Communication and heterogeneity in a commons dilemma: an experimental approach

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Heterogeneity is considered harmful for cooperation in common-pool resource extraction. In this study, we focus on the heterogeneity of users and communication, among the factors related to the success that are organized as Ostrom's enabling conditions. We use laboratory experiments to separately identify the effect of different formats of communication in a commons dilemma with user heterogeneity. This paper modifies the standard common-pool resources (CPR) game to represent the situation where two groups of users with different utility functions are spatially linked in the CPR. An example of this situation would be an upstream community that appropriates a river's water resource, which results in a change in the quantity or quality of the river, through pollution or extraction, to the downstream community that also utilizes the river. We will test the effect of communication in this environment.

Keywords: Common-pool resource, Communication, Heterogeneity, Spatial externality, Social preferences

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1. Introduction

The commons dilemma is a situation where a group of individuals jointly use a resource, and an individual's rational decision to utilize the resource is sub-optimal from the perspective of the group. In some cases, there may be more than one group of users who appropriate a resource, and in particular a situation can be convoluted when one type of use may unilaterally affect the other type of users. For example, groups of users can share a water resource in a river with upstream use affecting downstream use. An international conflict of this kind is seen between India and Bangladesh or between Malaysia and Singapore. These cases are attributable mainly to a spatial linkage, but it can be easily applied in a temporal context; a resource use at one time can affect the resource use for the subsequent times, but the subsequent use cannot affect the preceding use. A similar situation can result from a difference in usages such as a resource that is the target for both capturing and watching.

In this paper, we develop a model to analyze cooperation in this heterogeneous setting and test it using laboratory experiment. We are interested in understanding how such heterogeneity affects resource extraction, and in particular whether the group who negatively affects the other group's use changes their extraction rate as a result of knowing the adverse effect of their own extraction. Furthermore, building upon the literature that communication improves cooperation in a homogenous setting, we examine how communication can improve cooperation under the heterogeneous environment.

Typically, the heterogeneity in endowment and parameters has been implemented in both public goods and common pool resource games (Brick, Visser, & Hoven, 2015; E. Buckley & Croson, 2006; Chan, Mestelman, Moir, & Muller, 1999; Hackett, Schlager, & Walker, 1994; Robbett, 2016). Their results show a mixed evidence on whether the heterogeneity increases cooperation. For example, some studies found that the heterogeneity in endowment did not necessarily cause collective actions to fail, nor did it reach social optimum (E. Buckley & Croson, 2006; Chan et al., 1999). In a certain PG environment with the heterogeneity in both endowment and parameters aggregate contributions even increased (Chan et al., 1999).

The robustness of communication in a heterogeneous PG or CPR game has been also tested. While there is some evidence that communication can hinder cooperation when the heterogeneity is introduced in a difference in both endowment and parameters (Chan et al., 1999), the previous studies generally show its positive impact on cooperation even in a heterogeneous setting (Brick et al., 2015; Hackett et al., 1994; Robbett, 2016). This also held in asymmetric commons dilemmas, in which the decision to provide public infrastructure related to the use of a resource followed by the decision to appropriate the resource was made in a spatially dynamic environment (Janssen, Anderies, & Joshi, 2011).

The heterogeneity we consider in this study more generally corresponds to third party externality, where one's behavior affects someone else outside who cannot make any decision. The third-party externality calls for social preferences because those who can affect feel bad about those who get affected especially in the case of negative externality. The idea has been incorporated in a few games. The public goods contribution with the transfer from the outsiders is no better than without such mechanism (Blanco, Haller, & Walker, 2018). The proximity was found to be an important factor to have social preferences to play a part in contribution (Delaney & Jacobson, 2014). It was observed that people are more willing to incur a cost to avoid imposing a larger negative externality than a smaller or positive when it aligns with their incentives in a coordination game (Bland & Nikiforakis, 2015). The effect of an interested third-party's sending a message in a conflict game has been confirmed, and the third-party's incentive behind the message did not affect the decision of the people inside (Evdokimov & Garfagnini, 2017).

Our study is different from the previous studies in that we are interested in the effect of social preference brought about by the heterogeneity on resource appropriation of the privileged. The studies on the type of the heterogeneity we are concerned about are limited, because we do not treat those who are not privileged rather disadvantaged as a complete third party. They are disadvantaged but they do make a decision on their own resource appropriation unlike the previous studies on the third party externality except the one that considered it in a conflict game (Evdokimov & Garfagnini, 2017).

Our study also advances the literature on the effectiveness of communication. We test the effect of communication in the environment that has never been considered but reflects prevalent real-world situations. Many common pool resource appropriation involves unequal access to the resource due to various constraints such as geographical characteristics, spatial, temporal, and different usages. The effectiveness of communication (Balliet, 2009; Ostrom, 2006) needs to be tested in a more rigorous environment to infer practical implications as it can be hindrance in some situations (N. J. Buckley, Mestelman, Muller, Schott, & Zhang, 2017). To examine how communication in a heterogeneous setting can be different from the one in a homogeneous case we break down the effects of communication into two dimensions: local or global and one way or two way.

The reminder of this paper is organized as follows. The next section describes our model and its predictions. The following sections present experimental design and the results. The final section discusses the implications of the results and concludes.

