agreement. We can think of the coalition group as a single collusive Stackelberg leader that guides the decisions of followers. Coalition members, however, can break away from their group if they can earn more as followers. In order to find an equilibrium we need to solve for the first order condition of the Stackelberg coalition. The profit for the members of the coalition depends on the coalition's relative share of the common pool resource and the reaction of followers (x_F) to the joint effort of the Stackelberg coalition (X_C) . The Stackelberg coalition consists of n_C members that assume that others not in their coalition (n_F followers) will respond according to their best response function (like Stackelberg followers). We first derive the necessary condition for the followers (which is consistent with equation (4)):

$$\frac{(n_F-1)x_F+X_C}{X}AP+\frac{x_F}{X}MP=w \quad . \qquad (6)$$

We can solve (6) for x_F as a function of X_C, n_F, AP and MP:

$$x_F=\frac{X_C(w-AP)}{n_F-1+MP-wn_F}. \qquad (7)$$

The Stackelberg leaders will derive their optimal individual effort supply after substituting for x_F according to equation (7) in their joint profit function:

$$\pi_C=\frac{X_C}{X}F(X_C+n_Fx_F(X_C))-wX_C. \qquad (8)$$

The necessary condition for the Stackelberg coalition then becomes:

$$\frac{\partial\pi_C}{\partial X_C}=\frac{n_Fx_F}{X}AP+\frac{X_C}{X}MP(1+n_F\frac{\partial x_F}{\partial X_C})=w. \qquad (9)$$

An equilibrium is reached as long as there is no more incentive for followers to join the Stackelberg coalition.

Proposition2. *A stable coalition of cooperators is reached as long as no additional individual has an incentive to join. This implies that the individual profit for coalition members (π_i^C) in equilibrium is larger than the profit of followers before they joined, and no follower would like to join anymore. The equilibrium condition, therefore, is:*

$$\pi_i^C=\frac{\pi^C(n_C^e)}{n_C^e}>\pi^F(n_c^e-1) \text{ and } \frac{\pi^C(n_c^e)}{n_c^e}\le\pi^F(n_c^e).$$

Individuals will join the coalition as long as they will be better off after joining. As opposed to the stable equilibrium with information disclosure followers will be at least as well off as cooperators in equilibrium.

Result 2. A stable equilibrium with communication and no information about individual payoff and effort decisions will result in an asymmetric equilibrium with $n_C<N$ coalition members and $N-n_C$ followers.

Informal Proof: It will always be lucrative to act opportunistically when everyone else fully cooperates. Coordination will pay off, however, even if some individuals act opportunistically. There will, therefore, always be a critical number of followers and coalition partners.

Result 2 has some important and interesting implications for the role of communication in social dilemmas such as the CPR game. For someone to decide to either join a coalition or to act opportunistically depends on the type and quality of messages received and the perception of the number of cooperators and followers. If commitment can be achieved early on, none of the subjects might experiment with deviations and will commit to the cooperative effort allocation. As communication becomes weaker and is not refreshed some individuals might seek to unilaterally deviate since the fully cooperative equilibrium is not stable. If less people than the stable coalition member size signal cooperation we might end up with an outcome that is even less efficient than the symmetric Cournot-Nash equilibrium. We, therefore, expect E-mail communication to improve efficiency, but not as consistently as in structured and externally imposed repeated face-to face communication rounds that take place in less anonymous classroom settings. The level of cooperation and the individual effort supply will depend on the number of people that explicitly signal that they would like to join a cooperative coalition. E-mail communication also is not refreshed as often and lacks the power of interpersonal reassuring interactions that face-to-face communication provides.

2.5. Behavioral predictions with information disclosure and communication

With information disclosure a group quickly realizes who is part of their coalition and who behaves opportunistically. And when individual opportunists have higher payoffs than members of the cooperative coalition, cooperators are more likely to switch to opportunistic behaviour as they imitate those that have higher payoffs. It is possible that significant cooperation cannot be sustained when opportunistic players are easily detected. The necessary conditions for the Stackelberg coalition and followers are the same as without information disclosure (i.e. equations (7) and (9) respectively). The only difference is that coalition members are more likely to break away from the coalition as they can directly observe who is making the largest payoffs, and are more likely to engage in imitation behaviour.

Proposition3. *A stable coalition of cooperators is reached as long as no additional individual has an incentive to join and coalition members have at least as large of a payoff as followers. This implies that the individual profit for coalition members (π_i^C) is larger than the profit of followers before they joined and the remaining followers do not become the most successful players. The equilibrium conditions, therefore, are:*

$$\pi_i^C = \frac{\pi^C(n_C^e)}{n_C^e} > \pi^F(n_c^e - 1) \text{ and } \frac{\pi^C(n_c^e)}{n_c^e} \geq \pi^F(n_c^e).$$

Result 3. The stable coalition size with communication and information disclosure is smaller than with communication alone. The existence of a unique evolutionary stable equilibrium is less probable with communication and information about individual behaviour. As a consequence it is more likely that subjects will cycle between two equilibria and will frequently switch strategies.

Informal Proof: We established in result 2 that the payoff for followers in equilibrium is as least as large as for coalition members. This implies that individuals want to join a coalition until the last person that joins has a higher payoff than before joining but makes less than the remaining followers. The remaining followers, therefore, become the successful players that will be imitated by some coalition partners. As the followers are imitated, remaining coalition partners will increase their contributions and eventually become the successful players, and some followers will try to join the coalition again.

III. Experimental Design and Predictions

We designed a web-based experiment[4] where subjects in groups of six were assigned to one of four treatments:

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[4] 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.

(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.*

In most 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 and Oppenheimer (1998), Rocco (1998) and Rocco and Warglien (1996)), audio communication or videoconferencing (Brosig et al. (2003)) or by chat room communication (Bochet at et al. (2006))). In our experiment communication is in the form of anonymous E-mail exchange that does not reveal the identity of subjects. Communication patterns are not predetermined but are endogenously chosen by subjects in each group, and, therefore, can occur at any time before, during or after decisions have been made. In typical communication experiments, participants can only move to the next decision round once the designated communication period has ended, which provides more of an incentive to communicate as time is otherwise wasted and more emphasis is being made on setting time aside for communication.

We carefully recruited 1st and 2nd year students from various undergraduate and graduate (excluding Economics and Business) programmes at Carleton University and the University of Adelaide (1 session). We conducted 12 sessions (3 repetitions of each

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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.

treatment) with a total of 72 different participants (6 new participants for each session). Participants never met, did not know who was playing in their group and 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[5] website at Carleton University. Participants used the login information provided via email to enter a website that contained detailed instructions (see appendix A), a payoff matrix, a payoff calculator program, and a results section which provided information about payoffs from each round of the experiment. Once participants read and understood the instructions, they were directed to an online consent form that they needed to agree to. 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.

[5] WebCT stands for Web Communication Tools and is used for course-specific online interaction in many Universities around the world.

A new round was only opened once all six subjects in a group completed their decisions. Participants then received an E-mail notification that a new round was started. We ran two practice rounds in order to familiarize subjects with the environment and website, which is a common practice for CPR experiments. It also allowed participants in the communication rounds to initiate communication before the paid rounds if they so desired. Because of the nature of the experiment each session lasted 1-3 months. Debriefing surveys indicated that subjects enjoyed the participation, did not find it occupied an inappropriate amount of their time and were not bothered by the duration of the experiment.[6]

3.1. The Payoff function

Groups of six participants received endowments of 15 tokens each in every period that they could invest in either market 1 (the CPR) or market 2. Every token invested in market 2 received a return of 10 Lab $[7]. The total payoff (π) in market 1 (the CPR) to the entire group is based on the following quadratic function, which is similar to Walker et al. (1990):

$$\pi = 94\sum x_i - (\sum x_i)^2 \qquad (10)$$

Accordingly, each participant's total payoff is:

$$\pi_i = (15 - x_i)10 + \frac{x_i}{\sum x_i}(94\sum x_i - (\sum x_i)^2) \qquad (11)$$

which simplifies to:

$$\pi_i = 150 + 84x_i - x_i\sum x_i \qquad (12)$$

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[6] Surprisingly only one session had to be abandoned half way through the experiment because we could not get hold of one of the participants. We restarted that session with an entirely new group of subjects.

[7] 1 Lab $ was later converted to Can $ 0.005 or Aus $ 0.005. Subjects made between $ 15.73 and $ 38.03 in total in the experiment.

Individual endowments can be considered limited or small because all 6 individuals must make large contributions to dissipate rents. This is consistent with Walker et al. (1990), who had a small individual endowment of 10 tokens that required all 8 individuals to allocate their entire endowment to the CPR in order to dissipate rents. In Walker et al.'s large endowment treatment it required only 3 out of 8 individuals to dissipate rents. The payoff difference between complete rent dissipation and the symmetric limited access Nash equilibrium is significantly larger than in Walker et al. In our environment subjects only make 51 % of the symmetric Nash equilibrium earnings when rents are fully dissipated (see table 1).[8]

-insert table 1-

3.2. Optimal Outcomes and Nash Predictions

3.2.1. Socially Optimal Outcome

The socially optimal solution is reached when $\frac{\partial \pi}{\partial x_i} = w = 10$. This occurs when $\sum x_i$=42 or when each subjects contributes x_i^*=7 on average.

