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Communication in Asymmetric Group Competition over Public Goods

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Abstract

This paper examines whether and how communication can help groups solve coordination and free-rider problems when they compete with another group for a public-good prize. We find that when group members make an anonymous individual decision on whether or not to contribute to the group success, within-group cheap talk communication significantly reduces miscoordination and free-riding. To measure how much miscoordination remains when communication is allowed, we employ a control treatment where we remove coordination and free-riding incentives by having group members reach a unanimous group decision on how much to contribute. We find that group level contributions are not significantly different in the two cases. Communication therefore completely eliminates miscoordination and free-riding within groups and leads group members to act as one agent in making decisions. Content analysis of group communication reveals that groups explicitly designate specific contributors following a rotation scheme and they understand the essence of implementing mixed strategy equilibrium.

JEL Classification: C72, C91, C92, D72, H41

Keywords: Group contests; Threshold public goods; Coordination; Cheap talk Communication; Content analysis; Experiments

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1. Introduction

Although cheap talk communication is non-binding and costless, previous experimental studies have demonstrated that communication can nevertheless change behavior rather dramatically. For example, communication improves cooperation in prisoner dilemma games (Wichman, 1972), public goods game (Isaac and Walker, 1988b, Ledyard, 1995, Cason and Kahn 1999, Bochet et al. 2006, etc.), common pool resource game (Hackett et al., 1994), trust game (Charness and Dufwenberg, 2006) and some market experiments (e.g., sealed bid auction, Isaac and Walker, 1985). Communication helps to overcome coordination failure and enhances efficiency in coordination games (Van Huyck et al., 1993, Brandts and Cooper, 2007). While these games allow researchers to investigate the impact of communication on strategic interactions within groups, there have been few experimental studies, concerning how communication affects behavior when strategic interactions take place both within and between groups.

This paper reports a laboratory study of the effectiveness of communication in solving within-group free-riding and coordination problems when there is competition between groups. In particular, we study a contest between two unequal-sized groups for a monetary prize. The prize is shared equally by the members of the winning group, disregarding the level of their costly contributions to the group's success. This type of winner-takes-all contest can be seen as a step-level public goods game played within the groups, with the threshold determined by the performance of the other group. There are two levels of conflict in the contest. Within groups, there is an incentive to free ride on the other members' costly contributions. Between groups, there is an incentive to compete for the prize. Thus this environment departs from the classic single group public goods game by introducing between-group conflict. It also differs from the literature on contest games where the competitors are modeled as unitary players, which rules out within-group conflict.

This notion of public good provision in group contest has important applications in political science and economics. Examples include political races, rent seeking, and R&D contests in which groups compete by expending resources (e.g., money, effort, time) to achieve power, secure governmental subsidies or capture monopoly privileges. Often times, groups (especially those participating in research and other group-based contests) either do not know (all) other competitors or do not trust the information revealed by their competitors. Yet communication among group members is especially important when the groups' respective success in solving the within-group dilemma determines the

outcome of the between-group competition. Thus we focus on studying the effect of within-group cheap talk communication.¹

Our experiment restricts individual's strategy space to a binary decision between contributing and not contributing to the group account.² This can be easily related to the voter participation problem. Each group member decides whether or not to cast a private vote at some cost. The group with the highest turnout earns the prize, which is evenly distributed among group members. Thus we construct the experiment around a static voting model proposed by Palfrey and Rosenthal (1983, hereafter P&R).

Comparing to the existing experimental studies on voter participation problem, our study has a novel design and a different focus. First, our goal is to analyze how communication affects behavior in small group decision when groups are competing for a public-good prize. In particular, we examine a competition between a group of 3 and a group of 5. The probability of being decisive in small group decision is much higher than in a large-scale election. This separates our study from the strand of literature seeking explanations for the paradox of voter participation, in which the size of groups ranges 6-34 (e.g., Schram and Sonnemans, 1996a, b; Levine and Palfrey, 2007). Our game resembles more closely to the following situation. Whenever a small group of people, such as boards of directors, legislatures, committees, and lobbying groups need to reach a decision, communication takes place in subgroups before votes are cast. The final decision will be in favor of the subgroup with more votes.

Second, the competition we study is between a small group of 3 members and a large group of 5 members. Very few experimental studies have examined this type of asymmetric conflict and even fewer focuses on the effect of communication in this environment.³ Schram and Sonnemans (1996a, b) and Rapoport and Bornstein (1989) are the most related studies we are aware of. Schram and Sonnemans (1996a) compare the participation rates between a group of 6 and a group of 8 when communication is not allowed. They find that the relative participation rate is higher in the small group based on 2 independent sessions and the observed difference is not statistically significant. The effect of communication on voter participation is examined in Schram and Sonnemans (1996b), where a voting

¹ All discussions about communication hereafter refer to this type of communication, unless otherwise stated.

² The effects of communication reported here are robust even when we make the strategy space continuous, i.e., individuals decide how much to contribute instead of whether or not to contribute. A detailed discussion can be found in Zhang (2009).

³ Cason and Mui (2005) introduce uncertainty about the benefits of voting into a costly political participation game by adding one "floating" voter to two groups of two voters with probability 1/3 and 2/3 respectively. They conclude that uncertainty reduces the incidence of reform significantly even with costly participation. The main interest of their study is to investigate the payoff uncertainty under various voting costs rather than the asymmetry of groups per se. Yet their design constitutes an effective experimental paradigm to examine how unequal-sized groups behave in a competitive environment. Levine and Palfrey (2007) study a model with heterogeneous and privately known voting cost which leads to a unique Nash equilibrium under their parameters. They find that turnout rates decrease with group size. This is different from Schram and Sonnemans (1996a), Cason and Mui (2005) and the present study, which feature a homogenous voting cost. All these papers do not investigate the effect of communication.