2. Methods and materials

2.1. Common-pool resource extraction among heterogeneous users

This paper modifies a standard common-pool resources (CPR) game the previous studies on CPR relied on (Hackett et al., 1994; Ostrom, Walker, & Gardner, 1992; Walker, Gardner, & Ostrom, 1990). We then adopt a model of spatially linked CPR to represent the heterogeneity, in which one group's appropriation of a resource reduces the other group's enjoyment of the resource (Libecap & Wiggins, 1984; Sanchirico & Wilen, 1999, 2005; Schnier, 2009). A way of spatial linkages among patches of CPR can take various forms. While patches can be fully interconnected, allowing a mobility of a resource in all patches in both incoming and outgoing directions, the mobility can be restricted with a particular direction in some patches, describing a sink-source relationship, in which a patch is devoted to either receiving or sending a migrant resource. While in the model of spatially linked CPR the focus is on the distribution of efforts across multiple patches under different linking environments, our heterogeneous setting allows users only to appropriate a particular, single patch that either affects or is affected by the use of the other patch. Although our base model is structured in the context of spatial connectedness, our conclusions equally apply to temporal constraints as well as a difference in usages as discussed above.

We now elaborate on our model. A fixed number of individuals, *N*, with access to a resource in a community are partitioned depending on where they appropriate or for what purpose. To simplify we allow two subsets $j = 1, 2$, and denote the players in one group as $i = 1, 2, \ldots, M$, and the players in the other, $i = M + 1, M + 2, \ldots, N$. A player does not make a choice on which group to belong to, rather the assignment of groups is exogenously determined. Each individual is given an endowment *e* that can be devoted to appropriating the CPR or the outside alternative. The outside opportunity earns a sure amount *w* while the yield from the CPR depends on the own investment as well as the investment by the others. Let x_{ij} denote an individual *i*'s appropriation to the CPR in group j with $0 \leq x_{ij} \leq e$ and $X_j = \sum x_{ij}$ the aggregate level of appropriation at each group. The production function for the CPR is given as $F_j(X_j, X_{-j})$, which is assumed to be concave in X_j with $F_j(0,0) = 0$, $\partial_{X_j} F_j(0,0) > w$ and $\partial_{X_j} F_j(me, 0) < 0$ for each group. In particular, in our heterogeneous setting the effect is one-directional; an increase in appropriation at group 1 decreases the return from an appropriation at group 2, but not vice versa. This can be described by having $\partial_{X_{-j}} F_j(0, X_{-j}) < 0$ for group 2 but $\partial_{X_{-j}} F_j(0, X_{-j}) = 0$ for group 1.

As in the standard CPR model, we assume the following quadratic function:

$$F_j(X_j, X_{-j}) = (\alpha_j - \delta_j X_{-j} - \beta_j X_j) X_j$$

where δ_j controls the degree of interdependence between the appropriation at two groups. To reflect the previous description we impose $\delta_1 = 0$ and $\delta_2 > 0$. The profit function for each individual is:

$$\pi_{ij} = w(e - x_{ij}) + \frac{x_{ij}}{X_j} F_j(X_j, X_{-j}),$$

to be maximized subject to the endowment constraint. Assuming a symmetric, noncooperative game, we can derive a Nash equilibrium with each appropriating x_{ij}^* as follows:

$$x_{i1}^* = \frac{\alpha_1 - w}{\beta_1(M+1)},$$

and

$$x_{i2}^* = \frac{(\alpha_2 - w)\beta_1(M+1) - \delta_2 M(\alpha_1 - w)}{\beta_1\beta_2(N-M+1)(M+1)}.$$

The solution to x_{i1}^* is analogous to the standard, homogeneous case as $\delta_1 = 0$. Our design adds the other disadvantaged group as heterogeneity. The aggregate appropriation at the social optimum for each group is given by:

$$X_1^{OPT} = \frac{2\beta_2(\alpha_1 - w) - \delta_2(\alpha_2 - w)}{4\beta_1\beta_2 - {\delta_2}^2},$$

and

$$X_2^{OPT} = \frac{2\beta_1(\alpha_2 - w) - \delta_2(\alpha_1 - w)}{4\beta_1\beta_2 - {\delta_2}^2}.$$

This implies that from an individual perspective there is no reason for group 1 to consider the existence of group 2, but from the entire community perspective group 1 should consider how their behavior affects group 2 as well as group 2's production function in general.

In the parametrization used (Table 1), the individual effort level at Nash equilibrium for Group 1 multiplied by the number of players in the group exceeds the aggregate effort level at social optimum. On the other hand, for Group 2 the individual effort level at Nash equilibrium multiplied by the number of players in the group is lower than the aggregate effort level at social optimum. This reflects the situation, where downstream users' effort level is constrained by the excessive use of the resource by upstream users and when from the social perspective upstream users' usage should be limited to allow downstream users' extraction, whether upstream users alter the behavior for the existence of downstream users is the question we ask in this study. It should be also noted that the upstream users' group optimal (when the downstream users are absent) is greater than the aggregate effort level at social optimum for Group 1.