3.2.2. Baseline Prediction

Our baseline control treatment is a standard common pool resource environment without any form of communication and with aggregate effort information and average payoff levels. We can find a reaction function for each subject by maximizing π_i with respect to x_i in equation (11):

F.O.C.: $$84 - X - x_i = 0$$

[8] This is a much lower ratio than in Walker et al. where subjects still made 76-89 %[8]of the limited access Nash predictions. The difference in earnings is even more pronounced in our experiment when we compare the rent dissipation earnings to the individual earnings at the social optimum. In Walker et al.'s large endowment treatment subjects received 76% of the social optimum earnings at the rent dissipation outcome, while in our case individuals earn only 34 % of the maximum earnings when rents are dissipated.

Reaction function: $x_i = \dfrac{84 - X_{-i}}{2}$ (13)

A symmetric Nash equilibrium (SNE) can be derived from equation (12), and equals $x_i^{SNE} = 12$. We expect subjects to reach an equilibrium with an aggregate contribution to the common pool of 72 since they cannot compare their payoffs directly to any of the other subjects' payoffs and no coalitions can be formed. Subjects, therefore, will base their decisions on past observations and the best response to the aggregate decision of others.

3.2.3. Communication

Subjects now are expected to try to coordinate activities in order to increase payoffs compared to the baseline treatment. Subjects can, for example, suggest that everyone lowers contribution, which would increase everyone's payoff compared to the non-cooperative baseline Nash equilibrium. It becomes, however, very lucrative for individual subjects to raise contributions when everyone lowers contribution. We can, therefore, identify an equilibrium where it is in nobody's interest to switch between cooperative behaviour (joining the coalition) and opportunistic behaviour (behaving as a Stackelberg follower). Communication acts as an imperfect information and coordination device. It indicates to people how many people are signaling intentions to lower contributions. This constitutes, of course, *cheap talk* and without information disclosure subjects cannot verify if specific subjects follow their non-binding commitments. Subjects that are willing to lower their contributions will make their contributions contingent on the expected number of coalition members (n_C) and the number of expected opportunistic followers (n_F). We assume that subjects that signal cooperation will maximize joint profit given the reaction of n_F followers. Subjects that do not join the coalition will react according to the reaction function identified for followers (based on equation (7)):

$$x_F = \frac{84 - X_C}{n_F + 1} \qquad (14)$$

Coalition members are now assumed to jointly maximize the following profit function after substituting for x_F (from equation (14)):

$$\pi_C = 150 + 84X_C - X_C[X_C + n_F \frac{84 - X_C}{n_F + 1}] \qquad (15)$$

From the first-order condition we can derive the optimal contribution of the coalition:

$$\frac{\partial \pi_C}{\partial X_C} = 84 - 2X_C - \frac{84n_F}{n_F + 1} + \frac{2n_F}{n_F + 1} = 0 \qquad (16)$$

$$X_C^{*}=42 \text{ and } x_C^{*} = \frac{42}{n_C} \leq 15\,. \qquad (17)$$

Notice that x_C^{*} equals the social optimal contribution of 7 when everyone joins the coalition. The coalition behaves like a single owner or monopolist and always contributes 42 no matter how followers react due to a constant and identical opportunity cost of effort. However, since endowments are limited to 15 tokens per round for each subject, coalition members or followers are sometimes constrained to their maximum effort of 15. From our model we can make predictions about effort levels for coalition members and followers, the total contribution of effort and the profit for coalition members(π_C) and followers(π_F) as a function of n_C (see table 2).

-insert table 2-

From table 2 we can see that people are best off on average when everyone cooperates and joins the Stackelberg coalition. This equilibrium is, however, not stable. It would always be beneficial for one subject to behave as a follower and make a payoff of 555 rather than 444 (see figure 1).

-figure 1-

Once an equilibrium with 5 coalition members is reached, it would also be detrimental for members of the coalition to unilaterally break off and become followers, as their payoffs would be reduced. From table 2 we can identify a core that makes coalition members and followers better off than the noncooperative Nash equilibrium. A Pareto improvement occurs as long as $n_C \geq 4$. We, therefore, expect coalition-building of at least 4 members. When more than 3 people cooperate, there is, however, an incentive to become a follower and behave opportunistically, which might affect behaviour with communication and disclosure.

3.2.4. Information disclosure

When players can observe the distributions of payoffs and effort contributions they might follow the most successful player's strategy, which would be the Stackelberg leader's decision. A single Stackelberg leader would want to invest as much as 42 tokens to the CPR if there was no endowment constraint (of 15 tokens). Notice that with up to two Stackelberg leaders the outcomes are the same as with communication (see table 2 and 3), but as the number of Stackelberg leaders increases, payoffs decline and aggregate contributions rise. Notice that up to three individual Stackelberg leaders have a higher payoff than at a symmetric Nash equilibrium. There is, therefore a clear incentive for Stackelberg leader to first emerge and then for others to imitate the behaviour. Individual Stackelberg leaders will contribute the maximum of their endowments as long as rents can be earned, i.e. as long as the aggregate contribution to the CPR is less than 84.

-insert table 3-

When everyone wants to be a Stackelberg leader we reach a rent dissipation outcome that is equivalent to open access to a CPR or perfect competition between firms. The latter is, however, not a stable equilibrium. We assume that people will imitate the most successful other players as long as they will be better off than before they switched their strategy. For our profit function followers will copy the most successful strategies until there are 5 Stackelberg leaders and total contributions equal 79.5 (significantly above the symmetric Nash equilibrium without information disclosure (our baseline treatment)). Complete rent dissipation is not a stable equilibrium because it would always be in the unilateral interest of at least one person to become a follower and to significantly reduce contributions. Figure 2 shows that the payoff for leaders is always above the payoff for followers. Switching pays off until n_L=5. At n_L=6 the payoff for leaders is smaller than the payoff for followers when n_L=5.

-insert figure 2-

3.2.5. Communication and Disclosure

If we follow the same logic as before, subjects want to join a coalition that jointly supplies 42 units of effort as long as joining makes them better off than following and as long as they make more than followers. From table 2 and figure 1 it is clear that up to a coalition size of 3 it is worth joining the coalition because payoffs increase and subjects are better off as coalition members than followers. This changes, however, at a coalition size of 4 when followers become better off than coalition members. And because subjects can observe individual behaviour they will start to imitate the behaviour of followers until coalition members are better off than followers once again. We, therefore, predict a cycling between an aggregate contribution of 70-73.5 and a total number of 2-3 followers or 3-4 coalition members.

3.2.6. Summary of Predictions

From the evolutionary model developed in this paper we can make a number of predictions about the outcome from this experiment. The expected outcomes are summarized in table 4.

-insert table 4-

We predict that the least aggregate (but not individual) effort and highest payoffs will occur in the communication treatment. Since it will always be very lucrative for one person not to be part of the cooperative coalition, we predict an aggregate effort level of 57, which is significantly above the socially optimal allocation of 42. In addition we do not expect E-mail communication to be as effective of a coordination device as face-to-face or online chat rooms since it is sequential, endogenous and less predictable. We consequently expect that the highest variation in payoffs will occur in the communication treatment. Followers in communication treatments would have 47 % higher payoffs than coalition members in equilibrium, while in all of the other treatments the difference in payoffs for various strategies is at most 27 % (info disclosure), and is much smaller in absolute terms.

> <u>Prediction 1:</u> Communication without information disclosure will lead to the most cooperative outcome. The equilibrium effort is, however, significantly higher than the socially optimal effort contribution.
> <u>Prediction 2:</u> At least one person will not cooperate and react as a follower to the joint decision of cooperators.
> <u>Prediction 3:</u> Payoffs between different types of players will be relatively unevenly distributed in the communication treatment.

For the baseline treatment we have no reason to expect deviations from the standard results in the literature that predict a symmetric Nash equilibrium based on a best response by individual subjects or a static Cournot Nash plus noise model (see Offerman et al. (2002)). With information disclosure we predict, however, that aggregate effort will be significantly higher than in the baseline treatment and payoffs to all types of players will be significantly lower than in the baseline treatment. Complete rent dissipation is not a stable equilibrium, and, we, therefore, predict moderate rents will be made (above the opportunity cost of 150 (the return from market 2 if all effort is invested there)).

> <u>Prediction 4:</u> Information disclosure will not result in a symmetric Nash equilibrium. Instead two types will emerge: Stackelberg leaders and followers. Aggregate effort is significantly higher than in the baseline treatment, but rents will not be fully dissipated.

When we combine information disclosure with communication, a subset of subjects is expected to cooperate as long as they can raise their payoffs and as long as they make at least as much as followers that are not part of their coalition. We expect the number of coalition members to be between 3-4 and aggregate effort levels to cycle between 70-73.5. The distribution of payoffs between followers and coalition members will not be as unequal as with communication alone.

> <u>Prediction 5:</u> Communication and disclosure will lead to a significantly more efficient result than information disclosure, but will not be significantly different to the baseline symmetric aggregate Nash predictions.
> <u>Prediction 6:</u> We expect, however, a smaller number of cooperators than with communication alone.