game is played by two groups of 6 subjects. They report that communication significantly increases the participation rates of both groups. A point worthy to note here is that they use within-subject design with the same subjects played 20 periods of the game in no communication treatment followed by 5 periods in communication treatment. Thus the reported communication effect is confounded with learning effect in their design. Rapoport and Bornstein (1989) analyze the effect of communication in an asymmetric group competition for public goods between a group of 3 and a group of 5. Their results show that communication increases the participation rate in the large group but not in the small group. As a typical psychology study, their experiment is run as one shot game which prevents them from observing the impact of communication on group behavior in a more rich and dynamic (repeated game) environment. Moreover, they do not provide any predictions for game-theoretically rational individuals. Last, the prize in their experiment is a “pure” public good. That is, the individual share of the prize does not decrease in the group size. In contrast to the “perfect non-rivalry” characteristic of the “pure” public good, the prize in our study constitutes an “impure” public good. That is, the individual share of the prize is smaller in the large group than in the small group. In a single group public goods game, Isaac and Walker (1988a) find that more members free ride as group size increases in the provision of an “impure” public good but not a “pure” public good. Thus our design presents a severer free-rider problem for the large group relative to the small group.

Another novelty of our study is the way we implement communication in the lab. The two studies mentioned above all let subjects communicate face to face for only once before they make any decisions in the communication treatment.⁴ In contrast, subjects in the communication treatment of our experiment had the ability to send free-form non-binding messages to each other through a chat window for 90 seconds in the beginning of each period. They were informed that their messages would be recorded and they would be required to follow two simple rules: (1) to be civil to each other and not use profanity, and (2) not to identify themselves. After the chat period was over, subjects simultaneously made their decisions. Compared to face-to-face communication, chat room communication preserving anonymity and excluding facial expression and other non-verbal stimuli as the chat program assigns subjects an id number based on the order that they sent messages. Yet chat room communication still captures interesting social dynamics inherent in naturally-occurring communication and it has been found almost as efficient as face to face communication in voluntary contribution experiments (Bochet et al., 2006). Also, by enabling chat at the beginning of every period, we are able to observe how subjects respond to the history of the play or layout and adjust a plan across periods as they articulate them in the chat.

⁴ In Rapoport and Bornstein (1989), communication lasted for 10 minutes before subjects played the one shot game. In Schram and Sonnemans (1996b), after 5 minutes and no further communication, subjects played 5 periods of the game.

Forth, unlike most studies in the communication literature, we not only document whether communication affects group decision making, but also explicitly reveal why and how communication has such effect by systematically employing content analysis, a well-developed methodology used commonly in many fields of social science but rarely in economics. Content analysis involves taking all the recorded chat messages, developing a coding scheme which classifies messages into different categories and then hiring multiple coders, trained separately and independently to read all messages and code all messages into a variety of numerical codings. Thus we take the qualitative information of the chats, translate it through a coding scheme into quantitative measures and then relate those quantitative measures to outcomes in the experiment. Among the few published experimental papers with content analysis and multiple coders, the majority use across-coder correlation to measure coding reliability. This is problematic because the across-coder correlation is sensitive to the number of coding categories and overstates the coder agreement because some agreement occurs by chance. For binary data, agreement by chance is at least 50%. To correct this, we use Cohen's Kappa K as the measurement which accounts for the agreement that would result if coders merely make random assignments (Krippendorff, 2004, Hayes, 2005).

Last, besides the communication and no communication treatments, two control treatments are conducted. In one treatment, free-riding and coordination incentives are eliminated by the design and groups have to reach unanimous decisions on how much to contribute. Comparing to the outcomes in this controlled treatment, we are able to isolate how much miscoordination still remains in the original communication treatment when free riding and coordination problem are present. This is one step further than the existing literature documenting how much free riding is reduced or coordination is reached via communication. When there is no communication, we identify a particular mixed strategy Nash equilibrium among other multiple mixed strategy equilibria as the most behaviorally relevant equilibrium, where the participation rate is higher in the small group than in the large group. The large group wins only about half of the time despite the size advantage. When we add communication, we find that communication promotes the large group to participate and deters the small group from participation. Large group wins around 90% of the time. This is because groups can coordinate better when communication is allowed and groups are more likely to avoid free-riding and achieve the optimal group outcome. Anticipating this, the small group is discouraged from competing with the large group. More surprisingly, behavior in the communication treatment is well approximated by a different mixed strategy Nash equilibrium that models groups as one agent in play the game. Outcomes in the communication treatment are not significantly different from the control treatment featuring unanimous group decisions. Outcomes do not differ from another control treatment where two individuals are

competing with each other. Communication therefore completely eliminates miscoordination and free-riding within groups and leads group members to act as one agent in making decisions. Content analysis of group communication reveals that the most effective strategy for the large group is to explicitly designate specific contributors following a rotation scheme and group members understand the essence of mixed strategy equilibrium as they emphasize to be unpredictable in the chats.

In summary, this paper contributes mainly to two research areas: it fills in the gap of the participation game literature by examining the effect of communication in asymmetric group competition; it also adds to the development of laboratory methodology for the study of rich communication which not only allow us to document how communication influences decision making, but also reveals the mechanisms that are involved.

The remainder of the paper is organized as follows. Section 2 characterizes the structure of the game. Section 3 describes the experimental design and procedures. Section 4 reports the results. Section 5 elaborates on content analysis, and section 6 concludes.

2. Theory

The experiment is structured around P&R's voting model. There are two groups A and B with n_A and n_B members respectively; each member of group A and group B receives an endowment of size $e > 0$ and then he or she must decide independently and anonymously whether to keep the endowment or contribute it toward the group's benefits. The group with the most contributors wins the game and receives a prize R , while the losing group gets no prize. If the numbers of contributors are equal among the two groups, each group gets half of the prize. The contributions are non refundable. The public-good prize is then shared equally among the group members irrespective of whether or not each group member made a contribution. Thus if group G ($G = A, B$) is the winning group, each member in the winning group is rewarded $r_G = R/n_G$. In addition to the share of the group's benefit, each member in either group earns the part of the endowment that is not contributed to the group. The ordinal relation between the payoff parameters for an individual player in the model satisfies an inequality: $r_G > r_G/2 + e$, where e is the cost of contribution, r_G is the utility of a win and $r_G/2$ is the utility of a tie. Given the inequality, a payoff maximizing player should contribute when his or her contribution is critical to winning the game. The inequality can also be reduced to $r_G/2 > e$. A payoff maximizing player should contribute when his or her contribution is critical to tying the game. There is no pure strategy Nash equilibrium for this game.

