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The effect of constrained communication and limited information in governing a common resource

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Abstract: Allowing resource users to communicate in behavioural experiments on commons dilemmas increases the level of cooperation. In actual common pool resource dilemmas in the real world, communication is costly, which is an important detail missing from most typical experiments. We conducted experiments where participants must give up harvesting opportunities to communicate. The constrained communication treatment is compared with the effect of limited information about the state of the resource and the actions of the other participants. We find that despite making communication costly, performance of groups improves in all treatments with communication. We also find that constraining communication has a more significant effect than limiting information on the performance of groups.

Keywords: Common pool resource, conditional cooperation, costly communication, lab experiments, limited information

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1. Introduction

Today we possess an increased understanding of how communities can successfully self-govern their common resources. Lessons have been learned from comparative analysis of case studies, and some mechanisms which stimulate self-governance can be replicated in controlled experiments (Poteete et al. 2010). Laboratory experiments have shown the importance of communication and sanctions (Ostrom et al. 1994; Brosig et al. 2003; Bochet et al. 2006; Balliet 2010; Janssen et al. 2010). Conventional economic theory would have predicted that "cheap talk" (communication without the ability to enforce promises) and costly sanctioning (paying to reduce the earnings of others) would not have an effect. However, they have a significant effect, and this effect has been replicated in various social dilemma settings in the lab and the field (Chaudhuri 2011).

The increase of group performance due to communication has various explanations which are not mutually inclusive such as (1) formation of group identity, (2) better understanding of experimental environment and strategy, (3) better discernment of other players' type (i.e., whether others are cooperative or not), (4) voicing of mutual commitments, and (5) creation and reinforcement of norms (Ostrom 1997; Shankar and Pavitt 2002; Poteete et al. 2010).

The experiments we performed are inspired by observations from case studies of common pool resources (Poteete et al. 2010). One of the challenges in creating rules that are effective in governing common resources over the long period is to create rules that are easy to follow and easy to determine whether other resource users are also following them or not. When the costs of monitoring actions of others and the state of the resource are kept low, resource users can gain a sense of confidence in rule compliance without having to invest substantial time and effort in monitoring. When natural resources are large there can be substantial problems in monitoring. When fishers harvest fish from a large territory, there is no way that they can see what everyone else is currently doing. Many resource management systems developed by local resource users allocate space and time in such a way that authorized appropriators have some assurance that rules are being followed by others.

For example, in the Maine lobster fishery rules evolved to allocate permanent spots within a bay to specific fishers (Acheson 2003; Wilson et al. 2007). The map of those spots is common knowledge among the local resource users. If you find a pot of somebody else in your territory, this gives you the authority to challenge the owner of the pot. In irrigation systems a governance solution is to allocate certain time blocks to open their gates in a specific order (Tang 1992; Meinzen-Dick 2007). Not getting water at the specified times will mean that somebody else is collecting more water than defined, and more targeted monitoring and enforcement efforts might be implemented. Time is also used in some Alpine commons to define when an agreed-upon number of trees can be cut (Netting 1981; Stevenson 1990). After cutting the trees they are allocated into approximate equal stacks and randomly assigned to eligible households. Since trees cannot be harvested at any other date, enforcing those rules is easy since anyone who cuts at another time is breaking the rule.

In line with these observations, experiments reported in Janssen (2013) show that limiting the information to the resource users reduces the effectiveness of communication. An explanation is the large proportion of conditional co-operators in experimental studies (e.g. Fischbacher et al. 2001; Kocher et al. 2008; Rustagi et al. 2010). Reducing information that helps participants to estimate the level of cooperation by others, may affect the level of cooperation (Janssen 2013).

Experiments typically assume that communication occurs during a designated communication period without any cost to the participants, but in practice communication is not free. Attending meetings costs time and energy and can reduce the overall productivity of the resource user. For example, Brzezinski et al. (2010) analysed attendance of fishers in council meetings. The greater the distance that fishers had to travel the less frequently they participated. If communication is not free and participants have to decide to engage in communication or additional resource extraction, it is not clear whether participants will spend effort in communication. If they will do, this may indicate they anticipate gains from "cheap talk", which is defined as communication without the ability to enforce promises.

In our experiments we tested the consequences of costly communication by allowing communication and harvesting of the resource at the same time. The costs of communication might not be the same for everyone in our experimental environment since it depends on the speed in which participants type in their messages and cannot harvest resources. Participants have to make a trade-off between the benefits of communication and the benefits of collecting resources.