IV. Empirical Results

4.1.Efficiency by Treatment

We first report the average efficiency by treatment in figure 3. The efficiency measure is consistent with Walker et al. (1990) and measures the rents from resource extraction (actual group payoffs minus the opportunity cost of tokens contributed to market 1 (the common pool) as a proportion of the maximum achievable rent). We can make a number of interesting observations from figure 3.

-insert figure 3-

> Observation 1: Information disclosure results in less efficiency than any of the other treatments in every period (except for the final period). Efficiency is significantly below the Cournot Nash prediction.

Table 5 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 represents the omitted category in the regression.

-insert table 5-

The coefficient on the information disclosure treatment is the only significant indicator. Information disclosure has a large positive effect on contributions to the common pool (market 1). This is clear evidence that information disclosure is a significant factor and increases aggregate contributions to the CPR and is consistent with prediction 2 and result 1. As opposed to findings by Walker et al. (1990) and Ostrom et al. (1992, 1994) information disclosure significantly decreases efficiency.[9]

> Observation 2: *E-mail communication significantly increases cooperation when subjects have full information about all other subjects' decisions and payoffs.*

Table 5 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. Furthermore, we can reject the hypothesis that information disclosure and communication and disclosure are statistically not different in

[9] 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.

a F-test. This implies that E-mail communication is effective in reducing contribution to the common pool when subjects have full information about other subjects' decisions and payoffs.

4.2 Consistency with Aggregate Predictions

-insert figure 4-

From figure 4 we can see that aggregate contributions under the baseline treatment converge to the aggregate symmetric Nash prediction from below. Contributions with information disclosure, however, remain above the symmetric Nash predictions and also do not lead to complete rent dissipation as our theory suggest. In fact behaviour with full information disclosure seems to be consistent with our evolutionary stable model as aggregate contributions converge to our evolutionary stable equilibrium prediction characterized by Stackelberg followers and leaders.

> Observation 3: Aggregate contributions with full information about individual payoffs and CPR contributions are consistent with an asymmetric equilibrium based on a number of Stackelberg leaders and followers.

Our model seems to also predict the behaviour with communication and information disclosure quite well (see figure 5) as aggregate contributions first converge to the lower range of predicted contributions and then cycle between the upper and lower ranges.

-insert figure 5-

-insert figure 6-

Communication is the only treatment where we cannot observe a linear convergence trend (see figure 6). Contributions start slightly above our predicted asymmetric equilibrium that involves a Stackelberg coalition and one follower, diverge from this equilibrium and then return towards the evolutionary stable equilibrium in the latter part of the sessions. Table 6 summarizes aggregate investments to the CPR in 5-period blocks. Aggregate investment in the communication treatment is significantly lower in the last 5 periods than in the middle 5 periods.

-insert table 6-

We also expected the largest variation in individual behaviour in the communication treatment because it is contingent on the number of subjects that actively engage in communication and indicate that they would like to cooperate. The number of communicators in each of the communication treatment varies considerably, however. One group did not even communicate once, some groups started communicating in the practice rounds, some as late as paid round 7 (see table 7).

> Observation 4: There is convergence to the symmetric Nash equilibrium in the baseline treatment and convergence to the asymmetric evolutionary stable equilibria in the information disclosure and the communication and disclosure treatments. The communication treatment first diverges and then moves towards its asymmetric equilibrium in the last third of the session periods.

-insert table 7-

It, therefore, seems recommendable to have a refined analysis of individual behaviour in the communication treatment and how it relates to the use of communication and the number of identified communicators. We furthermore wish to identify how individuals update their behaviour, what induces them to change strategies, and if there are significant convergence trends.

4.3. Dynamic Learning and Individual Behaviour

4.3.1. Descriptive Statistics of Individual Behaviour and Payoffs by Treatment

The basic descriptive statistics of the individual data provide us with some interesting insights.

-insert table 8-

First we observe that there is no significant difference between mean contributions and payoffs between baseline, communication and communication & disclosure treatments. The median payoffs in the baseline and info disclosure treatment are slightly above the predicted payoffs. In the communication treatment the median payoff is below the predicted range and for the communication and disclosure treatment it is well within the predicted range. The mode payoff in the communication treatment is, however, the full cooperation (socially efficient) payoff of 444. Subjects seem to realize that it is a desirable group outcome but then diverge from it. It is also interesting to note that in 18.6 % of all rounds with information disclosure individual rents were dissipated or negative (returns from the common pool were equal to or below opportunity cost). The latter occurred in a small percentage of baseline and communication & disclosure treatment and was virtually absent in the communication sessions.

The ability to communicate might not be a significant factor by itself, but the way communication is used. E-mail communication as a treatment variation tended to increase the variance of outcomes in our experiment. This is consistent with findings by Rocco and Warglien (1996), Rocco (1998) and Frohlich and Oppenheimer (1998). We furthermore predicted from our evolutionary game theory model that aggregate effort is directly linked to the number of communicators or coalition partners (see table 2 and 4), and that we expect the number of stable coalition partners to differ between communication treatments. A stable coalition without information disclosure consists of 5 members and one follower, while a stable collation with information disclosure cycles between 3-4 members with 2-3 followers.

Observation 5: Full cooperation by 6 communicators was never achieved. At most 5 subjects signaled willingness to cooperate.

Observation 5 is consistent with our result 2 and our prediction 2. At most 5 players communicated in any of the sessions.

Observation 6: In all of the communication and disclosure treatments 3-4 people emerged as cooperators and coalition members.

Observation 6 is supporting our prediction 6, and entirely meets the predictions of our model. While the number of followers in all of the communication and disclosure sessions is entirely consistent with our predictions of 2-3 followers (two sessions had 2 followers and one session has 3 followers), the other communication sessions (without information disclosure) had a much larger variation in the number of communicators. One session reached a stable coalition equilibrium with 5 communicators, in one group only 2 people communicated and in the other session nobody communicated. This demonstrates again that groups converge much faster to an equilibrium when they have information about the behaviour of others. It also indicates the weakness of sequential E-mail communication compared to face-to-face communication and simultaneous communication in online chat rooms. E-mail communication often gets ignored, is read at a later time and lacks the spontaneity of nonverbal cues (compared to face-to-face communication). It is, nevertheless, an important environment to analyze since people increasingly do not come together at predetermined times to simultaneously chat about important decisions that affect everyone (as in a common pool scenario).

4.3.2. Communication Dynamics and Individual Behaviour

We first examine a simple correlation between aggregate effort and the number of communicators in each session. A nonparametric estimation confirms a negative correlation between aggregate effort and the number of communicators (a Kendall Tau coefficient of -0.243 that is significant at the 99% level). Figure 7 confirms this relationship and indicates that aggregate effort significantly declines as more than 4 subjects engage in communication.

-insert figure 7-

Next we analyze the impact that information about the behaviour of others and communication dynamics has on individual contributions to the common pool. We estimated coefficients for a random effects panel model and regressed individual effort levels in each period for each of the 4 treatments separately on a constant and a trend variable. For the communication and the disclosure and communication treatments we also entered the total number of communicators that engaged in communication up to that round and a dummy variable that indicated if a subject had been a communicator in past rounds.[10] The latter were estimated as factor rather than covariate variables, and, therefore, no constant was included in the estimation. Estimation assumes random effects at the subject level to account for correlation among effort decisions made by each subject and uses robust standard errors to correct for possible heteroskedasticity across subjects. The results are summarized in table 9.

-insert table 9-

Individual contributions in the information disclosure treatment start above the symmetric static Cournot-Nash predictions and slowly converge to around 13.18 tokens contributed per round by each subject. This is very close to our prediction of 13.25 tokens

[10] We did not consider coding all the messages into different categories. Communicators generally either signaled cooperation or agreement, stated that they wanted to join a coalition or discussed suggested investments by coalition members. There was not enough variation in the type of messages and discussion to perform a more detailed content analysis or regression analysis that incorporates the type of messages sent.

contributed on average at equilibrium (79.5/6). The information disclosure treatment has the weakest and least significant trend, indicating that equilibrium is reached relatively quickly. In the baseline treatment subjects started significantly below the Cournot-Nash contribution but then increased contributions much faster than in the information disclosure treatment, ending up at 11.88 tokens in round 17 (which is very close to the static Cournot-Nash prediction of 12). The communication treatment had a significant non-linear trend as we noticed from the aggregate contributions per round. Contributions started relatively low and then increased sharply before declining again towards the end of the sessions. This nonlinear trend is not as strong and significant in the disclosure and communication treatment. When we divided players into two types (communicators in past or no previous communication) we can see that communicators are clearly more cooperative (two tokens less on average in the communication sessions and one token less in the disclosure and communication sessions). Communicators in the communication sessions contributed by far the least amount, particularly when the number of communicators reached 5. With less than 5 communicators contributions were 3.71-4.79 tokens larger per round, which is consistent with our predictions about contributions by smaller coalitions. The largest contributions were made in the communication treatment by coalitions of three and 0, whereas in the disclosure and communication treatment only coalitions of one and two significantly contributed more. Consistent with our predictions in table 2 individual contributions first rose with the number of communicators and then declined when 4 or more communicators became involved. The starting contributions in the disclosure and communication sessions were also higher than in the communication sessions.