P&R show that this game has two classes of mixed strategy Nash equilibria:

1) Mixed-pure strategy equilibria where all members of one group contribute with a positive probability and members of the other group are divided into subgroups of contributors and non-contributors. P&R consider these equilibria implausible.⁵ This paper thus focuses on the second class of Nash equilibria.

2) Totally mixed strategy quasi-symmetric equilibria (hereafter, mixed strategy equilibria) where all members in the small group contribute with the same probability p and all members in the large group contribute with the same probability q .

The mixed strategy equilibria are determined by equating the expected payoff from contributing to the expected payoff from not contributing so that no one can increase or decrease his or her payoff by changing the contribution decisions unilaterally. Specifically, for any player i in Group A to be willing to randomize, that is, he or she is indifferent to contribute or not, it must be the case that: $EV_i^A(\text{Contribute}) - EV_i^A(\text{NContribute}) = 0$, which is a function of two unknowns p, q and can be simplified to $(P_1 + P_2)/2 = e/r_A$ where P_1 is the probability that the contribution of player i will change a losing situation into a tie and P_2 is probability that the contribution of player i will break a tie and lead to a win. Thus if $(P_1 + P_2)/2 = e/r_A$, i.e., the probability of being critical exceeds the cost to benefit ratio, player i should choose to contribute. Similarly, we can get another function of p, q for players in Group B such that $EV_i^B(\text{Contribute}) - EV_i^B(\text{NContribute}) = 0$. With two functions and two unknowns, we can numerically solve the mixed strategy equilibria.

3. Experimental Design and Procedures

The asymmetric competition we implement in the laboratory is between a small group of three members and a large group of five members, i.e., $n_A = 3, n_B = 5$. With at least three members, coalitions can be formed and some kind of organization is present. Also, in one of the treatments, we ask groups to reach a unanimous decision. The odd-numbered group makes it easier since it admits the possibility of a decisive majority vote to reach a group decision. Without loss of generality, individual endowments are set to be unity ($e = 1$). That is, the un-refundable cost of contribution equals one.

Our experiment consists of 35 statistically independent sessions with a total of 184 subjects across four different treatments, as summarized in Table 1.

⁵ The mixed-pure strategy equilibria involve coordination that is especially implausible when within-group communication is not allowed or is not enforceable.

Table 1: Summary of Experimental Design

Treatment	# of Sessions	# of Subjects	Communication	Decision	Free-riding Incentives
3x5 NC	6	48	No	Individual	Yes
3x5 C	6	48	Yes	Individual	Yes
1x1 G	7	56	Yes	Group	No
1x1 I	16	32	No	Individual	No

Treatment 3x5 NC: A group of 3 members and a group of 5 members compete for a prize of $R = 18$ tokens in the IPG game. Each member is endowed with one token and decides whether to contribute the token to the group account or keep it to him or herself. The group with more tokens in the group account wins the prize, which is shared equally among the contributors and non-contributors. When there is a tie, the prize is split between the two groups. There is an incentive to free ride because only the contributors bear the cost of contribution. No form of communication is permitted.

Treatment 3x5 C: This treatment adds to treatment 3x5NC, it allows group members the opportunity to communicate with one another in the beginning of each period. Group members have 90 seconds to send free-form messages to each other through a chat window before deciding whether to contribute the endowed token. Communication is non-binding—group members (who make their contribution decisions privately and anonymously) are not constrained to keep any agreement that they may have reached during the chat period.

Treatment 1x1 G: This treatment differs from treatment 3x5 NC and 3x5 C in the way that tokens are endowed. Tokens are distributed collectively, to the entire group, instead of separately, to each individual. The large (small) group decides how many of the 5 (3) endowed tokens to contribute. The group with the higher contributions wins a prize. Group members share the prize and the retained endowment equally. There is no incentive to free ride because the cost of the contributions is born by every group member. Again, non-binding, within-group communication is allowed for 90 seconds before group members make the actual decisions simultaneously and anonymously in the beginning of each period. The unanimous decision selected by all members in the group is implemented as the group decision. Each group has up to 10 rounds to reach a unanimous decision. If a unanimous decision is not reached by the 10th round, the choice of allocating “0” tokens to the group account is automatically implemented as the “group decision”. Communication is only permitted for the first round at the beginning of each period.

Treatment 1x1 I: Two individuals rather than groups compete for a prize of 18 tokens in this treatment. One individual is endowed with 3 tokens and the other is endowed with 5 tokens. Each of them is asked to decide how many tokens to contribute. The individual with higher contributions wins

the prize. Any tokens that are not contributed are added to the individual's benefits. The intra-group level of conflict is eliminated in this game. No communication is permitted in this treatment.

The effectiveness of communication in solving miscoordination and free-riding problems within groups is examined in the pair-wise comparisons of the first three treatments: 3x5 NC, 3x5 C and 1x1 G. More specifically, treatment 1x1 G should be equivalent to the case where communication completely eliminates miscoordination and free-riding. The difference between treatment 3x5 NC and treatment 3x5 C allows us to measure the degree to which miscoordination and free-riding is reduced, while the difference between treatment 3x5 C and treatment 1x1 G conveys the extent to which miscoordination and free-riding still remain. The comparison between treatment 1x1 G and treatment 1x1 I indicates whether individual choices differ from group decisions in this paradigm. This contributes to the experimental literature on the investigation of the general differences between the decisions of individuals and groups.⁶

All subjects were recruited from a wide cross-section of undergraduates at Purdue University. A computerized interface using the software z-tree was adopted to implement the experimental environment (Fischbacher, 2007). Instructions were read aloud while subjects followed along on their own copy. Subjects were given a quiz on the computer to verify their understanding of the instructions before the games were played. For each correct answer, they earned 50 cents. More than 90% of the quiz questions were answered correctly in all sessions.