In this paper we will report a series of experiments with groups of resource users who experience different degrees of difficulty in communication and who derive information based on the actions of others. Note that our analysis makes use of data from earlier experiments on limiting vision of resource users (Janssen 2013), plus new data from experiments in which we included constrained communication. This allows us to test the effect of both limited information as well as constrained communication and their interactions. We will test whether communication still leads to improved performance if communication is constrained and information is limited. This may provide us insights into the role(s) of communication.

In applying the Institutional Analysis and Development (IAD) framework (Ostrom 2005) we changed the biophysical context and explored the consequences on the outcomes in the action arena. The biophysical context here affects the costs and availability of information. The biophysical context is the implementation how visible actions of others are, and whether participants can communicate and harvest resources at the same time. We found that communication still improves group performance even with increased difficulties in communication and limited information about the resource, but the level of benefit for having communication is reduced.

The next section will describe in more detail the experimental design and specific hypotheses we are testing. We will then present the results of the experiments. The paper closes with a discussion of the results and the insights we derived on the role of information and communication on governing the commons.

2. Experimental design

Our experiments are focused on understanding the effect of limited information and constrained communication on collective action in a social-ecological system. We developed our experiments within a real-time dynamic resource harvesting setting (Janssen et al. 2008, 2010). The software used for this experiment is open-source and available at https://bitbucket.org/virtualcommons/foraging/. The protocol of the experiments is available in the online appendix.

Participants in our experiments appropriate renewable tokens from a shared renewable resource environment. Each group is made up of five participants who share a 29×29 grid of cells. In the initial state, 25% of the grid space is filled with tokens, thus 210 tokens. The avatars are initially placed in the middle row of the screen with equidistant spacing between them. In order to collect a token a participant must position their avatar on the location of that token and explicitly press the space bar. Each token harvested is worth $0.02 USD. There are two treatments for the way information is presented on the screen (Figure 1). In the first situation, participants have complete information on the spatial position of tokens and can watch the harvesting actions of other group members in real time. Participants can see the total harvested tokens of all participants at the top of the screen. In the second case only the tokens and avatars within a radius of six cells can be seen. The environment outside their vision radius is depicted black. Furthermore, participants can only see the number of harvested tokens for another participant when that participant's avatar is visible and within their field of vision.

Every second empty cells have the potential to generate new tokens. The probability that a given empty cell will generate a token is density-dependent on the number of adjacent cells with tokens. The probability p_t is linearly related to the number of neighbours: $p_t=\lambda*n_t/N$ where n_t is the number of neighbouring cells containing a green token, N is the number of neighbouring cells (N=8), and (λ=0.01). If an empty cell is completely surrounded by eight tokens, it will generate a token at a higher probability than an empty cell that abuts only three tokens. At least one adjacent cell must contain a token for a new token generation to occur. Therefore, if participants appropriate all of the tokens on the screen, they have exhausted the resource and no additional token generation will occur. By designing the environment in this manner, we capture a key characteristic of many spatially dependent renewable resources. The optimum level of appropriation

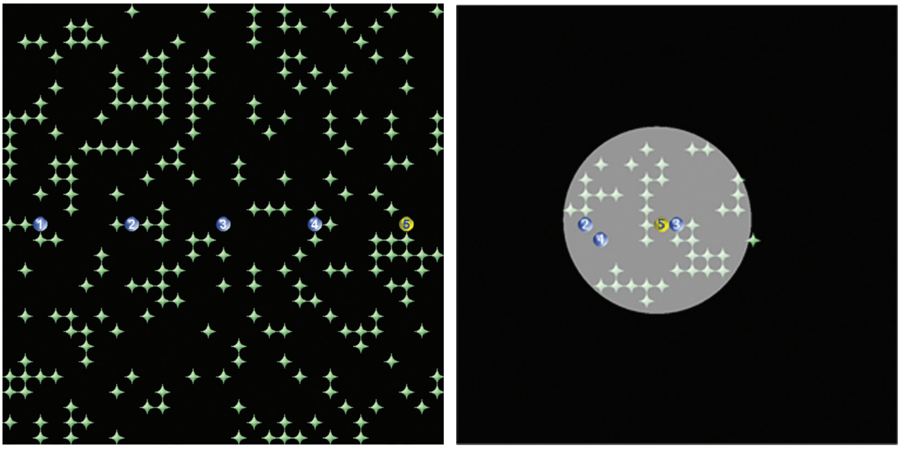

Figure 1: Screenshot of the experimental environment where participants can harvest. The green diamond shaped tokens are the resource units. The yellow avatar is the active participant; the blue avatars are the other group members. On the left is the full vision environment and on the right is the limited vision environment.

depends on the initial starting conditions, and probabilistic renewal of the empty cells. Janssen et al. (2010) estimated the optimal group level harvesting amount to be 665 tokens by the end of the session. The participants get the qualitative description of the resource dynamics and have four minutes of practice with the experiment before the experiment starts.