In order to better understand how individuals in different environments update their decisions in response to the decisions of others we also regressed individual changes in contributions to the common pool on the change in individual payoff (for nondisclosure treatments) and the lagged difference to average and or maximum payoff. We did not introduce a trend variable in order to evaluate the dynamics of the individual contributions in more detail.

-insert table 10-

The results indicate that the lagged difference to average payoffs is only significant in the baseline and communication treatments. In the information disclosure and communication and disclosure environment, subjects exclusively focused on the lagged difference to maximum payoff not average payoff. This provides strong support for imitation behaviour rather than a best response strategy in detailed information environments. Subjects always raise contributions in response to a deviation of their payoff from maximum payoff since the difference to maximum payoffs can never be positive. Subjects seem to, however, try to escape rent dissipation by lowering contributions by 0.70 if there is no deviation from maximum payoff. In the baseline treatment subjects raise contributions when they earn less than the average payoff and lower contributions when they make more than the average. This is slightly adjusted by personal experience in the lagged change of individual payoffs. As someone's payoff increases from round to round contributions tend to be raised and vice versa, which provides support for our conjecture that subjects are more backward looking in the baseline treatment. Behaviour is the latter treatment is more consistent with fictitious play or belief learning.

In the communication treatment we estimated that there is a tendency to reduce contributions by one token once 5 subjects have engaged in communication. This behaviour does not differ by type, i.e. if someone is a communicator or not. The opposite holds in the disclosure and communication sessions. Here the type tends to matter to some degree but the decision to change contributions does not vary significantly with the number of communicators.[11] There is a general tendency to want to reduce contributions by 1.17 (no previous communication) to 1.35 (communicator) tokens, but this is counteracted by a constant increase in contributions when a subject makes less than the most successful player. It is also interesting that in all treatments the lagged difference to average or maximum payoffs has an almost identical magnitude.[12]

4.4. Distribution of Payoffs

Next we evaluate both payoff inequality in a given round and the distribution of payoffs by treatment aggregated over all the rounds. Both are important in evaluating the usefulness of E-mail communication, particularly with respect to tradeoffs between efficiency and equity implications.

4.4.1. Payoff inequality in a given round

We used the coefficient of variation (COV) 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

[11] It is of course the case that we never reached 5 communicators in the communication and disclosure sessions.

[12] The coefficients on lagged difference to average and maximum payoff are similar for all treatments. The interpretation of the coefficients for strategy changes is however different as lagged difference to maximum payoff always induces marginal increases of contributions.

payoff. As payoff inequality increases, the COV increases as well. Table 11 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. All communication use and treatment variables are insignificant in explaining the inequality of payoffs. Information disclosure, however, significantly reduces income inequality in a given round.

-insert table 11-

There also appears to be a slight time trend towards lower inequality.

> Observation 7: *Information disclosure significantly reduces the inequality of payoffs in a given round.*

4.4.2.Total individual payoff distribution by treatment

Individuals are likely to be sensitive to the round-by-round distribution of payoffs as well as the aggregate distribution of payoffs (over all rounds). 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 8). From figure 8 two interesting results emerge. First almost everyone in the information disclosure sessions has lower payoffs than the lowest recipients in any of the other treatments. Secondly payoffs in no-communication treatments are distributed around a single peak, while communication treatments have a bimodal payoff distribution.

-insert figure 8-

A significant proportion of individuals in any communication treatments had relatively low payoffs, while another considerable segment of individuals had larger than average payoffs. This is consistent with prediction 3 and our equilibrium predictions in table 4. Followers have considerably larger payoffs than coalition members, and the latter are less likely to switch behaviour than in the disclosure and communication treatment.

Observation 8: *Individual payoffs aggregated over all paid periods are bimodally distributed in communication treatments, while payoffs in other treatments are distributed around a single peak.*

Notice that the peaks in the disclosure and communication treatment are in closer proximity to each other than in the communication treatment due to the equality enhancing effect of information disclosure.

V. Conclusion

An evolutionary game theory model based on Stackelberg leaders and followers and potential coalition building creates some important insights that challenge some of the theoretical predictions and the robustness of experimental results in the CPR literature. Our evolutionary game theory model emphasizes the importance of considering the stability of asymmetric equilibria when information and communication environments are varied. Our empirical results are consistent with Sell and Wilson (1991) and evidence from oligopoly or market learning games (Offerman et al. (2002), Altavilla et al. (2006), Matthey (2006), Apesteguia et al. (2007)). The latter papers have shown that the type of information available to subjects influences learning behaviour and, therefore, dynamic decisions in multi-period decision-making settings.

We also developed a theory that explains why communication might improve cooperation and efficiency, but might not lead to perfect cooperation and efficiency. Our experimental results seem to support the predictions of our model. Our theory is an attempt to conceptualize the impacts of "cheap talk" on potential coalition-building. E-mail communication lends itself to such an evaluation as it is not biased by the often difficult to measure groups dynamics and nonverbal communication effects that prevail in face-to-face communication environments. Groups might be able to sustain full cooperation as long as they use other measures such as peer pressure, sanctioning or reassurance signals, which are easier achieved in regular face-to-face meeting or regularly scheduled chat room conversations. The effectiveness of E-mail communication seems to critically depend on the number of communicators and communication dynamics (i.e. at what point of time subjects engage in communication and what type of feedback they provide). The use of anonymous, sequential E-mail communication could create a challenge and an opportunity for the decentralized management of CPRs. It creates a challenge because outcomes are far less predictable than with face-to-face communication, videoconferencing and real time chat rooms. Continuous face-to-face communication and other forms of real time communications, on the other hand can be very time consuming and costly because they need to involve the majority of all CPR users that need to be at the same place (at least in virtual space) at the same time. Especially for larger groups this would be very costly and difficult to sustain. E-mail communication can work as long as a critical number of subjects signal cooperation. We need to understand what that critical number is and what the cooperation limits of E-mail communication and other forms of communication are.

E-mail communication is far less effective with detailed individual information as subjects imitate noncooperative followers with higher payoffs. The same might be true for face-to-face and chat room communication and needs to be examined in further detail. The danger of relying on any kind of communication alone to resolve social dilemmas is that it could lead to the formation of small coalitions that find it optimal to raise rather than lower effort levels. Only as coalitions reach a sufficient size will they decide to lower aggregate effort towards the cooperative outcome.

We have also shown that subjects not only imitate the most successful other players but they also care about their own payoffs and will switch strategies. Detailed information about individual decisions and payoffs, therefore, will reduce rents and payoffs, and can even lead to temporary rent dissipation. A Walrasian equilibrium with complete rent dissipation is, however, not stable and will not be sustained with a limited number of players or blockaded entry to an oligopolistic industry.

Our paper has emphasized the importance of behavioral assumptions and the stability of equilibria for making predictions about oligopoly markets and social dilemmas such as CPR games. This understanding about dynamic learning and the transition between equilibria is even more important for dynamic resources that could be driven to extinction when subjects imitate successful players and temporarily exhaust rents or even incur negative rents. Further exploration of the dynamic CPR environment with information disclosure and communication, therefore, seems to be and important extension of this research. While more precise information about individual behaviour can enhance the competition between firms in oligopoly markets it could seriously threaten the sustainability of renewable resources.

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Tables

Table 1: Experimental Design Parameters and Expected Earnings per Round at Different Group Outcomes

Number of subjects	6
Individual token endowment	15
Production function for market 1 (the CPR)	$94\sum x_i - (\sum x_i)^2$
Market 1 return/unit of output	$ 0.005
Market 2 return/unit of output	$ 0.05
Individual earnings at social optimum	$ 2.22
Individual earnings at symmetric payoff Nash	$ 1.47
Individual earnings when rents are dissipated	$ 0.75

Table 2: Asymmetric Decisions and Payoffs with Communication

n_C	x_C	x_F	X	π_C	π_F
0	0	12	72	n/a	294
1	15	11.5	72.5	322.5	282.25
2	15	10.8	73.2	312	266.64
3	14	10.5	73.5	297	260.25
4	10.5	14	70	297	346
5	8.4	15	57	376.8	555
6	7	0	42	444	n/a

Table 3: Asymmetric Decisions and Payoffs with Information Disclosure

n_L	x_L	x_F	X	π_L	π_F
0	0	12	72	n/a	294
1	15	11.5	72.5	322.5	282.25
2	15	10.8	73.2	312	266.64
3	15	9.75	74.25	296.25	245.06
4	15	8	76	270	214
5	15	4.5	79.50	217.50	170.25
6	14	0	84	150	n/a

Table 4: Expectations about Aggregate Effort, Profits and the Number of Followers (n_F)

Treatment	**Aggregate Effort (X)**	π_L **or** π_C	π_F	n_F
Baseline	72	n/a	294	6
Communication	57	376.8	555	1
Info disclosure	79.5	217.50	170.25	1
Comm.& Disclosure	70-73.5	297	260.25-346	2-3

Table 5: OLS regression of aggregate investment on treatment indicators[1]

Treatment	OLS Coefficients	SE	SE[2]
Communication	1.18	1.94	5.91
Information Disclosure	***11.13	1.94	3.254
Information and Communication	2.31	1.94	3.84
Constant	***65.27	1.37	3.23
N	180		
R Squared	0.188		
F(3,176)	10.63***		

1 The reference category refers to groups assigned to the baseline treatment.
2 Standard errors are clustered at the session level to account for within session correlation.
*** indicates significance at the 99 % confidence level.