In treatment 3x5 NC, treatment 3x5 C and treatment 1x1 G, 16 subjects were randomly and anonymously placed into either a 3-person group or a 5-person group. Each 3-person group was then paired with one of the 5-person groups to form a single session of 8 subjects. Group compositions remained the same for the first 10 periods. Before the start of period 11, subjects were regrouped.⁷ After the regrouping, another 10 periods were played. Subjects' own group decision, the decision of the opponent group, subjects' individual earnings for each period and the cumulative individual earnings were provided at the end of each period. Similarly, in treatment 1x1 I, 16 subjects were randomly split into 8 sessions and assigned to two roles: Person A (endowed with 3 tokens) or Person B (endowed with 5 tokens). The role of subjects were fixed for the first 10 periods and switched at the beginning of period 11 for another 10 periods. Decisions made by the two subjects as well as subjects' individual period and cumulative earnings were reported at the end of each period.

⁶ A detailed literature review of studies on the general differences in the decisions of individuals and groups is provided in section 4.

⁷ All subjects in the 3-person group were matched with two randomly selected 5-person group members to form a new 5-person group. The remained three 5-person group members participated as a new 3-person group. The regrouping occurred separately within the two sessions in the lab.

Subjects' earnings were designated in "experimental tokens". They were paid for all periods, and their cumulative token balance was converted to U.S. dollars at a rate of 4 tokens to one dollar for the group treatment and 20 tokens to one dollar for the individual treatment. Sessions with communication typically lasted for 60-75 minutes including instructions, while sessions without communication proceeded more quickly, some as short as 35 minutes. The average per-person earnings are \$15 for short sessions and \$20 for long sessions.

4. Predictions, Hypotheses and Results

We conducted all sessions with a prize of 18 tokens. This parameter choice generates relatively distinct types of equilibrium. We refer to one equilibrium as Type H to reflect the higher contribution rates from both groups relative to the other Type L equilibrium. Table 2 presents the theoretical predictions and data in treatment 3x5 NC pooling across sessions.⁸

Table 2: Theoretical predictions and data in treatment 3x5 NC

	Individual Contr. Rate		P(large wins)	P(large ties)	P(large loses)
	Small	Large			
3x5 Game Type L Eq.	0.48	0.03	2.0%	17.3%	80.7%
3x5 Game Type H Eq.	0.91	0.74	67.1%	23.4%	9.5%
3x5 NC data	0.64	0.56	56.7%	25.8%	17.5%

As Table 2 shows, in both equilibria, small group contributes at higher rate than large group. Large group loses most of the time (80.7%) in Type L equilibria because large group rarely contributes. In Type H equilibria, groups compete aggressively at an individual contribution rate of 0.91 in small group and 0.74 in large group. Despite the size advantage, large group is able to win just over half of the time (56.7%). Small group still has 9.5% chance to win.

The theoretical predictions highlight the fact that small group members contribute more often than large group members. Three hypotheses are formed based on the theoretical predictions.

Hypothesis 1: Without communication (treatment 3x5 NC), the relative individual contribution rate is higher in the small group than in the large group.

Hypothesis 2L: Without communication (treatment 3x5 NC), the large group rarely contributes and loses most of the time.

Hypothesis 2H: Without communication (treatment 3x5 NC), both groups contribute the majority of the time. The small group still has a reasonable chance to win the game in spite of the size disadvantage.

⁸ The equilibrium predictions we report here is derived from a one shot game. In our experiment subjects played a repeated game with fixed grouping and were informed that the session would last for 20 periods. Thus the stage game equilibrium predictions also hold for this finitely repeated game.

Results 1: Hypothesis 1 is supported.

Results 2: Hypothesis 2H is supported.

Results are reported in Table 2. In treatment 3x5 NC, the individual contribution rate is higher in the small group than in the large group. Data are completely at odds with Type L equilibrium. Groups were competing aggressively. Averaging across six sessions, the large group only wins the game 56.7% of the time and ties the game 25.8% of the time.

To form a set of testable hypotheses for the communication treatment, we thus consider the extreme benchmark where within-group communication completely eliminates the free-riding incentives in the group competition. In this case, members of each group are able to reach an agreement to coordinate their individual choices and act as one agent and also believe that members of the other group behave in the similar fashion. This implies a restructuring of the group competition into a two-player nonzero-sum game (hereafter, 1x1 game; we refer to the group competition as 3x5 game corresponding to 1x1 game.): A small player endowed with 3 tokens and a large player endowed with 5 tokens, decide how many tokens out of their endowments to contribute to a group account. Contributions are not refundable. The player with higher contributions wins a prize of 18 tokens and the player who loses gets no prize. When there is a tie, each player gets 9 tokens. Treatment 1x1 I and treatment 1x1 G are designed based on the 1x1 game. The key difference between these two treatments is whether the two players in the game are two individuals (1x1 I) or two groups of 3 members and 5 members each (1x1 G).

Given the payoff structure of the 1x1 game, it is straightforward to solve the mixed strategy Nash equilibria for the 1x1 game. Figure 2 compares the predicted probability mass function of group level contributions in the 3x5 game and in the 1x1 game.⁹

The white bars in the figures display the predictions in the 3x5 game while the black bars represent the predictions in the 1x1 game. In the 1x1 game, the small player should abstain from the competition about 78% of the time. This is quite different from the prediction in the 3x5 game where the most frequent choice for the small group is to contribute 3 tokens 75% of the time. On the other hand, the large player in the 1x1 game should contribute 4 tokens 78% of the time and either 1 token or 3 tokens the rest of the time. By contrast, in the 3x5 game, the distribution of contributions in the large group is much more dispersed. Note that the large group is expected to contribute 5 tokens about 22% of the time.