We had previously implemented communication as a discrete round, four minutes of free chat between group members via a chat box. We changed this so that communication would be available during the harvesting period while the participants were sharing the common resource. A chat box was placed on the screen next to the resource environment so that participants could only communicate if they stopped harvesting for a moment. When limited information (radius of six cells) was combined with constrained communication, participants could only chat with those visible on the screen.

Earlier studies showed that groups always overharvest the resource the first time they share the resource, and that allowing communication in subsequent rounds increases performance significantly (Janssen 2010; Janssen et al. 2010). In those experiments, as in the ones reported here, participants are informed on the number of periods in the experiments as well as the length of each period. When participants cooperated, the harvesting levels during the first few minutes of the experiment are lower compared to the case of rapid overharvesting. Since the duration of the period is known, and a clock shows the amount of time left, the participants harvest levels increase in the last minute of the period to collect all the tokens. Analysis of chat data did not reveal insights into specific message content leading to better performance although more equal participation of all group members did lead to better performance (Janssen 2010). In this paper we will distinguish four different environmental conditions that vary the amount of information visible and whether chat is happening before or during the harvesting period (Table 1).

In this study we want to test the following hypotheses:

Hypothesis 1. The increase of earnings in rounds of the communication is reduced if communication is costly.

Communication has been demonstrated to increase earnings in common pool experiments due to a reduction of the harvesting efforts (Ostrom et al. 1994; Janssen et al. 2010). In those experiments participants could chat online or face-to-face for a limited amount of time freely without any competing activity. If communication is not free, but is a competing activity to resource appropriation, a different outcome can be expected. In line with the principles of economics, participants have to make a trade-off between harvesting and communication. Participants may communicate less or not at all in order not to forgo harvesting opportunities. As such we may expect less communication and a smaller effect of communication rounds.

Hypothesis 2. Allowing participants to communicate will still increase performance of groups compared to no communication periods, in all four conditions.

If communication is possible but difficult all five possible mechanisms as discussed in the introduction are still possible and thus we may see an increase of performance. Since participants are expected to be more strategic with

Table 1: The four different experimental conditions that affect information observed and exchanged.

General description	Participants have a separate four minute period in which they write and read each other messages.	Participants are allowed to send messages only during the harvesting period, and when reading and writing it reduce attention from harvesting activities.
	Unconstrained chat	Constrained chat
Full vision	Four-minute chat before harvesting period. In the harvesting period participants have full information about the actions of all other participants.	Writing and reading messages occurs only during harvesting period. During harvesting period everyone can see chat messages, and everyone has full information of the actions of all other participants.
Limited vision	Four minute chat before harvesting period. In the harvesting period participants can only see resources and avatars within a radius of six cells.	Writing and reading messages occurs only during harvesting period. Participants can only receive messages of senders who are within a radius of 6 cells at the time the message is sent. Participants can only see resources avatars within a radius of six cells.

communication, the content of the communication may also reveal which kind of information is more important to the participants.

Hypothesis 3. The level of cooperation significantly drops when communication is not possible anymore after a series of communication periods.

If communication is not possible anymore after various periods of communication we typically see cooperation remains at the same level (Janssen et al. 2010). In the introduction we listed five possible explanations of the effect of communication. These explanations have a different effect on the outcomes of stopping with communication. If formation of group identity and a better understanding of the experiment were the only factors explaining the benefit of communication (and therefore the other three factors are irrelevant), we would not expect to see a change in the cooperation level. But other explanations like getting better discernment of other players' type, voicing mutual commitments and creation and reinforcement of norms are critical factors, lead us to expect a significant drop when communication is stopped. When participants cannot reinforce norms and expectations, this reduces the cooperative behaviour.

We tested eight treatments in an AB-BA, AC-CA, format in which each treatment consists of three periods of no communication and three periods where text chat communication is allowed (Table 2). We tested the effect of communication for two different orders. If communication happens in the last three periods group identity and improved understanding could explain the increase of performance. But if group identity and improved understanding are key factors due to communication, this will predict that there would be no decline of performance if communication is not allowed anymore if we start with the periods of communication.

Table 2: Experimental design. The name refers to the specifications of the experiment. For example, NC-C-LV is an experiment where participants could not chat during first 3 periods, but could chat for a few minutes before each harvesting period in the last 3 periods. The vision on the resources is limited to a radius of 5 cells.