Table 6: Mean Aggregate Investment By Treatment In 5-Period Blocks.*

	Periods		
Treatment	**1 to 5**	**6 to 10**	**11 to 15**
Communication	62.33	72.20	64.80
	3.17	1.89	3.71
Information Disclosure	73.53	77.87	77.80
	2.04	1.41	1.74
Communication and Information	64.13	67.40	71.20
	2.11	1.87	2.15
Baseline	62.20	64.20	69.40
	1.72	2.27	2.37

*Standard errors are presented under each estimated MAI.

Table 7: Heterogeneity in Communication Rounds

Group	Treatment	Average Efficiency (over all 15 periods)	First Communication	First Confirmation
B	Com & Disc.	73 %	Practice	Practice
C	Com	41 %	-----	-----
G	Com	90 %	Practice	Practice
H	Com & Disc.	48 %	Round 4	Round 7
K	Com	57 %	Round 7	Round 7
L	Com & Disc.	66 %	Round 2	Round 2

Table 8: Descriptive Statistics of Individual Behaviour

	Baseline	Communication	Info disclosure	Communication & Disclosure
Predicted Mean Contribution	12	9.5	13.25	11.67-12.25
Predicted Payoffs	294	376-555	170-218	260-346
Mean Contribution	10.64	10.8	12.31	11.07
Median Contribution	11	11	13	11
Mean Payoff	350	332	259	332
Median Payoff	343.50	315	240	331
Mode Payoff	360	444	135	270
Range of Payoffs	150-690	150-705	120-630	90-570
Frequency of rent dissipation	2.3 %	0.3 %	18.6%	2.3 %

Table 9. The Effects of Communication, Information and Contribution Dynamics on Individual Effort by Treatment

Dependent Variable: *Individual effort per period*

Independent Variables	Baseline	Information Disclosure	Communication		Disclosure & Communication	
			(1)	(2)	(1)	(2)
Constant	9.23***	12.07***	----	----	----	----
	(0.58)	(0.43)				
Trend	0.156***	0.065*	0.76***	0.70***	0.38***	0.12
	(0.05)	(0.04)	(0.13)	(0.14)	(0.11)	(0.13)
Trend Squared	----	----	-0.03***	-0.024 ***	-0.01*	0.007
			(0.007)	(0.007)	(0.006)	(0.007)
Communicator	----	----	6.13 ***	2.38*	8.13***	8.41***
in past			(1.06)	(1.32)	(0.76)	(0.89)
No previous	-----	----	8.18***	3.79**	9.15***	8.95***
communication			(0.69)	(1.46)	(0.56)	(0.80)
Number of	- - - -	----				
communicators						
=0				4.48***		0.64
				(1.47)		(0.73)
=1				----		1.91**
						(0.76)
=2				3.85**		1.96***
				(1.48)		(0.72)
=3				4.79***		-0.29
				(1.62)		(1.01)
=4				3.71***		set to zero
				(0.77)		
=5				set to zero		----
Observations	288	288	288	288	288	288
Individuals	18	18	18	18	18	18

Notes: Robust standard errors in parentheses. *** significant at 1%, ** significant at 5%, * significant at10%. All models include a random effects error structure, with the individual subject effects. The number of communicators is based on the number of individuals that have engaged in communication at least once as of that round. The observations include 2 practice rounds (16 rounds of data due to the lagged variables).

Table 10. Determinants of Changes in Individual Effort

Dependent Variable: *Change in Individual effort* ($x_{i,,0}$-$x_{i,-1}$)

Independent Variables	Baseline	Information Disclosure	Communication	Disclosure & Communication
Constant	0.062 (0.302)	-0.70*** (0.24)	- - - - -	----
Lagged Difference to Average Payoff	-0.023*** (0.004)	-0.012 (0.008)	-0.025*** (0.005)	-0.009 (0.006)
Lagged Difference to Maximum Payoff	n/a	-0.026*** (0.004)	n/a	-0.024***(0.004)
Change in individual payoff	0.005*** (0.0016)	----	0.003 (0.002)	-----
Communicator in past	n/a	n/a	not significant	-1.35*** (0.46)
No communication in past	n/a	n/a	not significant	-1.17*** (0.42)
Number of Communicators	n/a	n/a		not significant
=0			0.20 (0.30)	
=2			-0.30 (0.45)	
=4			0.42 (0.42)	
=5			-1.08* (0.54)	
Observations	288	288	288	288
Individuals	18	18	18	18

Notes: Robust standard errors in parentheses. *** significant at 1%, ** significant at 5%, * significant at10%. All models include a random effects error structure, with the individual subject effects. The number of communicators is based on the number of individuals that have engaged in communication at least once as of that round. The observations include 2 practice rounds (16 rounds of data due to the lagged variables).

Table 11: OLS regression of COV per round

Explanatory Variable	Parameter estimate[1]
(Constant)	19.44(3.36)***
Disclosure	-9.074(3.75)**
Communication	-3.387(3.76)
Com & Disclosure	-4.555(3.93)
Round	-0.29(.122)**

1 Standard errors are clustered at the session level to account for within session correlation.
, * indicates significance at the 95% and 99 % confidence level respectively.

FIGURES

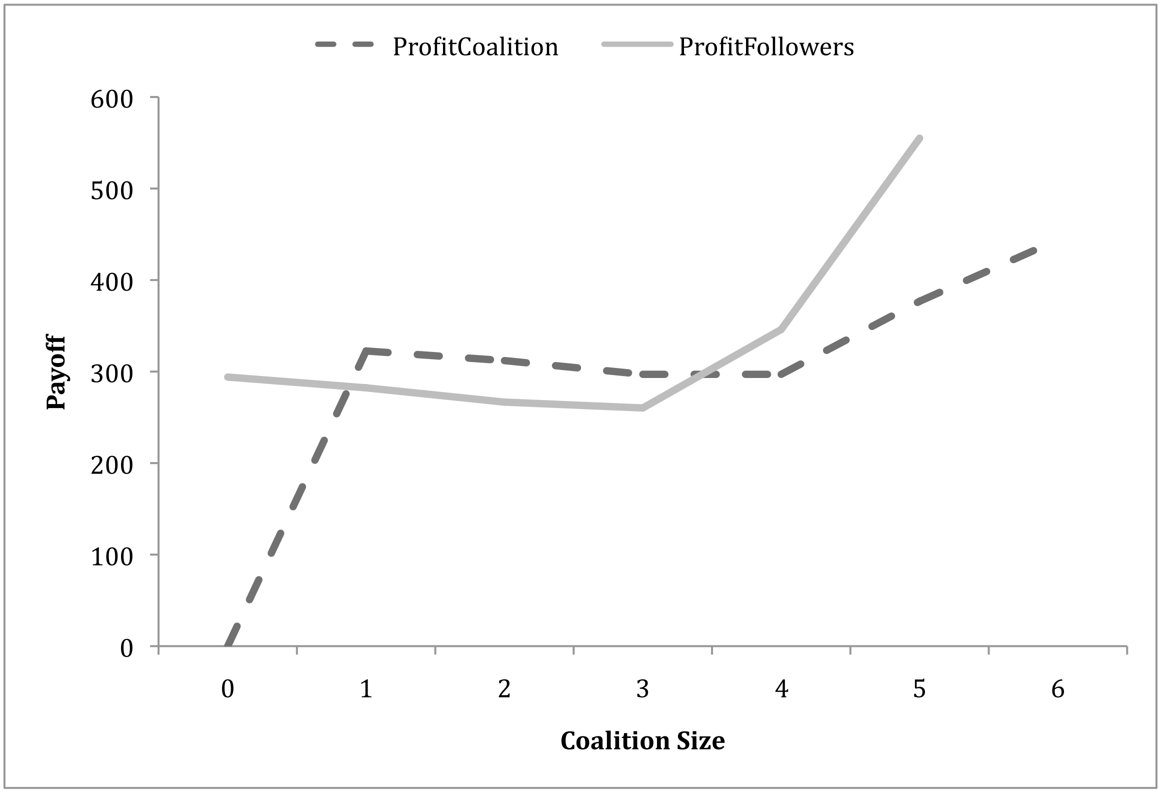

Figure 1: Payoffs for Coalition Members and Followers as a Function of Coalition Size