Table 1. Parameters

Number of players (*N*)	8

Number of players in Group 1 (M)	4
Endowment (e)	14
Production function for Group 1	$(11 - 0.2X_1)X_1$
Production function for Group 2	$(14 - 0.25X_1 - 0.2X_2)X_2$
Per-unit return from the outside alternative (w)	1
Individual effort level at Nash eq. for Group 1 (x_{i1}^*)	10
Individual effort level at Nash eq. for Group 2 (x_{i2}^*)	4
Group effort level at social opt. for Group 1 (X_1^{OPT})	15
Group effort level at social opt. for Group 2 (X_2^{OPT})	20

2.2. Experimental design

Our experimental design is in two-fold: user heterogeneity and communication. The baseline setting is either homogeneous (Group 1 only) or heterogeneous (Group 1 and 2) with no communication and various communication treatments are introduced in the latter part of the experiment in each setting (Fig. 1). All the parameters presented in the heterogeneous environment are identical in the homogeneous environment except that N coincide with M to be 4. Communication is local when it includes the same user type only and global when it includes both types. Interactive communication through chatting (local and global) and one-way communication through messaging (global only) are considered. We also included a control session with no communication. All the variation of communication is introduced in the heterogeneous environment while only local treatment is applicable in the homogeneous environment (Table 2).

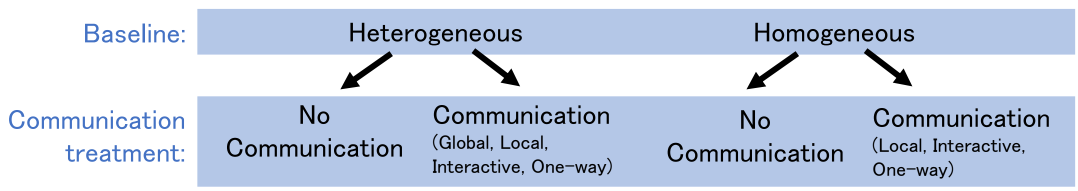

Figure 1. Experimental design

Table 2. Communication treatment

	Communication partners:	
Communication features:	Global	Local
Interactive	Heterogeneous	Homogeneous, Heterogeneous

One-way	Heterogeneous	Homogeneous, Heterogeneous

The experiment was conducted at Kyushu University in July through November 2019. A total of 11 sessions were conducted, each of which lasted about for 60 minutes with no communication and 75 minutes with communication. Participants were recruited through undergraduate engineering and economics classes, and none of them had ever experienced similar experiments. In total, we collected a sample of 176 subjects, of which 147 were male (84%) and the mean age was 20.26 years old. Subjects were paid privately in cash a show-up fee of 1,500 yen (about US$15) plus the cumulative earnings from the CPR game at the end of the experiment. The fixed show-up fee is set comparatively high to offset the worst-case earnings for Group 2 participants. The average earning was 3,985 yen (about US$40). Subjects were asked to sit at a computer terminal with partitions, which was intended so that no participant can see others' screen. At the beginning of the experiment, subjects were told that they would make a sequence of investment decisions, which would be kept anonymous, and their identity would never be revealed for the duration of the experiment and after. The sessions were administered through z-tree (Fischbacher, 2007). The written instructions were read aloud, and a full copy of the instructions are provided in the supplementary information.

In a session, 16 subjects repeated the decision to invest in either a group account (CPR) or a private account with the endowment of 14 tokens for eight times in either Homogenous or Heterogenous environment in the first half. The subjects were randomly paired into groups of four in the Homogeneous environment and groups of eight in the Heterogeneous environment and then randomly assigned a type either in Group 1 or Group 2. Membership of the groups and types stayed unchanged throughout the sessions. Communication treatments including no communication as a control took place with the same environment in the second half. The decisions were also repeated eight times in the second half.

Subjects in the Heterogeneous environment went through the details on the productivity of the group account for both Group 1 and 2 without knowing which Group to be assigned to. Prior to commencing the experiment subjects were informed of their type in the Heterogenous environment. Group 1 made a decision first and then Group 2 observed Group 1's decision in the same group and then made own decision. This course of decisions narrows down the strategy space for Group 2, which simplifies their task as well as instructions. In the Homogeneous environment all the subjects made a decision simultaneously. After each round, subjects were shown the information on the profits for that round, own investment decision, a total number of tokens invested by the other group members, as well as a total number of tokens invested by Group 1 for Group 2 members in the Heterogeneous setting. A historical record of the same items were also displayed, which was kept in display during the investment decision time.

In the second half of the communication treatment subjects were provided new instructions. In the instructions, it was informed that before they made every investment decision subjects were allowed to communicate in a specified way. When it was local and interactive, participants with the same type in the same group were allowed to send and read messages each other through a chatting function for four minutes for the first two rounds, three minutes for the next two rounds, two minutes for the fifth and sixth rounds, and one minute for the last two rounds in the second half. When it was global and interactive, only occurring in the Heterogeneous setting, participants with both types in the same group were invited to chat. The duration for chatting was identical for the local treatment. When it was local and one-way, participants with the same type in the same group were allowed to send a pre-defined message to the rest of the members. The options for a message were "Our investment is not doing well. Let's bring down the investment."; "Our group investment is doing well. Let's keep this."; or no message. After the decision for sending a message all the participants were informed of the number of senders in their group for each message. When it was global and one-way, the participants as Group 2 were given a choice to send the pre-defined message to the participants as Group 1 in the same group. The options for a message were identical to the local, one-way treatment except that "our" investment was replaced with "your" investment. After the decision for sending a message all the participants were informed of the number of Group 2 senders in their group for each message.