Name	Number of groups (individuals)	Vision	Periods 1–3	Periods 4–6
NC-C-LV	6 (30)	Radius	No chat (NC)	Chat (C)
C-NC-LV	7 (35)	Radius	Chat (C)	No chat (NC)
NC-C-FV	5 (25)	Full	No chat (NC)	Chat (C)
C-NC-FV	4 (20)	Full	Chat (C)	No chat (NC)
NC-CC-LV	5 (25)	Radius	No chat (NC)	Constrained Chat (CC)
CC-NC-LV	5 (25)	Radius	Constrained chat (CC)	No chat (NC)
NC-CC-FV	7 (35)	Full	No chat (NC)	Constrained Chat (CC)
CC-NC-FV	5 (25)	Full	Constrained Chat (CC)	No chat (NC)

3. Experimental results

3.1. General statistical results

We report results from two separate series of experiments. The experiments were performed in an experimental laboratory at Arizona State University (ASU) on the Tempe campus. All participants were undergraduate students at ASU who were recruited by sending out invitations to a random sample from a database of more of 1500 potential participants. The average participant's age was 19 years old and their average earnings were 17 dollars (including a 5 dollars show-up compensation) for a one-hour experiment. The first four treatments were conducted during the 2010 spring semester, while the second batch of four treatments was conducted during the 2012 spring semester. Participants of the first set of experiments could not be invited for the second set of experiments. Participants could familiarize themselves with the experimental environment during a four minute individual round using a size of the environment equal to 20% of the group experiment. At the time of the individual round participants did not know the real experiment would be a group experiment. A detailed analysis of the first four treatments, which focused on the role of information, is reported in Janssen (2013). In this paper we focus on the role of communication in both sets of experiments.

To illustrate the dynamics of the experiment we present the average amount of tokens in the resource for the five groups in treatment NC-C-FV (Figure 2).

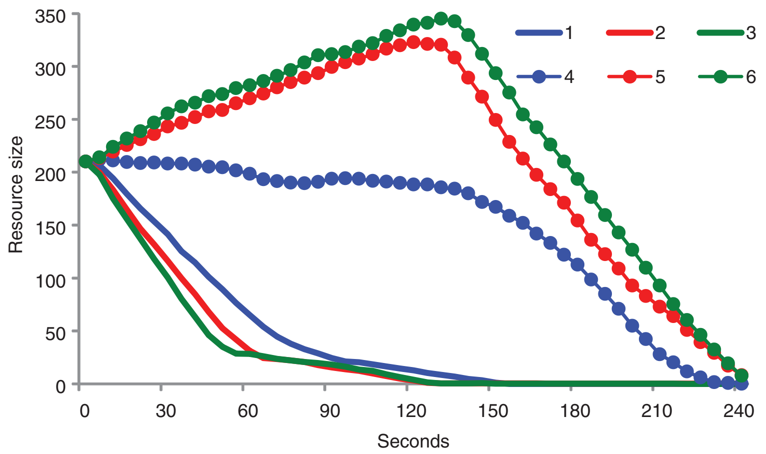

Figure 2: Resource availability at given times (seconds). The figure shows the average remaining level of the resource for the groups of 5 participants exposed to treatment NC-C-FV for the 6 periods during the experiment (numbers 1–6 in the figure refer to the periods). The treatment is a combination of two sets of three periods of a specific condition. Participants can see the whole screen (Figure 1, left) and cannot communicate during the first 3 periods. In the last three periods communication is allowed for four minutes before each period of harvesting.

Participants know the length of the period and the seconds left during a period were displayed at the top of the screen. Participants can earn more as a group if they do not harvest quickly at the beginning, allowing the resource to grow. We see that in period 1 the group depletes the resource within 150 seconds. In subsequent periods the resource is depleted more rapidly. In the last 3 periods participants can communicate for four minutes before each harvesting period. The resource is depleted more slowly after communication, and over the periods groups learn to first let the resource grow before they deplete it entirely. This led to an increase in the group earnings from 264 tokens in period 3 to 520 tokens in period 6. If we compare the first three periods we have an average of 271 tokens while the last three periods have an average of 480 tokens.

When communication is allowed the resource level stays at a higher level during the four minute period. Figure 3 shows that allowing groups to communicate leads to higher levels of tokens collected. Communication increases earnings significantly when we use the Wilcoxon Matched-Pairs Signed-Ranks test for the average of 3 periods with and without the possibility of communication of all four treatment groups ($p<0.001$). Figure 3 shows that the groups with unconstrained communication have a significantly bigger increase in earnings than those with constrained communication. Using the Mann-Whitney test on the relative increase of earnings after communication we find a significance of $p<0.01$ for FV-C compared to FV-CC and LV-CC, and $p<0.02$ for LV-C compared to FV-CC and LV-CC. No significant effects are found between FV and LV with the same type of communication. This result indicates that costly communication leads to an improvement of performance but significantly less than communication without constraints.