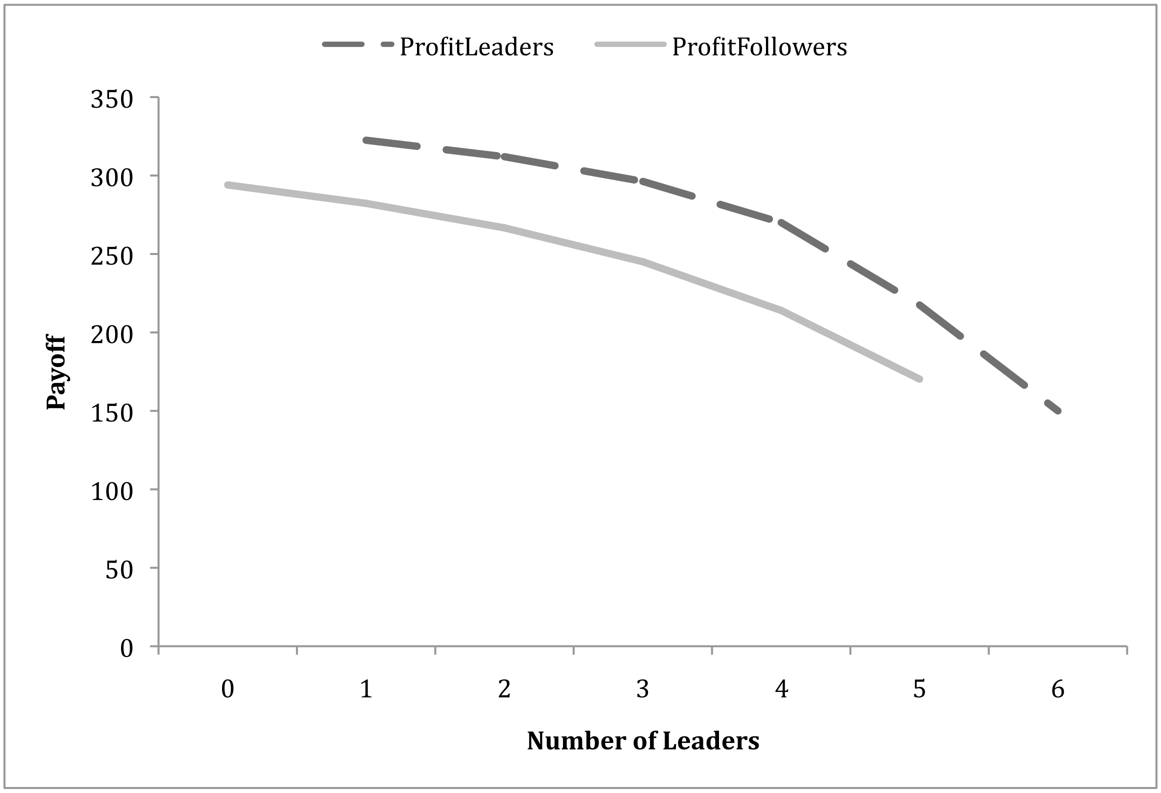

Figure 2: Payoffs for Leaders and Followers as a Function of the Number of Leaders

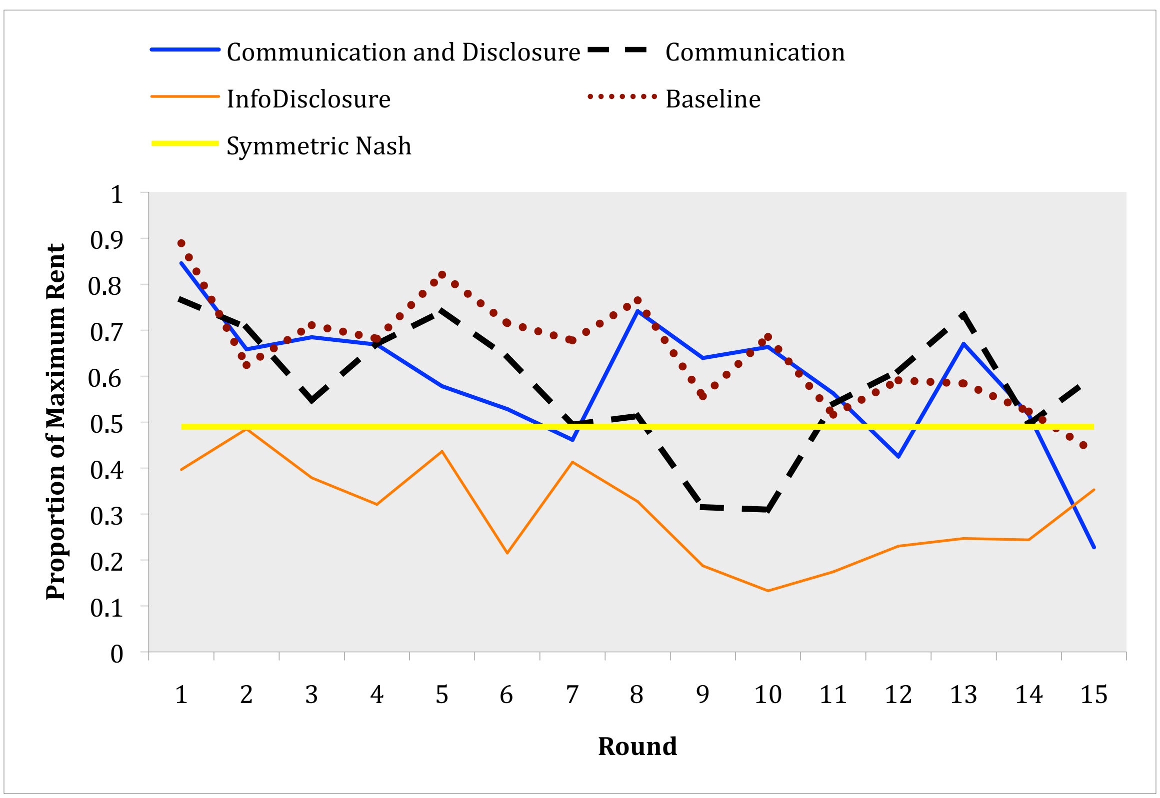

Figure 3: Efficiency as a Proportion of Maximum Rent by Treatment

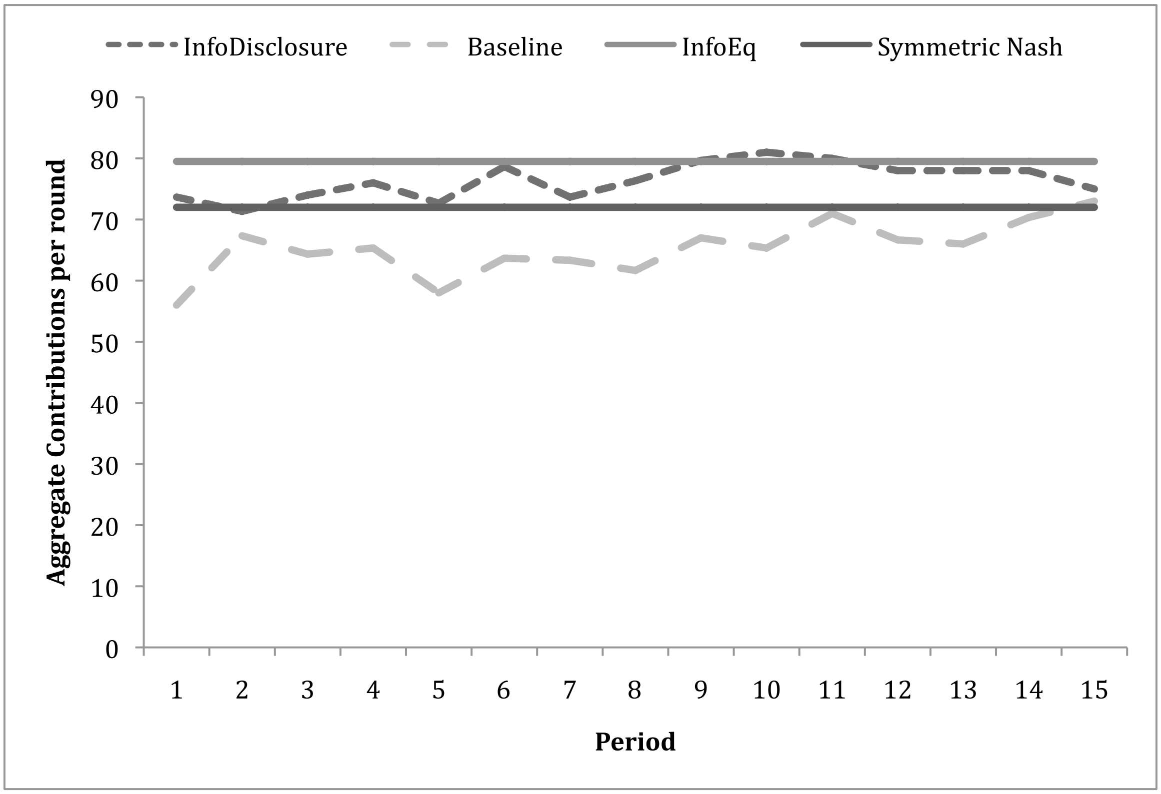

Figure 4: Predicted and Actual Aggregate Contributions with and without Information Disclosure