3. Results

We examine five hypotheses relating to two major questions on heterogeneity and communication. Unlike the heterogeneity in the previous studies in terms of endowment and parameter our heterogeneity is unique in that it examines the situation where use of a common-pool resource by a group of users not only imposes the negative externality on each other but also produces additional costs on the people outside of the group who is at their mercy of the group's resource use. In theory, the existence of "the disadvantaged" do not alter the incentive for the group to appropriate the resource. However, in the ultimatum game and the public goods game social preferences actually changes the behavior. Our heterogeneity allows us to examine social preferences in the contest of a common-pool resource use. It provides additional reason that is non-material to refrain from appropriating. Our first question is how the heterogeneity affects the resource exploitation, which underlies the first hypothesis that the existence of "the disadvantaged" reduces the effort by the excessive users. The remaining hypotheses relates to our second question on the robustness of communication in the heterogeneous CPR use. The second hypothesis is that local, interactive communication promotes cooperation (Balliet, 2009; Ostrom, 2006), which is to confirm the findings from the literature. The second hypothesis is extended to test the robustness of the previous finding in the heterogeneous global setting. The third hypothesis is to test the effectiveness of one-way communication. This hypothesis breaks down the effect of communication and helps us understand how communication increases cooperation. It has been established that communication increases cooperation, but it is not clear what is essential in well-functioning of communication. When the public goods game was repeated over many rounds, a message that appealed to a participant's goodwill increased cooperation (Chaudhuri & Paichayontvijit, 2017). In the global, one-way communication it stresses the messaging channel from the disadvantaged to the excessive users. We test that the important part of communication is in conveying the message (or the intent or opinion) to other members. The fourth hypothesis, bringing in both elements—heterogeneity and communication, compares the efficiency of communication in the global settings with that of the local settings and hypothesizes that the efficiency diminishes in the global, interactive communication (N. J. Buckley et al., 2017).

3.1 Descriptive statistics

Figure 2 shows the time trend of the mean appropriation rates by treatment. With no communication Group 1 subjects in either homogenous or heterogeneous CPR settings appropriated around the Nash prediction level while subjects in Group 2 do not necessarily play a Nash prediction in response to the Nash appropriation by Group 1. The difference between the homogeneous and heterogeneous settings is not obvious (Fig. 2a). With interactive communication Figure 2b presents a sharp decline in appropriation rate after the treatment is introduced, which gradually increases back towards the end of the experiment. The difference between the homogenous and heterogeneous settings or between local and global communication is unclear (Fig. 2b). A reduction in effort by Group 1 possibly allows Group 2 subjects to increase their effort level up to the social optimum in a few rounds after the introduction of the treatment. With one-way communication the introduction of the treatment does not induce an obvious change in the appropriation pattern for both groups, but a modest increase in Group 2's appropriation is suspected.