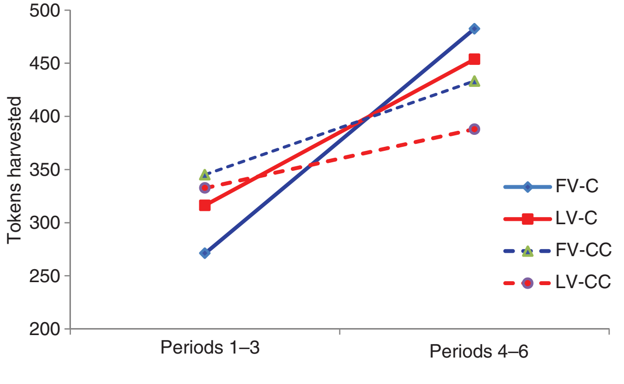

Figure 3: The average harvested tokens of the first three periods and the last three periods when groups do not communicate in the first three periods, but can communicate in the last three periods.

Groups that started with communication and then had three rounds without communication incurred a significant reduction of earnings using a Wilcoxon Matched-Pairs Signed-Ranks test ($p<0.001$) (Figure 4). There are no significant effects of decrease of performance between the four different treatments.

When participants were placed in an environment with full vision and had unconstrained communication in periods 1–3 (C-NC-FV), they earned a higher number of tokens compared to the situation where the group had no communication in periods 1–3 (NC-C-FV) ($p<0.05$ Mann-Whitney test). All other settings with or without communication, constrained or not, with limited vision or full vision, do not experience significant differences if this configuration happens in the first three or last three periods.

In Table 3 the results of a multilevel mixed-effect linear regression are presented where the dependent variable is the group level harvest of tokens. The analysis included the following variables:

- Limited vision (1 for groups if from treatment with limited vision; 0 otherwise)
- Unconstrained communication (full vision) (1 for groups who can communicate and with full vision, C-FV situation from Table 2; 0 otherwise)
- Unconstrained communication (limited vision) (1 for groups who can communicate and with limited vision, C-LV situation from Table 2; 0 otherwise)
- Constrained communication (full vision) (1 for groups who can communicate and with full vision, CC-FV situation from Table 2; 0 otherwise)
- Constrained communcation (limited vision) (1 for groups who can communicate and with limited vision, CC-LV situation from Table 2; 0 otherwise)
- Had unconstrained communication (full vision) (1 for groups in periods 4 to 6 who experienced the C-FV situation in periods 1–3; 0 otherwise).
- Had unconstrained communication (limited vision) (1 for groups in periods 4 to 6 who experienced the C-LV situation in periods 1–3; 0 otherwise).
- Had constrained communication (full vision) (1 for groups in periods 4 to 6 who experienced the CC-FV situation in periods 1–3; 0 otherwise).
- Had constrained communication (limited vision) (1 for groups in periods 4 to 6 who experienced the CC-LV situation in periods 1–3; 0 otherwise).
- Had no communication (1 for groups in periods 1–3 when communication is not allowed; 0 otherwise).
- Learning (communication) (1 for first period when communication is allowed, 2 for second, and 3 for third; 0 otherwise).
- Learning (no communication) (1 for first period when communication is not allowed, 2 for second, and 3 for third; 0 otherwise).

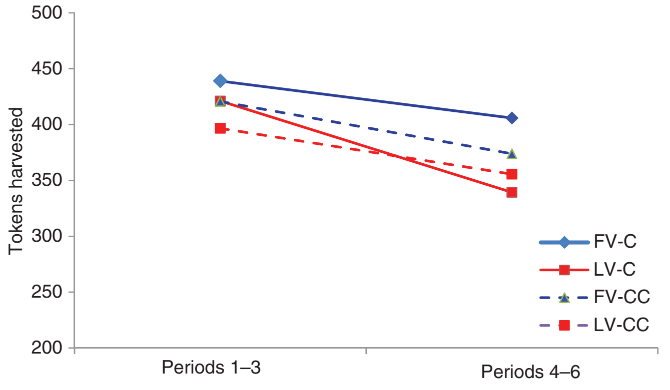

Figure 4: The average harvested tokens of the first three periods and the last three periods when groups can communicate in the first three periods, but cannot communicate in the last three periods.

The effects of the treatments are compared to the situation of no communication with full vision during the first three periods. This is the default setting. Unconstrained communication and full vision have a strong significant effect. Periods with unconstrained communication and full vision have 84 more tokens on average than the default situation. When a group was allowed in periods 1–3 to have unconstrained communication with full vision the harvest is 129 tokens higher in periods 4–6 when communication is not allowed anymore compared to the default situation. Another significant effect was in the periods where groups experienced constrained communication with full vision. Note that we did not find any significant effects of limited vision.