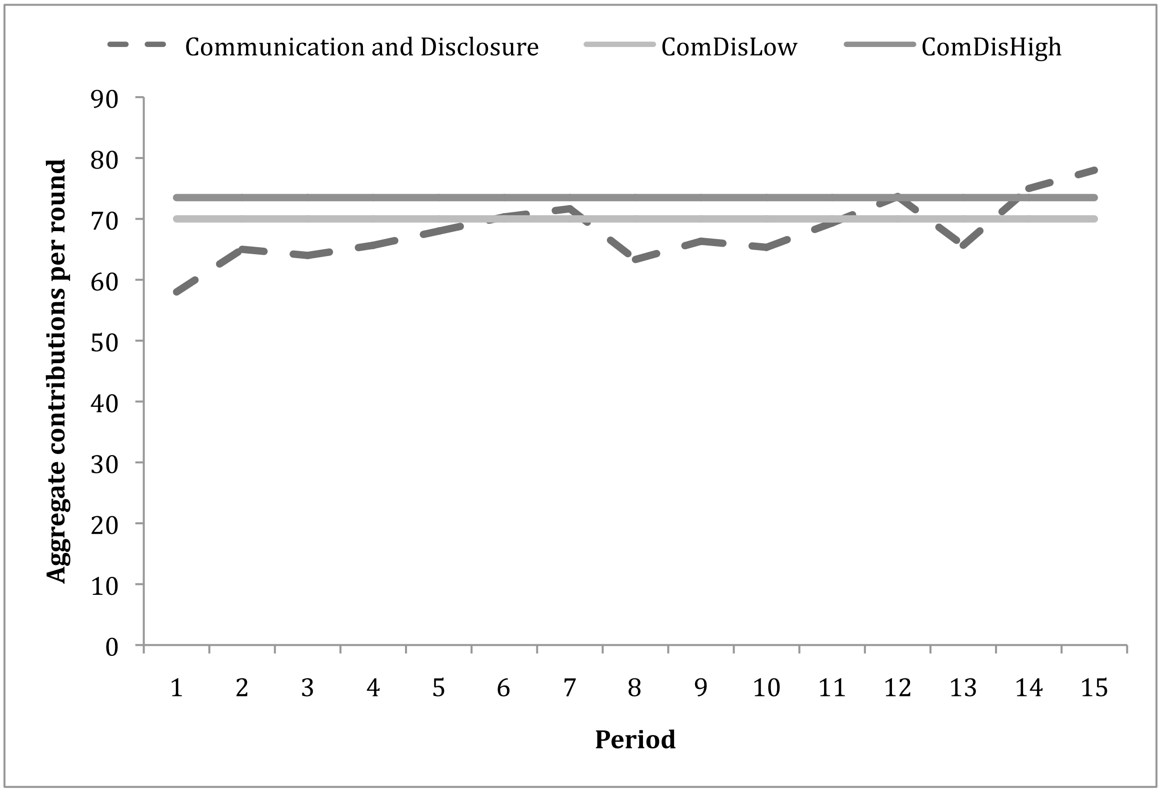

Figure 5: Aggregate Contributions with Communication and Information Disclosure versus Predicted Ranges (Low and High)

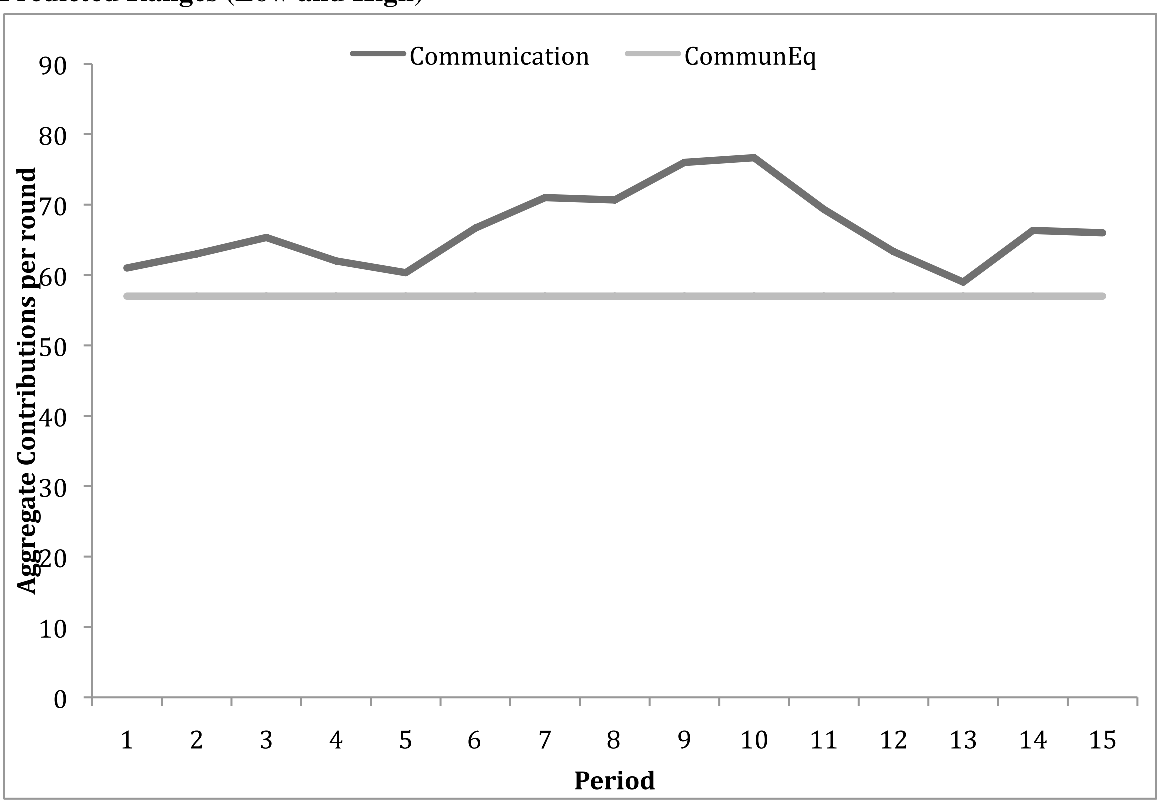

Figure 6: Aggregate Contributions with Communication versus Predicted Equilibrium Prediction