⁹ The proof of the Nash equilibria can be found in the appendix I. In the 1x1 game, there are two sets of mixed strategy Nash equilibria for the small player. They are very similar and behaviorally indistinguishable. We only present one of them in figure 2. The mixed strategy Nash equilibria for the large player is unique as shown in figure 2. The frequency of contributions in the 3x5 game is calculated using the type H equilibria value. As we documented earlier, the data are completely at odds with the type L equilibria. Thus we focus on examining the type H equilibria here.

Yet, only four tokens are needed for the large group to beat the small group. This highlights the fact that miscoordination within the large group causes inefficiency.

Figure 2: Theoretical comparison between the 3x5 Game and 1x1 Game

Table 3 presents the predicted average group contributions, average group earnings and the probability the large group wins, ties and loses the game in the 3x5 game and the 1x1 game along with the data we observed in four treatments.

Table 3: Theoretical predictions and observed data¹⁰

	Average Group Contribution		Average Group Earnings		P(large wins)	P(large ties)	P(large loses)
	Small	Large	Small	Large			
3x5 Game Prediction	2.74	3.68	6.78	15.52	67.1%	23.4%	9.5%
1x1 Game Prediction	0.44	3.56	3.00	19.00	96.3%	2.5%	1.2%
Data: 3X5 NC	1.92	2.78	6.56	14.75	56.7%	25.8%	17.5%
Data: 3x5 C	1.07	3.70	3.36	17.88	88.3%	7.5%	4.2%
Data: 1x1 G	0.84	3.48	3.84	17.85	89.3%	2.9%	7.9%
Data: 1X1 I	1.21	3.52	3.45	17.82	85.9%	9.7%	4.4%

Recall that the 1x1 game is structured as the extreme benchmark where within-group communication completely eliminates the free-riding and miscoordination problems. Based on the theoretical comparison between the 3x5 game and the 1x1 game, we form the following hypotheses:

Hypothesis 3: Within-group communication (treatment 3x5 C) helps to reduce free-riding and miscoordination. The small group abstains from contributing quite often and the large group is able to

¹⁰ All the data reported in this paper are pooled across all periods and all sessions for a given treatment.

win the game most of the time. This leads to relatively higher earnings for the large group and lower earnings for the small group compared to the no communication case (treatment 3x5 NC).

Result 3: Hypothesis 3 is supported.

As shown in Table 3, the probability the large group wins the game increases from 56.7% to 88.3% when within-group communication is allowed. Figure 3 reports the observed distributions of contributions in treatment 3x5 NC and treatment 3x5 C. When we permit communication, the most conservative Mann-Whitney test which takes each session as independent data indicates that: 1) Average group contributions decrease significantly in small groups ($n=m=6$; $z = -2.330$, $p = 0.0198$) and increase significantly in large groups ($n=m=6$; $z = 2.887$, $p\text{-value} = 0.0039$). 2) Average group earnings decrease significantly in small groups ($n=m=6$; $z = -2.882$, $p\text{-value} = 0.0039$) and increase significantly in large groups ($n=m=6$; $z = 2.882$, $p\text{-value} = 0.0039$). 3) There is a statistically significant decrease in the probability that small groups win the game ($n=m=6$; $z = -2.908$, $p\text{-value} = 0.0036$).

Figure 3: Data comparison between 3x5 NC sessions and 3x5 C sessions

Our extreme benchmark captures the idea that pre-play within-group communication results in a restructuring of the game with members of each group coordinating their individual strategies and acting as a single group. The next hypothesis follows.

Hypothesis 4: Within-group communication leads group members to act as one agent when making decisions. Thus contribution decisions made by groups in treatment 3x5 C are not different from those made in treatment 1x1 G.

Result 4: Hypothesis 4 is supported.

Mann-Whitney test reports no significant difference in average group contributions, average group earnings and the probability small group wins in both types of groups. Recall that in treatment 1x1 G, the incentive to free-ride is removed by the structure of the game. Also, the observed distributions of contributions in both groups in treatment 1x1 G and treatment 3x5 C line up closely (Figure 4). Thus this result tells us that group level contributions are not significantly different in the presence or the absence of the free-riding incentives as long as groups have the opportunity to communicate. This result is consistent with the finding in Sutter and Strassmaire (2009) examining effort-choices in team tournaments.

Figure 4: Data comparison between 1x1 G sessions and 3x5 C sessions

The comparison between treatment 1x1 I and treatment 1x1 G allows us to examine whether groups behave differently from individuals.

Literature in social psychology and economics has provided compelling evidence that group behavior is different from individual behavior.¹¹ Concerning the performance of groups in inter-group

¹¹ For example, in the games with no strategic interactions, groups are just as quick as individuals to reach decisions and require no more information than the individuals before coming to a decision (Blinder and Morgan, 2005); groups gain higher expected payoffs at a significant lower risk in investment games (Rockenbach, et al., 2007) or at a constant level of risk in lottery choices (Sutter, 2007). In the strategically interactive games, groups demand more in the role of proposers and accept

competitions, psychologists report that inter-group relations tend to be highly competitive as compared to individual relations under the same functional conditions (Tajfel, 1982; McCallum et al., 1985; Insko et al., 1987). Evidence supporting this observation has also been reported by economists. Cox and Hayne (2006) find that groups bid more competitively than individuals when they have more information about the value of the auctioned item, which leads to more overbidding and less profit than individuals in a common value auction game.

Based on these findings, we form the last hypothesis:

Hypothesis 5: Contribution decisions made by groups in treatment 1x1 G are different from those made by individuals in treatment 1x1 I since groups perceive the situation more competitively than individuals.

Result 5: Hypothesis 5 is not supported.

The Mann-Whitney tests on the average group contributions and average group earnings of both groups and the probability the small group wins indicate no significant difference across the two treatments. The comparison of the frequencies of contribution in the two treatments (Figure 5) also supports this conclusion.