When we look at learning effects, we find a significant reduction of earnings in the no communication periods. Every period without communication leads to an average reduction of 21 tokens. Communication has a positive effect over the periods as each period with communication corresponds with an increase of 22 tokens.

When participants have unconstrained chat they send an average of 45 messages per group per period if they chat in periods 1, 2 and 3 (Figure 5A). If groups first experience three no communication periods, they exchange more chat messages, 54 messages per group per period, a significant increase ($p<0.1$ using a Mann-Whitney test on the cumulated number of chat messages per group). When participants are constrained in their communication, there is a dramatic reduction of chat messages (Figure 5B). On average there are 7.5 messages in the first three periods and 11 messages in the last three periods. This is a significant higher level of communication when this happened in the last three periods ($p<0.05$ using a Mann-Whitney test).

Table 3: A multilevel mixed-effects linear regression is performed with the gross number of tokens that groups collected for each period. The independent variables are dummies indicating the treatment differences: unconstrained communication or not, full or limited vision, past experiences with communication, and learning (periods 1, 2 and 3 will have dummies 1, 2 and 3, same for periods 4, 5 and 6). If we mentioned a dummy like "had X" we mean a dummy with value 1 in periods 4–6 if X happened in periods 1–3. The values between parentheses are standard deviations.

	Harvest
Constant	**353.548*** (19.217)**
Limited vision	13.900 (21.439)
Unconstrained communication (full vision)	**84.218*** (26.864)**
Unconstrained communication (limited vision)	22.80 (25.900)
Constrained communication (full vision)	–6.630 (25.942)
Constrained communication (limited vision)	–42.184 (26.788)
Had unconstrained communication (full vision)	**129.462*** (27.226)**
Had unconstrained communication (limited vision)	24.675 (24.085)
Had constrained communication (full vision)	**43.161* (25.373)**
Had constrained communication (limited vision)	8.160 (26.157)
Had no communication	21.075 (18.796)
Learning (communication)	**22.568*** (4.927)**
Learning (no communication)	**–20.670*** (4.927)**
N	264
Log Likelihood	1436.797
Wald χ^2	364.55 ($p<0.001$)
χ^2	120.69 ($p<0.001$)

*p<0.1, **p<0.05, ***p<0.001.

What can be said on who is sending chat messages and what is the impact on their earnings? We do not find any statistical significant effect (using 2-tailed Mann-Whitney tests) between participants who send messages during the experiment when still tokens are on the screen, and those who do not send messages. Note that we don't include the situation when participants are chatting when no resources are left as this does not include a social dilemma situation. Hence we have no evidence that those who communicated gave up a significant level of earnings relative to those who did not communicate.

What can explain the higher volume of chat messages in periods 4–6 compared to periods 1–3? Participants that have experienced resource collapse three periods in a row understand what it means to be trapped in a tragedy of the commons and are eager to chat when they get the opportunity. When they have the ability to communicate at the start of the experiment, they may have less motivation to do so. However, this lower volume of chat messages still leads to a significant increase in earnings.

The chat data shows that there is a significant reduction in the communication volume when communication is constrained. The smaller increase in group performance with constrained communication confirms hypothesis 1.

We investigated the content of the chat by coding each period (Tables 4 and 5). We evaluated each period to determine whether there was coordination

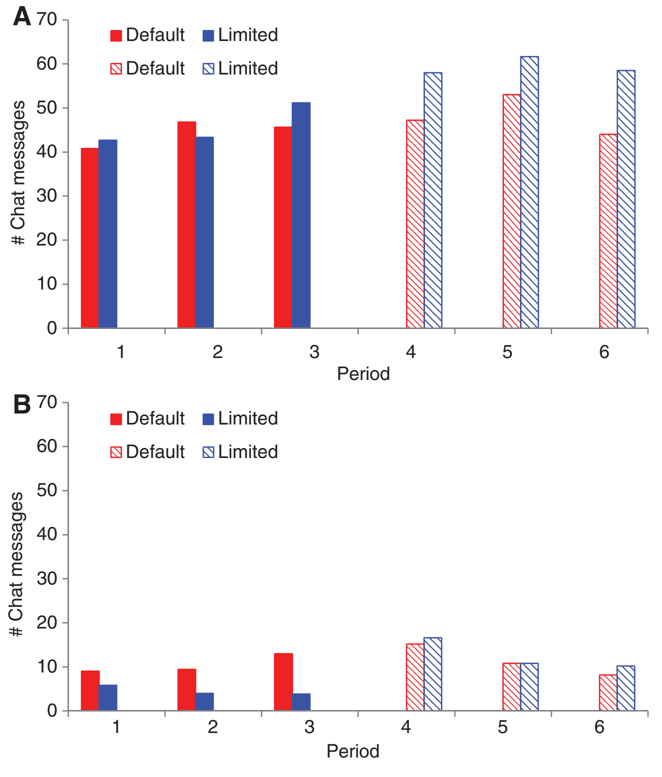

Figure 5: (A) The average number of chat messages in experiments in treatments with unconstrained communication. (B) The average number of chat messages in experiments in treatments with constrained communication.