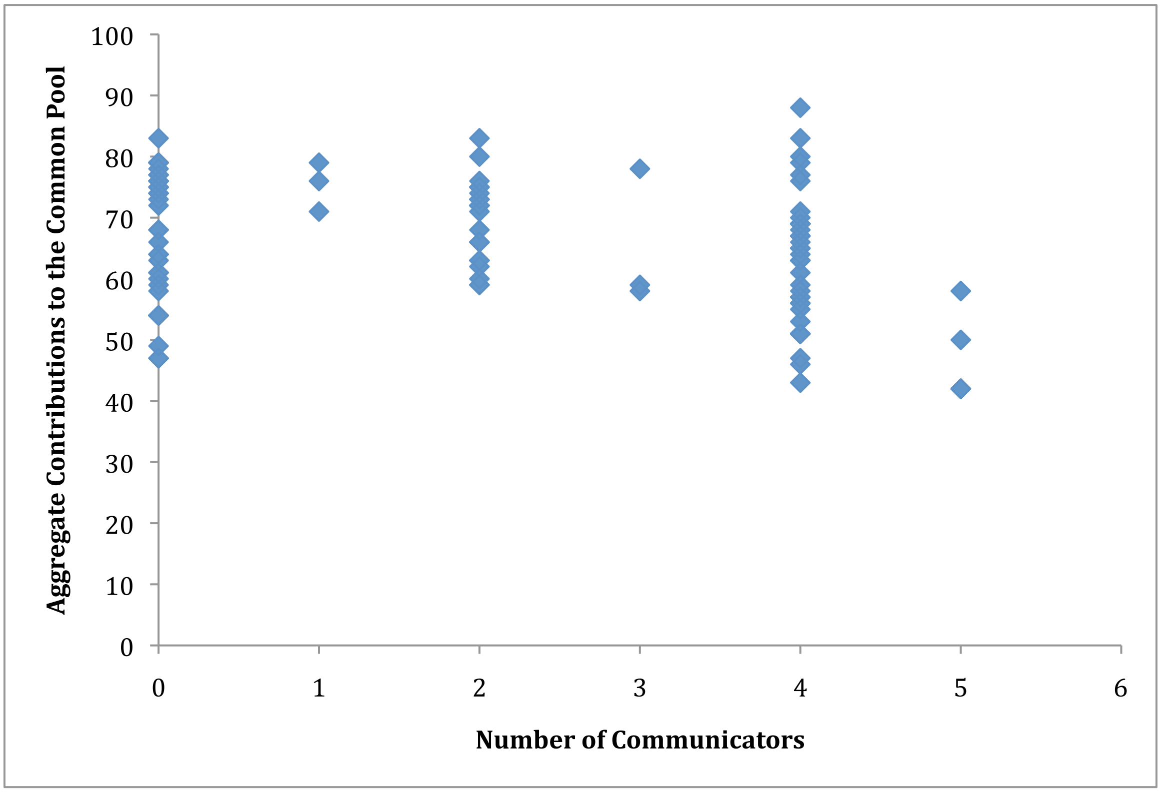

Figure 7: Aggregate Effort as a Function of the Number of Communicators

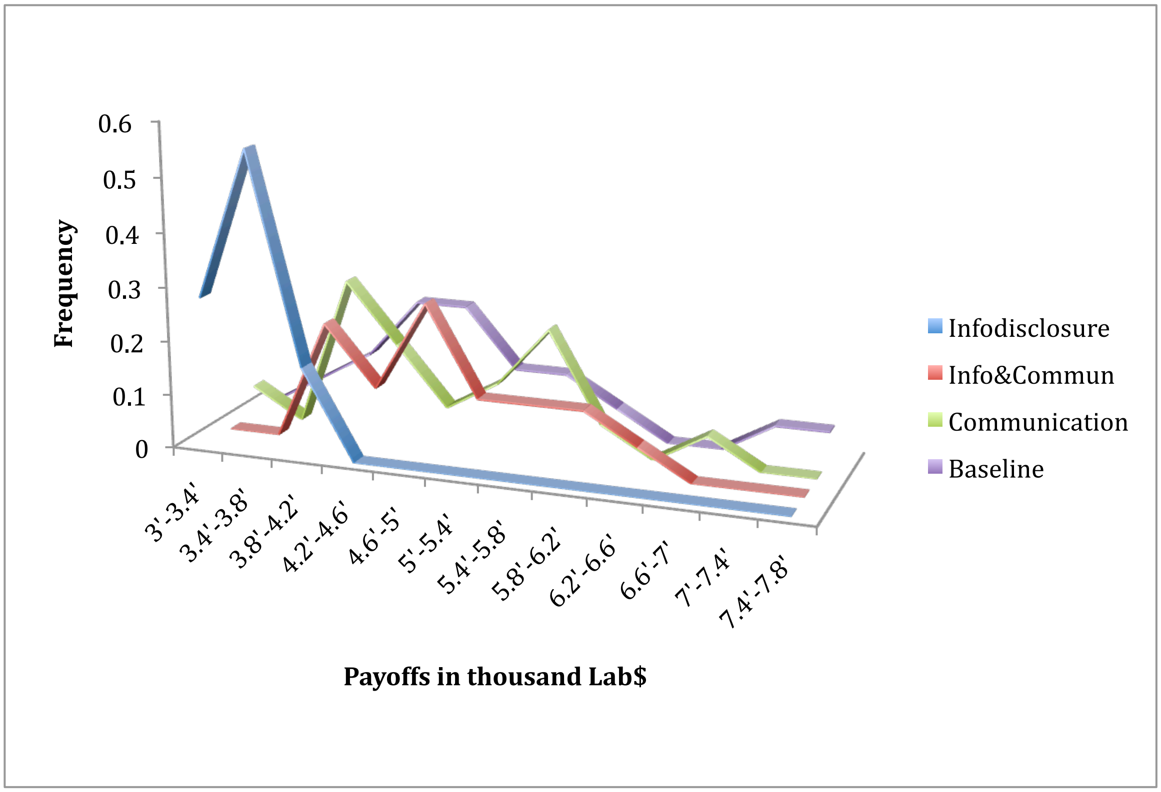

Figure 8. Individual Total Payoff Distribution (over all 15 rounds) by Treatment

APPENDIX A-Instruction Sample for Communication and Information Disclosure Treatment

Instructions

Thank you for agreeing to participate in this experiment. Essentially, you will be asked to make several economic choices and to input those choices using a WebCT site. The experiment consists of a series of 2 practice rounds and 15 rounds for which you will be paid. In each round you will receive 15 tokens to allocate between two different investment opportunities. Your earnings will be paid to you privately at the end of the 15 periods. No payment will be made for participants that do not complete all of the rounds. Should someone in your session not finish the experiment, you will be paid according to your accumulated earnings up to the round when the experiment ended. The money for the project is provided by the Social Science and Human Research Council (SSHRC).

Confidentiality

Your identity will remain private throughout the experiment. No participant will be able to link you with any specific investment decision. You will be provided with an online alias for the duration of the experiment and no participant will be able to link the alias to you outside the experiment.

The Investment Environment

You and 5 others will make decisions about investing in two different markets over 17 rounds. The first two rounds are practice rounds, designed to let you explore the environment without worrying about being paid. The final 15 rounds are paid rounds. In each round you will be provided with 15 tokens to invest in either Market A or Market B.

Market B pays you 10 tokens for every token you invest in it. Specifically, the return from Market B is: Bi = 10(15 – Xi)

Where: Bi is the return (in tokens) from Market B you (person i) will receive; and Xi is your contribution to Market A (note that because you must invest all of your 15 tokens, anything that you do not invest in Market A will automatically be invested in Market B).

In contrast, the return from Market A depends on the tokens invested by all of the 6 participants. Specifically, the return you will receive from Market A is: Ai = (Xi/X) (94X – X^2)

Where: Ai is the return (in tokens) from Market A that you (person i) will receive; Xi is the amount of tokens you invested in Market A;X is the sum of all of the tokens invested in Market A by the entire group (the total investment); andX^2 is X squared.

For a less abstract explanation of this relationship, please refer to the payoff table and calculator available on the website (see below for details).

Each round will end when the last participant has made his or her allocation decision. For this reason, we encourage participants to make their decisions in a timely fashion in order to ensure the experiment moves at a reasonable pace. At the end of 15 paid periods your accumulated Lab tokens will be converted into Canadian dollars at a rate of C$ 0.005 per token.

Using the WebCT

As outlined above, this experiment requires you to make investment decisions and to enter those decisions online using a WebCT site. Each participant has been given a specific login name and password. If you do have any problems, questions, or concerns with accessing and/or using the site, please do not hesitate to contact us (see contact information on the left). When you log on to the WebCT, you will see a brief introduction to the site and a menu of options on the left side of the screen. The menu contains nine links:

- Homepage (which is a link to the homepage of the site);
- Tips and Suggestions (a list of short explanations of various aspects of the website);
- Instructions (a link to this page);
- Example (a link to an example investment scenario)
- Calculator (a link to the calculator program)
- Payoff Table (a link to a table that summarizes the rate of return information related to Market A);
- Results (a link to a table that displays the individual investments and results for each round of the experiment that has been completed);
- Decision Environment (The link to the quiz where you will enter decisions every round);
- Contact Us (how to reach us)

Using The Calculator

The Calculator is available for download from the website. When you click on the "Calculator" link on the course menu, a table of contents screen should appear. Click on "The Investment Calculator" link to bring up a file download dialogue box. Click the "Save" button. When the Save As dialogue box appears, check the file name and make sure it reads Investment Calcultator.exe (Internet Explorer sometimes truncates the name). Once you have ensured that the file name is correct, choose where you would like to save the file on your computer and then click the "Save" button (remember where you saved the file).To use the calculator, simply double click on the icon entitled "Investment Calculator. You can use the calculator do consider the outcome of a variety of potential scenarios. When you run the calculator program, you will see a series of text windows labeled as players 1 through 6. You can enter different investments for each player and click calculate to see what you (and the others) would receive in that scenario. If you do not enter an investment for a particular player, the calculator will assume that that player has invested all their money in Market B. The calculator will not allow any individual investment to exceed 15 tokens (the maximum investment).

Email
Although you will not know the identity of your fellow participants in the real world, you will be able to communicate with them within the experiment. You can exchange email messages with the other participants in the game by clicking on the “email” link on the course menu. These messages will use your login name (stupapm24, for example). The email system is fairly simple (click on a message to read it, use the reply and compose buttons to write emails, and choose who you want to send to by clicking the browse button. There are a few rules that should be followed when using the email system:

1. Do not provide personal information (don’t share your other email addresses, real names, telephone numbers, etc.)
2. Do not send emails to people who are not participants in the experiment.
3. Do not change the email settings (this will complicate things considerably.
4. Do not delete any of your emails.

Otherwise, you may use the email as much or as little as you wish.

The Results Table
Clinking on the "Results" link will display the investment decisions and payoffs (in tokens) for each player in every round that has been completed. The table will be updated at the beginning of every round. Checking the results table allows you to see how much your investments have earned as well as how much the investments of the other players have earned.

The Decision Environment
Before making your decision in each round of the game you are free to consult the instructions, payoff table, calculator, email, and results sections of the site as often as you deem necessary. When you are ready to make your decision, follow the step-by-step instructions below.

1. Click the “Decision Environment” link on the menu on the left side of the screen.
2. When the quizzes and surveys page has loaded, click the link to the current round of the experiment (i.e. Practice Round 1, Practice Round 2, Round 1, etc.) that appears on the screen.
3. The introduction to quizzes and surveys page should now appear. Click the “Begin Quiz” button to continue.
4. A new window will open and you will be asked to answer several questions.
5. After answering a question, click the "Save Answer" button before continuing to the next question.
6. When entering your investment in Market A, remember that you have a total of 15 Tokens and that whatever you do not contribute to Market A will automatically be invested in Market B. For example, if you enter 0 in the answer box, you are investing nothing in Market A and 15 Tokens in Market B. Conversely, if you enter 15 in the answer box, you are investing nothing in Market B, and 15 tokens in Market A. Investing 5 Tokens in Market A, means that you are also investing 10 Tokens in Market B.
7. Once you have answered all the questions, and entered your contribution in the answer box, click the “Save Answer” button (this is an essential step).

8. Now, click the "Finish" button to finalize your decision. Once you have made your decision, you will not be able to make any other investment decisions until all the other participants have made their allocation decisions. You will be notified by email when the next round has begun. In the meantime, you may still refer to the payoff, history, and instructions sections of the website.