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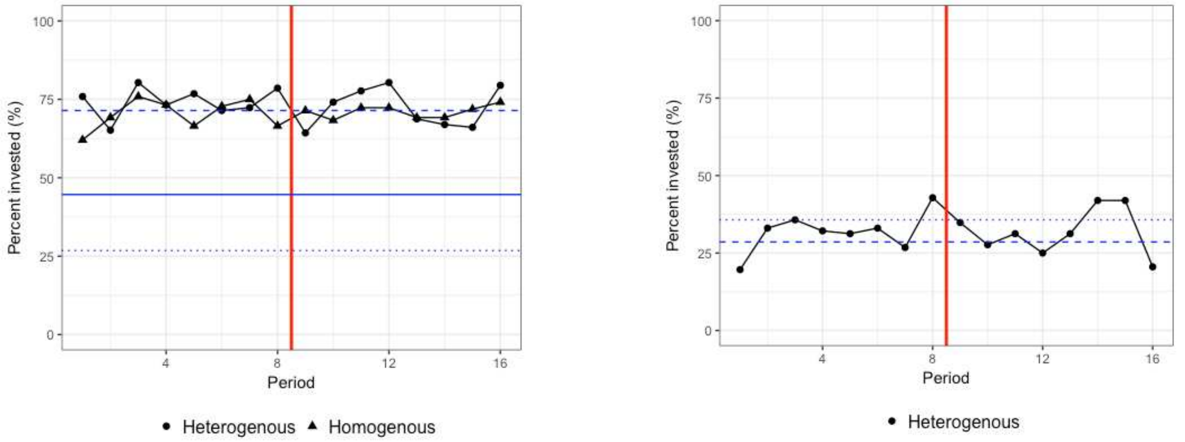
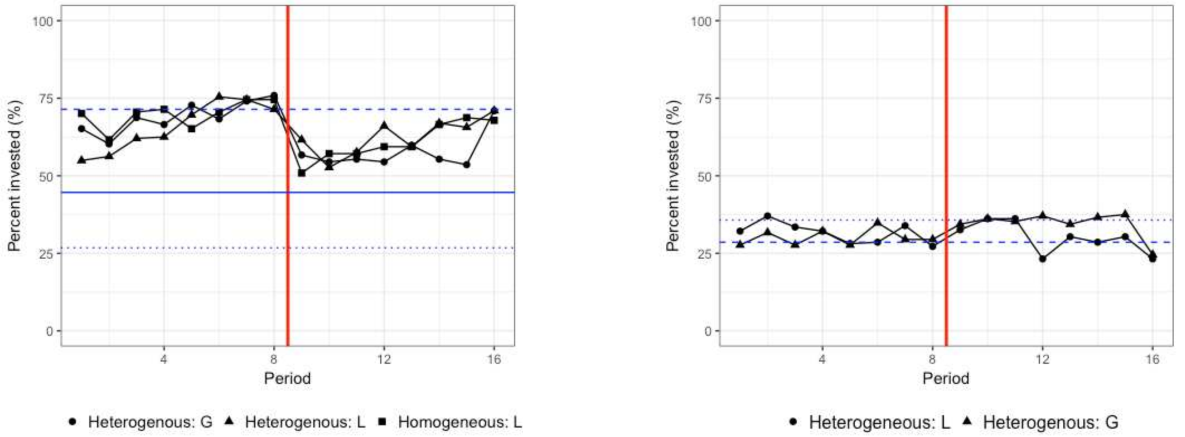
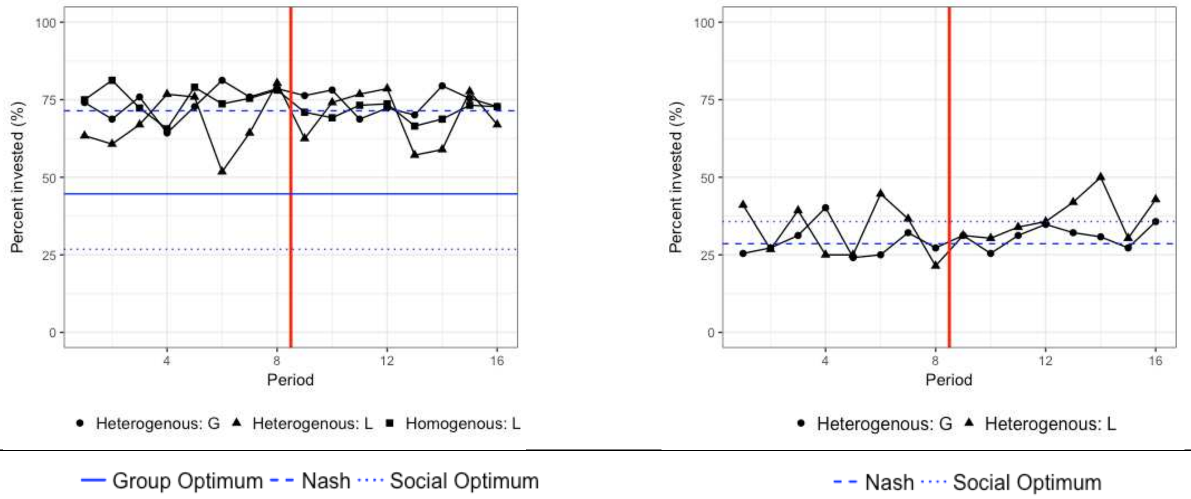
a. No communication treatment



b. Interactive communication treatment (chat)



c. One-way communication treatment (message)



Group 1 Group 2

Figure 2. Mean appropriation rate by treatment (%) over time

As we are interested in the effect of heterogeneity as well as the effect of communication, we exploit between-subjects design for the effect of heterogeneity and a within-subjects design for the effect of communication. To compare the appropriation rate in the homogeneous CPR with that in the heterogeneous CPR, Figure 3 exploits between-subjects experimental design. As shown, the difference is minimal. To compare the appropriation rate prior to the intervention with that after the intervention, Figure 4 exploits within-subjects experimental design. After the interactive communication is introduced in the homogeneous CPR setting the effort greatly reduced (Fig. 4a). The introduction of one-way communication in the homogeneous CPR setting also reduced the effort, although not as much as the interactive communication. The global, interactive communication in the heterogeneous CPR setting induced a significant reduction in the effort by Group 1 appropriators, which surprisingly seems greater than the local, interactive communication (Fig. 4b). Regardless of the features, one-way communication suggests no effect if not deteriorating (Fig. 4c). Followed by a reduction in the effort by Group 1, a small increase in the effort by Group 2 is observed, although Group 2 appropriators increases their effort on average without seeing a reduction of the effort by Group 1 in the other communication treatments.

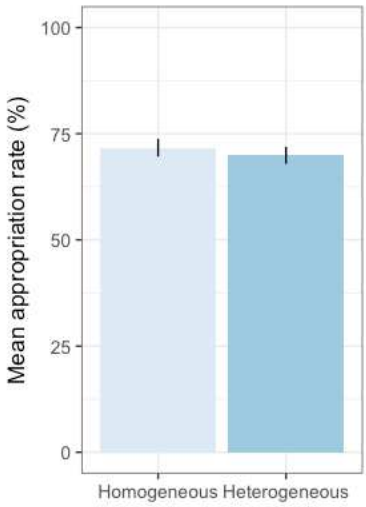


Figure 3. Between-subjects comparison of mean appropriation rate (%).