Figure 5: Data comparison between 1x1 G sessions and 1x1 I sessions

lower offers in the role of responders in the ultimatum game (Bornstein and Yaniv, 1998); groups exit the centipede game earlier (Bornstein, et al. 2004); groups exert less efforts as second movers in a gift-exchange game (Kocher and Sutter, 2007); groups play more strategically in signaling game (Cooper and Kagel, 2005); groups perform better in terms of payoffs in beauty-contest game (Kocher and Sutter, 2005). In the trust game, Cox (2002) observes that groups return less in the role of responders but reports no differences in the role of senders; By contrast, Kugler et al. (2007) find that returns of groups and individuals are not significantly different but groups send smaller amounts than individuals. Experimentalists also report inconsistent results in the dictator game. Cason and Mui (1997) find groups behave more altruistically than individuals whereas Luhan, Kocher and Sutter (2007) show that group decisions are more selfish and less altruistic than individual decisions.

5. Content Analysis

At this point we know that communication reduces free-riding behavior and leads group members to act as one agent in making decisions. This brings us to the heart of the matter: what kinds of messages are linked to this effect? We use content analysis to answer this question.

We used the following procedure to systematically quantify the recorded messages. First, we randomly selected a test sample from pilot sessions to develop a coding scheme which classifies messages into different categories. Second, we employed two undergraduate coders, trained separately, to independently read all messages and classify all messages according to the coding scheme. They were not informed about any hypotheses of the study.¹² We implemented binary coding—a message is coded as a 1 if it is deemed to contain the relevant category of content and 0 otherwise. Each message can be coded under as many or few categories as the coders deem appropriate. Category1 has six sub-categories. Coders are free to code a message under as many or few sub-categories as they desire.

Cohen's Kappa K is used to measure coders' agreement which follows the conceptual formula:

$$\text{Chance-corrected agreement} = \frac{P_a - P_c}{1 - P_c}$$

where P_a is the proportion of messages that both coders agree on and P_c is the proportion of agreements expected by chance. The denominator quantifies the difference between perfect agreement and expected chance agreement. The numerator quantifies the difference between the observed agreement and the expected chance agreement. Thus, this measure quantifies agreement as the proportion of the difference attained between perfect agreement and chance agreement. If $P_a = P_c$ agreement and therefore reliability equals zero. Reliability is greater than zero only if the proportion of agreements exceeds the proportion of agreement expected by chance (i.e., $P_a > P_c$). It is possible for reliability to be less than zero if the coders agree less than expected by chance (i.e., $P_a < P_c$). In that case, reliability should be treated as

¹² The instructions for coders are attached in appendix III.

zero. For reliability of quantitative measurements, 0.7 is generally acceptable (Neuendorf, 2005). But for chance corrected measures of agreement, we should be more lenient in our definition of acceptability because correction for chance sometimes makes it nearly impossible to achieve agreement above 0.7 (Hayes, 2005). We, therefore, take $K \geq 0.6$ as a satisfactory reliability standard.

Table 4 Coding Table and Reliability Indexes¹³

Category	Description	Reliability (Cohen's Kappa K)			
		1x1 G		3x5 C	
		Large	Small	Large	Small
1	Coordination on the contribution level for the current period	0.88	0.88	0.82	0.88
1a	Propose a specific contribution level	0.91	0.86	0.46	0.76
1b	Ask for the opinions of other group members (should not specifically refer to a contribution level)	0.58	0.75	0.64	0.59
1c	Disagree with group members' proposals	0.85	0.82	0.50	0.57
1d	Agree with group members' proposals on the contribution level	0.88	0.86	0.39	0.81
1e	Propose to rotate or explicitly designate contributors and (or) non-contributors	N/A	N/A	0.93	0.86
1f	Push for consensus on the contribution level	0.83	0.77	0.48	0.54
2	Appeal to fool the other group across periods (be unpredictable, to trick them, pretend to be predictable)	0.83	0.84	0.56	0.73
3	Make choices by reasoning from the other group's point of view	0.86	0.88	0.78	0.83
4	Discussion about benefits for own group	0.82	0.83	0.77	0.82
5	Discussion about benefits for the other group	0.85	0.88	0.74	0.67
6	Reference to the previous choices of the other group	0.83	0.62	0.58	0.64
7	Reference to the previous choices of own group	0.82	0.84	0.78	0.91
8	Reference about the size asymmetry	0.74	0.83	0.78	0.68
9	Reference to the game rules	0.81	0.71	0.80	0.51
10	Appeal to play safe	0.74	0.69	0.66	0.48
11	Appeal to take risks	0.63	0.80	0.60	0.53
12	Comments about time	0.76	0.90	0.50	0.64
13	Discussion about what game they are actually playing	0.81	0.88	0.85	0.73
14	Use of humor	0.51	0.33	N/A	N/A
15	Other	0.85	0.88	0.83	0.82

Table 4 displays the coding scheme along with the reliability indexes Cohen's Kappa K for the two treatments. For the vast majority of our main categories, $K \geq 0.6$ or is slightly below 0.6. Unsatisfactory agreement levels are found in a few of the main categories and some sub-categories resulting from infrequent coding. All discussions of codings hereafter are based on the average of the two independent codings, unless otherwise stated. Specifically, the value of the codings is treated as 1 if two coders agreed that a message belongs to a given category; 0 if the two coders agreed that a message does not belong to a given category; 0.5 if two coders disagreed with each other. Table 5 compares the frequency of codings for the two treatments. It also reports the ratios of coding frequencies between

¹³ In treatment 1x1 G, category 1 refers to "Propose how many tokens to contribute as a group" while in treatment 3x5 C, it refers to "Propose how many people contribute to the group account and/or keep to the individual account". Subcategory 1e and subcategory 1f only apply to treatment 3x5 C. Messages that appeal to play safe under category 10 are associated with contributing 0 tokens in the small group and contributing 4 tokens in the large group. By contrast, messages that appeal to take risks under category 11 mean to increase contributions in the small group and decrease contributions in the large group. Typical messages fell into this category 13 are: "you realize... we're comparable to Wal-Mart beating up on the small grocery stores"; "that's gambling basically, this whole experiment is gambling; that's what these experiment people were looking." An example of messages coded under category 14 is "Don't give them an inch. They fooled us once. Fool me once, shame on you, fool me twice, shame on... fool me a third time oh shit—George Bush."

small groups and large groups across the two treatments as well as the ratio of coding frequencies between the two treatments.