within the group (when, where and how to harvest), a commitment or confirmation ("yes, we need to split the resource in equal parts," a normative statement ("everybody should wait the first minute"), statements that create a group identity ("if we work together we all will win"), or statements that explain the experiment ("if you eat a single token, it will not grow back"). We only did this classification for constrained communication, since in groups with unconstrained communication all types of comments were used since they could chat for three times four minutes and all classifications were found in almost all the groups. Hence our classification was not meaningful for the unconstrained communication experiment. Each type of comment was made by about half the groups (who could communicate with constraints). We could not find a pattern in the data that could explain why some groups increase their performance more than others. If we look at the number of chat messages we also do not see a pattern.

Table 4: Analysis of chat data for experiments that experienced constrained communication in periods 1–3. The order of the rows is based on the harvesting level during the first 3 periods. The first two columns represent the average harvest per period for the first three periods (P1-3) or last 3 periods (P4-6). The third column represents column 2 divided by column 1. The fourth column indicates whether the participants had full vision (FV) or limited vision (LV). The fifth column depicts the number of chat messages over 3 periods. The last 4 columns indicates whether in the content of the communication participants explain the game, commit to certain actions, establish norms or try to create a group feeling.

P1-3	P4-6	Change	Vision	#chat	Coordination	Explain	Commit	Norm	Group
352	270	–23%	LV	9	X	X		X	X
427	335	–22%	LV	8	X				
361	283	–21%	FV	22	X	X	X	X	X
304	268	–12%	FV	0					
470	415	–12%	FV	14	X	X	X	X	
411	367	–11%	LV	45	X		X		
402	363	–10%	LV	3					
528	498	–6%	FV	90	X	X	X	X	X
440	431	–2%	FV	21	X		X		
391	444	+14%	LV	3	X	X			

So, why is it that the number of chat messages and the type of comments do not fully explain the outcomes? If participants are conditional cooperators and intend to cooperate, not much communication is needed to coordinate their actions. However, if participants have different goals or expectations, communication may facilitate agreements among group participants, or enflame disagreements between participants. Hence the type of communication depends on the composition of the group. Differences in personalities will lead to different intentions and actions and different effects of the communication.

Just the fact that participants can communicate leads to a better performance and how communication is used depends on the context of the group. Will they use it to explain the instructions of the experiment, when some participants have some difficulty with the instructions? Will the group initially not communicate but at the end of the period when the resource is depleted start chatting on how to improve the performance? Will group members voice their intentions ("SHARE") etc.?

To illustrate the complexity of quantifying the communication patterns we provide below all 14 messages in the best performing group of Table 5 where the average harvest goes from 325 in period 1–3 to 524 in periods 4–6. The number in parentheses refers to the number of seconds into the period in which the message was posted. We have not recorded the time participants took to type in messages. We see that in the beginning of period 4 three of the five participants voice statements to cooperate, and confirmation to do so ("yeah sharing is awesome!") and create a group identity ("if we wait we can all get more"). In period 5 we see this reinforced with some normative statement ("we should share more"). Note that the participants are not very specific about how they will cooperate, nor do

Table 5: Analysis of chat data for experiments that experienced constrained communication in periods 4–6. The order of the rows is based on the harvested tokens during the last 3 periods. The first two columns represent the average harvest per period for the first three periods (P1-3) or last 3 periods (P4-6). The third column represents column 2 divided by column 1. The fourth column indicates whether the participants had full vision (FV) or limited vision (LV). The fifth column depicts the number of chat messages over 3 periods. The last 4 columns indicate whether in the content of the communication participants explain the game, commit to certain actions, establish norms or try to create a group feeling.

P1-3	P4-6	Change	Vision	#chat	Coordination	Explain	Commit	Norm	Group
326	341	+4%	FV	31	X	X	X		
338	356	+6%	LV	45	X		X	X	X
301	328	+9%	LV	55	X	X	X	X	X
291	321	+10%	FV	52	X	X	X		X
383	428	+12%	FV	20	X			X	X
422	481	+14%	FV	33	X	X	X	X	X
322	370	+15%	LV	34	X	X			X
397	475	+20%	LV	23	X		X	X	X
305	411	+34%	LV	25	X		X		
350	485	+39%	FV	28	X		X	X	
319	451	+41	FV	22	X	X	X		
325	524	+61%	FV	14	X		X	X	X

they make explicit statements. The fact that the majority of the group signals cooperative behaviour (and give up harvesting to write this message) may make these statements convincing.