Notes: Baseline (rounds 1-8) only. Error bars indicate 95% confidence intervals.

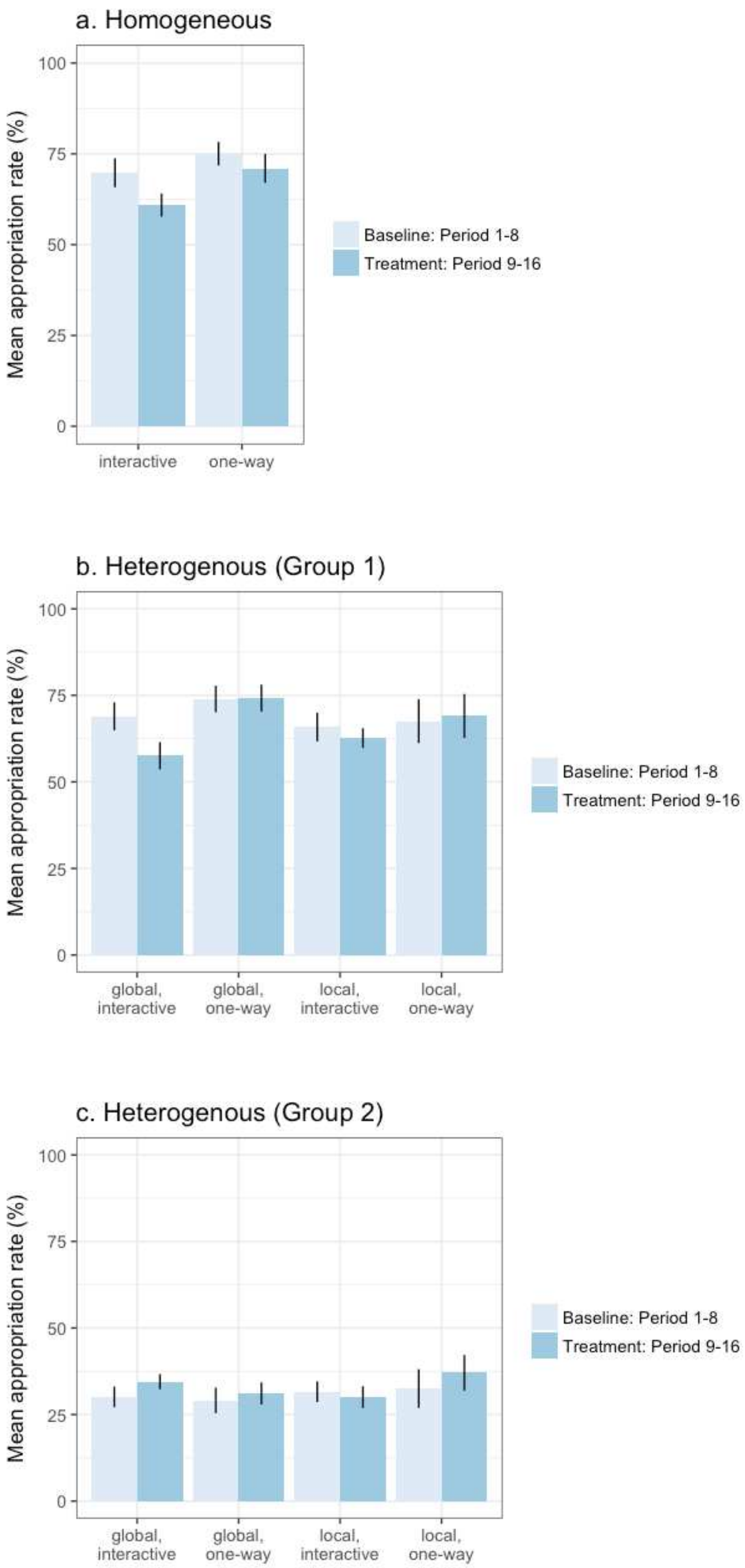

a. Homogeneous
Mean appropriation rate (%)
100
75
50
25
0
interactive
one-way
Baseline: Period 1-8
Treatment: Period 9-16
b. Heterogenous (Group 1)
Mean appropriation rate (%)
100
75
50
25
0
global, interactive
global, one-way
local, interactive
local, one-way
Baseline: Period 1-8
Treatment: Period 9-16
c. Heterogenous (Group 2)
Mean appropriation rate (%)
100
75
50
25
0
global, interactive
global, one-way
local, interactive
local, one-way
Baseline: Period 1-8
Treatment: Period 9-16

Figure 4. Within-subjects comparison of mean appropriation rate (%).

Note: Error bars indicate 95% confidence intervals.