Table 5: Comparison of Frequencies across Treatments and across Group types¹⁴

Category	Description	1x1 G Treatment			3x5 C Treatment			Ratio	
		Frequency of Codings			Frequency of Codings			(1x1 G/3x5 C)	
		Large	Small	Ratio (L/S)	Large	Small	Ratio (L/S)	Large	Small
1	Coordination on the contribution level for the current period	44.25%	35.06%	1.26	56.93%	35.45%	1.61	0.78	0.99
1a	Propose a specific contribution level	4.35%	5.87%	0.74	3.83%	8.15%	0.47	1.14	0.72
1b	Ask for the opinions of other group members	1.67%	2.75%	0.61	3.11%	3.98%	0.78	0.54	0.69
1c	Disagree with group members' proposals	4.99%	2.79%	1.79	4.58%	4.46%	1.03	1.09	0.62
1d	Agree with group members' proposals on the contribution level	29.83%	20.54%	1.45	12.40%	17.80%	0.70	2.41	1.15
1e	Propose to rotate or explicitly designate contributors and (or) non-contributors	N/A	N/A	N/A	36.48%	0.44%	83.57	N/A	N/A
1f	Push for consensus on the contribution level	3.99%	3.34%	1.19	2.02%	2.42%	0.83	1.98	1.38
2	Appeal to fool the other group across periods	7.31%	8.06%	0.91	9.43%	6.35%	1.48	0.78	1.27
3	Make choices by reasoning from the other group's point of view	7.33%	9.53%	0.77	3.55%	11.98%	0.30	2.06	0.80
4	Discussion about benefits for own group	10.12%	8.65%	1.17	6.39%	8.15%	0.78	1.58	1.06
5	Discussion about benefits for the other group	1.38%	1.77%	0.78	0.85%	0.68%	1.26	1.62	2.61
6	Reference to the previous choices of the other group	2.72%	2.88%	0.94	2.22%	3.98%	0.56	1.23	0.73
7	Reference to the previous choices of own group	24.30%	4.75%	5.11	6.32%	4.51%	1.40	3.85	1.05
8	Reference about the size asymmetry	2.47%	4.23%	0.59	2.29%	3.73%	0.61	1.08	1.13
9	Reference to the game rules	2.07%	3.87%	0.54	1.37%	2.96%	0.46	1.52	1.31
10	Appeal to play safe	5.53%	2.20%	2.52	2.87%	1.75%	1.64	1.93	1.26
11	Appeal to take risks	2.34%	2.16%	1.08	0.96%	2.13%	0.45	2.45	1.01
12	Comments about time	0.82%	1.93%	0.43	0.27%	0.53%	0.51	3.02	3.62
13	Discussion about what game they are actually playing	0.62%	0.92%	0.68	0.27%	0.19%	1.41	2.28	4.73
14	Use of humor	1.14%	1.21%	0.94	0.58%	0.82%	0.70	1.96	1.47
15	Other Messages	17.30%	18.71%	0.92	18.34%	24.10%	0.76	0.94	0.78

The most frequently coded category is category 1 in both treatments. It codes messages that coordinate individual choices by some specified decision rules, occurring for more than 35% of the time in both types of groups. The six sub-categories under category 1 help us to identify the different strategies groups adopt to coordinate their members' behavior. In treatment 1x1 G, the large group used majority rule to reach the unanimous decision as shown in the following messages: "group strategy proposal: if our decision is not agreed on the first round, we do NOT want to get caught with our pants down voting "0" because of disagreement.... so if somebody disagrees, go to the most voted number." Thus, we observe more messages falling into category 1d (Agree with group members' proposals on the contribution level) and category 1f (Push for consensus on the contribution level) in treatment 1x1 G relative to treatment 3x5 C. On the other hand, in treatment 3x5 C, the large groups came up with the rotation strategy where the member with the same ID number as the period number was designated as the non-contributor in that period. The following messages were sent in a large group: "if one of us holds individual we will maximize what we can make cause they can't get more than 3, take turns according to rounds and don't be selfish; member 1 hold everyone else group, we will rotate to 2 next time and so on". This strategy was followed from period 1 to period 4. In period 5 some new ideas came into the large group: "hey...for this round only 1 person should put it into the group account...everyone

¹⁴ In 1x1 G treatment, the large group sent out 2243 messages in total and small group sent 1526 messages. In 3x5 C treatment there are 1463 messages sent out in the large group and 1031 messages in the small group.

else the other...coz they are always 0". The large group formed the strategy of contributing 1 token as a group instead of contributing 4 to optimize group earnings. And they actually rotated to be the non-contributor to equalize individual earnings. By contrast, the small group rarely rotated or explicitly designated contributors or non-contributors. The small group members' strategy was typically to contribute either everything (59% of the time) or nothing (31% of the time).

Another common strategy adopted by both types of groups is to fool the other group across periods. A typical quote from the large group in treatment 3x5 C is "We need to bet 4 for several rounds to make them confident we won't budge, and then while they are betting zero, we'll bet 1 for 1 round and get lots of earnings, and then go back to betting 4. So let's start off doing 4 for the first several rounds. We need to get them to establish a solid few sets of zeros." A quote from the small group is "that's why if we are going to do it [everyone contributes] we have to be completely random." These messages fall into category 2. This indicates that subjects understand the essence of mixed strategy equilibrium and try to implement their decisions in an unpredictable way across periods.

To decide the contribution level, groups spent a fair amount of time on reasoning from the other group's point of view in both treatments. For example, in treatment 1x1 G, after observing a previous "1 token" choice of the small group, one member in the large group said "ok they are going for a 0 now sure, let us go for 1" Another member responded: "Remember!: they are thinking the exact same thing we are, 4 is our only guarantee. They [small] think we think they're gonna put 0, so they'll try 3, let's just stick with 4." Thus category 3 reveals the strategic sophistication of the subjects. It provides evidence for the Level-K thinking model (Crawford and Iriberri, 2007a, b).