- **Period 4:**
- Player 3: WAIT!!!!!!! (4)
- Player 4: please share crop (7)
- Player 4: everyone stop (12)
- Player 4: ok only take when there are others (23)
- Player 4: if we wait we can all get more (31)
- Player 1: yeah sharing is awesome! (32)
- Player 1: just give them time to come back (40)

- **Period 5:**
- Player 1: share! (4)
- Player 3: SHARE! (5)
- Player 5: wait for them to regenerate (6)
- Player 4: we should share more money take them all in the last 30 (14)
- Player 2: yessir/ma/am lol (16)

- **Period 6:**
- Player 3: same plan (2)
- Player 2: let tem regernerate!!!!! (39)

Tables 4 and 5 provide an overview of the communication quantity and content of each group, and are ordered in the relative change between periods with and without communication. When groups start with communication we see coordination in almost all groups and less of the other four roles of communication. The group with the lowest performance does not chat at all, while the group with the highest performance has the highest number of chat messages. Both are in the full vision treatment, and this illustrates that vision on average does not have an impact. However, full vision seems to be more polarizing in the outcomes. The groups with low vision all have similar performance independent of the content and amount of communication. Groups with the lowest performance in periods 1–3 also have the largest decline in performance when communication is no longer possible.

Groups that start with three periods without communication all chat when communication is enabled and coordinate. They also make commitments frequently. Groups with low performance in the periods with communication often spend their communication time explaining the experiment. The lowest performing groups with constrained communication have many chat messages, as they also have more time to chat after they have depleted the resource during the period. We see in best performing groups a combination of commitment and norm sharing. Normative statements are less frequent in low performing groups.

The individual group results lead to some qualitative insights but it is important to realize the complexities of the communication analysis. Individuals can make normative statements but this norm might not be adopted or understood by others. Individuals can explain the experiments to others, but this might not help the understanding of others. Hence, we only measure the information exchange and observe the behaviour. We cannot determine how the information is processed. Nevertheless, the qualitative analysis shows that there is a combination of factors playing a role in the effectiveness of communication. In high performing groups, there is frequently a combination of normative statements and expressions of commitment. This suggests that reinforcement of normative behaviour is important in the effectiveness of communication.

4. Discussion

One of the persistent findings of behavioural economics on social dilemmas is the high frequency of conditional cooperation observed in experiments (e.g. Fischbacher et al. 2001; Kocher et al. 2008; Rustagi et al. 2010). If cooperation is conditional, we should expect that cooperation varies with the ability to receive the information necessary to determine whether the conditions for cooperation have been met. If information becomes more difficult to derive, this may affect the expectations participants have about others.

In this paper we presented the results of a series of experiments where we manipulated the information available to resource users and the constraints in communication among the group members. We find that constraining communication has more effect on the harvesting levels in comparison to limiting the information derived from observation. Combining both limited vision and constrained communication has the worst performance, while full vision and unconstrained communication has the best performance.

Can we explain the major effect of constrained communication? First, the amount of chat messages is dramatically lower when communication is constrained. Just the reduction of the volume of information might explain the lower performance. Additional analysis on the content of the chat messages suggest that all groups do coordinate their actions, but high performing groups typically combine normative statements and confirmative statements. The positive effect of communication on cooperation seems not to be explained by communication as ways to explanation the experiment or develop a group identity.

Our analysis confirms that communication increases group performance in commons dilemmas, even if communication is costly. Being able to express normative statements and commitments might be effective if the group consists of conditional cooperators. Participants that are willing to sacrifice harvesting opportunities to express their commitments are sending costly signals for cooperation. A lack of communication may indicate that others are not willing to give up harvesting to communicate and provides some information on the behavioural types of the other actors.

Although the experiments were performed in highly controlled and abstract settings with financial rewards, they provide some insights in the conditions for self-governance of the commons (Ostrom 1990). The results illustrate the importance of information due to direct observation and/or communication. The harder it is to obtain information, the more difficult it is to derive cooperative outcomes. The biophysical context can limit the information, but rules can be developed to overcome some of those biophysical constraints.

We also derived some better understanding on why communication is effective in stimulating cooperation. Our experimental results raise the hypothesis that communication may have a positive effect on cooperation due to its ability to derive information on the motivations of other participants, which should be tested in future studies. There might be various ways to do this, including making specific plans, voicing commitments, or giving up resources to communicate. Conditional cooperators are likely affected by communication (affecting expectations), while pure altruists and egoists will by definition not be affected by communication. Future research may focus on whether and how motivations and expectations of participants are affected by communication.

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