3.2 Treatment effects

To verify statistically the comparison discussed above we conducted a series of statistical tests (Table 3). As suggested previously the behavior of appropriators when they are homogenous do not statistically significantly differ from that of Group 1 appropriators in a heterogeneous setting (P=0.47 from the Wilcoxon-Mann-Whitney test in Table 3). Exploring the effects of communication we find the statistically significant effect of interactive communication (P<0.01) and although more questionable, the effect of one-way communication (P=0.17) in a homogeneous setting. In a heterogeneous setting, the intervention of interactive communication results in a significant change in the behavior of Group 1 whether local (P<0.1) or global (P<0.01), but for Group 2 only global interactive communication leads to updates of their appropriation patterns (P<0.01) but not local (P=0.36). Any of the one-way communication treatment in a heterogeneous setting did not yield statistically significant results at a conventional level, but the effect may be suspected for Group 2 in local (P=0.19).

Table 3. Mean appropriation rate (%)

	Homogeneous	**Heterogeneous**	
		Group 1	**Group 2**
Baseline: Period 1-8	71.7 (1.1) N=384	69.9 (1.0) N=512	30.7 (0.9) N=512
Wilcoxon-Mann-Whitney test	P=0.4725		
Treatment: Period 9-18			
No communication:			
	71.1 (1.6) N=128	72.2 (3.2) N=64	31.8 (2.6) N=64
Interactive communication:			
Local	60.9 (1.6) N=128	62.6 (1.4) N=128	30.0 (1.6) N=128
Wilcoxon signed rank test	P=0.0006	P=0.0742	P=0.3609
Global		57.6 (2.0) N=128	34.5 (1.1) N=128
Wilcoxon signed rank test		P=0.0005	P=0.0097
One-way communication			
Local	71.0 (2.0) N=128	69.1 (3.2) N=64	37.1 (2.6) N=64
Wilcoxon signed rank test	P=0.1716	P=0.6754	P=0.1888

Global	74.2 (2.0) N=128	31.1 (1.6) N=128
Wilcoxon signed rank test	P=0.9800	P=0.8761

Notes: Standard errors in parentheses. The Wilcoxon-Mann-Whitney test compares appropriation between Homogeneous and Group 1, Heterogeneous. The Wilcoxon signed rank tests are against the baseline treatment in its corresponding setting.

To rigorously assess the treatment effect by controlling common trends in treated and control sessions, we employ Difference-in-Differences (DiD) by using no communication treatment as control. We estimated individual appropriation rate with the following model with individual specific random effects.

$$x_{ikt} = \alpha_0 + \alpha_1 Period_t + \alpha_2 Treated_t + \sum_{j\in J} \beta_j Comm_{ik} + \sum_{j\in J} \gamma_j Comm_{ik} \cdot Treated_t + \alpha_3 Affected_{ik} + \sum_{j\in J} \delta_j Comm_{ik} \cdot Affected_{ik} + \sum_{j\in J} \zeta_j Comm_{ik} \cdot Affected_{ik} \cdot Treated_t + \nu_{ik} + \epsilon_{ikt},$$

where subscript *i* indicates individuals, *k* groups, and *t* period. A unit of groups is the group that shares a resource with the same production function, and thus Group 1 and Group 2 are identified as different even when they share the same resource. The model includes a time trend variable that spans from 1 to 18 ($Period_t$), a treatment dummy indicating the intervention from rounds 9 to 18 ($Treated_t$), a binary variable indicating whether an individual is in a Group 2 ($Affected_{ik}$). J is a set of four communication treatment dummies—global interactive, local interactive, global one way, local one way. "No communication" treatment is suppressed as a base. Our parameters of interests are γ_j and ζ_j, and the estimation results are summarized in Columns 1 and 2 in Table 4 and the full results are in Appendix.

Both Models 1 and 2 in Table 4 show the same model explained above, but the Model 2 excludes the observations from the final rounds to highlight the behavior when the relationship is expected to continue. Consistent with the previous findings, interactive communication in a homogenous setting significantly reduces over-exerted effort, and this remains unchanged in the Model 2. Without having any significant change in Group 1 subjects' behavior Group 2 subjects significantly increased their effort when they communicate with each other in a local, one-way setting. Interestingly, we found that the effect of interactive communication in a global setting that was found statistically insignificant in the Model 1 turns to be significant in the Model 2 when the relationship is expected to continue. The same trend is observed in the effect of interactive communication in a local setting for Group 2 subjects. Correspondingly, Group 2 subjects significantly increases their effort in a global, interactive communication treatment and their change is significant in the Model 1 when Group1's change is not significant.

The next question that may arise is whether those behavioral changes improve social efficiency in resource appropriation. We define group efficiency as $\Pi_j = \sum\sum \pi_{ij}/\Pi^{OPT}$, where Π^{OPT} denotes the summation of the profits when X^{OPT}, and estimate it with the following model with group specific random effects.

$$\Pi_{jt} = \alpha_0 + \alpha_1 Period_t + \alpha_2 Treated_t + \sum_{j\in J}\beta_j Comm_i + \sum_{j\in J}\gamma_j Comm_i \cdot Treated_t + \nu_i + \epsilon_{it},$$

where subscript j refers to an entire community that includes both types when in a heterogeneous setting, and t period. The model includes a time trend variable, a treatment dummy, and a communication type, and the interaction between the treatment and the communication type. The estimation results are summarized in Columns 3 and 4 in Table 4 and the full results are in Appendix.

As expected, the observed behavioral change leads to an increased efficiency in local, interactive communication but not in global, interactive communication even with Model 4 although a significant change in the appropriation behavior is observed in the Model 2. The local, one-way communication induces an increase in Group 2's effort without a decrease in Group 1's effort, and thus an improvement in efficiency is not achieved.

Table 4. Estimation results

	Appropriation rate				Social Efficiency			
	(1)		(2)		(3)		(4)	
γ_j								
Local interactive	-6.0547	(2.9723)**	-7.0791	(3.1929)**	8.2164	(4.8325)*	8.6964	(4.8441)*
Global interactive	-11.356	(7.7351)	-13.1975	(7.8751)*	10.4904	(9.6639)	11.8155	(9.2611)
Local one-way	-2.1298	(2.1657)	-2.1219	(2.4406)	2.5918	(4.7602)	2.5206	(4.5933)
Global one-way	0.2511	(4.2448)	0.5222	(4.7354)	-0.5166	(6.4942)	-1.1279	(6.9216)
ζ_j (Group 2)								
Local interactive	4.5759	(3.0391)	6.6526	(3.3541)**				
Global interactive	15.7924	(7.8183)**	19.1247	(7.8898)**				
Local one-way	6.7336	(1.6489)***	5.9683	(2.4320)**				
Global one-way	1.7857	(5.5354)	0.9247	(5.9437)				
Observations	2,816		2,640		448		420	
Final rounds excluded?	No		Yes		No		Yes	
Clusters	44		44		28		28	
χ^2	314,482		5,219		97		91	

Notes: Robust standard errors are in parentheses. * p<0.1; ** p< 0.05; *** p<0.01.

3.3 Messaging effect

Different messages may affect the appropriation behavior differently. We explore the effect of one-way communication by breaking down by the type of the message. Table 5 shows the percent of each message sent. Overall, about half of the message was “restraint” (50%), but when it is observed by treatment, the global setting sends more “restraint” messages (68%) than the local (38% and 47%). The difference in the frequency between global and local is greater in the message for encouragement than for restraint (Table 5).

Table 5. Percent of the message sent

(%)	Pooled (N = 384)	Global (N=128)	Local (Group 1 only) Hetero (N=64)	Homo (N=128)
No message	28	20	25	27
Encouragement	22	12	28	34
“Our/Your group investment is doing well. Let’s keep this.”				
Restraint	50	68	47	38
“Our/Your group investment is not doing well. Let’s bring down the investment.”				

One question that may arise is whether the heterogeneous setting alters the nature of communication. We test it by comparing the types of the messages sent by Group 1 in the local one way communication in the heterogeneous setting with the counterpart in the homogenous setting using the Wilcoxon-Mann-Whitney test. We found that the hypothesis that these two are identical is rejected at P = 0.35, which is not considered to be significant at the conventional level.

Different messages in different settings can have varying effects not captured in the overall treatment effect estimated above. To reveal such effects we estimated the following model with group specific random effects.

$$x_{ikt} = \alpha_0 + \alpha_1 Period_t + \alpha_2 \sum_{N_k} x_{-ik(t-1)}/(N_k - 1) + \sum_{l \in L} \beta_l Message_{-ik(t-1)} + \nu_{ik} + \epsilon_{ikt},$$

where N_k refers to the number of individuals in each k group. The $Message_{-ik(t-1)}$ variable is the sum of the number of messages except oneself in each message type in the previous round. L is a set of two message types, either restraint or encouragement. Our parameters of interests are β_l, and the estimation results are shown in Table 6 and the full results are in Appendix.

One of the things that newly appear in this estimation is that Group 1 subjects reduce the appropriation effort when they receive more restraining messages sent by Group 2, and this effect is significant only when the final rounds are excluded and the relationships are expected to continue. The other thing is that the encouraging message in the local setting, in which the same type sends the message each other, further reduces the appropriation effort although it loses a significance when the final rounds are excluded.

Table 6. Estimation results

	Global one-way communication				Local one-way communication			
	(1)		(2)		(3)		(4)	
Encouragement	-0.0817	(7.0584)	-1.566	(7.7795)	-9.5585	(5.3387)*	-8.1239	(5.6552)
Restraint	-3.1429	(2.6771)	-4.2641	(2.1385)**	-2.9159	(3.4582)	-2.5125	(3.9505)
Observations	112		96		168		144	
Final rounds excluded?	No		Yes		No		Yes	
Clusters	4		4		6		6	
χ^2	139.83		35.93		4.05		2.64	

Notes: Robust standard errors are in parentheses. * p<0.1; ** p< 0.05; *** p<0.01. Only treated observations for Group 1 subjects are included.

4. Conclusion

Our results suggest that the mere presence of disadvantaged appropriators (Group 2) did not affect the other appropriator's behavior (Group 1). Consistent with the literature, local interactive communication effectively reduces the appropriation effort and improves the efficiency. Global interactive communication affects the behavior of both types but not to the extent that it improves social efficiency. One way communication was not as effective as interactive communication in either homogeneous or heterogeneous setting. However, closer examination reveals that and receiving the global message for disapproval decreases the appropriation level among Group 1 appropriators and local messaging to endorse a good behavior possibly decreases the appropriation level among Group 1 appropriators.

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