Discussions about monetary benefits were coded under category 4 and 5. For the majority of the time, group members focused on their own group benefits. They specified payoffs associated with all potential strategies. For example, messages sent out by the members of the large group in treatment 1x1 G: "so if do 1 and win we get 4.4, if we 4 & win we get 3.8 & if we do 1 & lose we get .6"; "if we choose 3 and win, we get an extra nickel, if we choose 3 and tie, we lose 80 cents." This suggests that reinforcement learning model which assumes subjects know absolutely nothing about the forgone or historical payoffs from strategies they did not choose is a poor model by itself of group learning (Erev, I. and Roth, A., 1998).

Moreover, the reference to the previous choices made by the other group suggests that subjects update beliefs about what other group would do based on history and use those beliefs to determine which strategies are the best. Typical quotes in the large group falling into this category are: "they never did 3 or 0 three times a row before."; "last time we did 1 they tried beating us for like 5 rounds after." A Belief-based learning model seems to better capture the data, given this direct evidence that players look

back at what other players have done previously and also give weights to forgone payoffs from unchosen strategies (Crawford, 1995).

Groups referred to their own choices in the previous rounds much more often in treatment 1x1 G than in treatment 3x5 C. They either cheered for their success, “our group rocks” or regretted the choices, “Damn it, I told you guys 1 wouldn’t work, stick with 4.” This reflects strong group identity in treatment 1x1 G due to the absence of the free-riding incentive.

Just because a category of message is used frequently doesn’t necessarily mean it accomplishes much. Table 6 reports the results of the probit regressions on the contribution decisions made in the large group across treatments. The dependent variable is whether or not the large group contributed 4 tokens in a given period. Table 7 reports the results of the probit regressions on the contribution decisions made in the small group across treatments.¹⁵ The dependent variable is whether or not the small group contributed 0 tokens in a given period (Model 1) and whether or not the small group contributed 3 tokens in a given period (Model 2). The independent variables are the numbers of messages coded under each category in a given period. Categories that are coded less than 2% of the time are not included in the regression. We also include three lagged dummies to control for any effects from observing last period outcome. They are whether large group contributed 4 tokens in the last period, whether small group contributed 3 tokens in the last period and whether small group contributed 0 tokens in the last period. Also, messages in category 1e “Propose to rotate or explicitly designate contributors and (or) non-contributors” and category 2 “Appeal to fool the other group across periods” may affect contribution decisions over a few periods as they are often referring to multi-period strategies. We thus include up to 3-period lag of relevant variables in regressions. All models include dummies to capture the differences among sessions and a time trend variable (expressed as 1/period) as well. Standard errors are corrected for clustering at the group level.

Now let us discuss the marginal effects of the messages exchanged upon the large groups’ contribution decisions of 4 tokens. In treatment 1x1 G, communication significantly improves coordination in two ways: through communication, group members are able to push for a consensus of contributing 4 tokens (category 1f); also, communication enables them to coordinate across periods and strategize unpredictable decisions. This in turn reduces free-riding behavior that is due to the uncertainty about other group members’ intentions across periods (category 2). In treatment 3x5 coordination

¹⁵ The reason to use binary probit regressions instead of ordered probit regressions is that there are several strong modes in the contribution decisions—contributions of 4 tokens in the large group (78.6% of the time in treatment 1x1 G and 65.8% of the time in treatment 3x5 C); contributions of 0 tokens (68.6% of the time in treatment 1x1 G and 59.2% of the time in treatment 3x5 C) and contributions of 3 tokens (25% of the time in treatment 1x1 G and 30.8% of the time in treatment 3x5 C) in the small group. The parallel regression assumption is violated in the ordered probit model.

through the rotation strategy (category 1e) is effective in reducing the free-riding and making groups act as one agent. Messages about being random to fool the other group across periods (category 2) significantly affect group decisions up to 3 periods. One typical quote from the large group can explain the positive effect in the current period and the negative effects in lag periods: “let us do 4 for 2 to 3 rounds and then drop to 1.”

Table 7 reports the marginal effects of messages on the small groups’ contributions of 0 tokens and 3 tokens. We observe similar effects of category 2 in small group decisions. Messages about making choices by reasoning from the other group’s point of view (category 3) make the small group to contribute 0 tokens less often and 3 tokens more often. This is clear when we look at a typical message under this category: “they [large group] will get greedy and go down soon after a few 4.” Another interesting finding from lagged variables is that small groups understand that large groups are trying to be unpredictable. If the large group contributed 4 tokens in the last period, it is unlikely that they would reduce contribution to 1 in the consecutive period. Thus, to best respond to that, small groups keep contributing 0 in the current period.

Several other categories of messages have significant effects on groups’ decisions across treatments. In large groups, playing safe means to contribute 4 tokens to ensure a win in large groups and taking risks means to contribute less. By contrast, in small groups, playing safe means to contribute 0 tokens to save the endowment and taking risks means to contribute more. Our regressions correctly capture these effects as can be seen from the coefficients on categories 10 and 11 in Tables 6 and 7. Also, messages about the size asymmetry (category 8) increase large groups’ contributions but decrease small groups’ contribution. Lastly, discussions about benefits for own group (category 4) increases small groups’ contributions. This is because these discussions emphasized the fact that the individual share of the prize in the small group is more than in the large group.

Table 6: Probit regressions on large group contribution decisions

<i>Dependent variables:</i> 1= the large group contributed 4 tokens in a given period, 0= otherwise		Treatment 1x1 G	Treatment 3x5 C
<i>Independent variables:</i> (coding categories)			
1a	Propose how many people to contribute to the group account	-0.031 (0.071)	0.185* (0.110)
1b	Ask for the opinions of other group members		-0.150* (0.078)
1c	Disagree with group members' proposals	-0.052** (0.024)	-0.102** (0.044)
1d	Agree with group members' proposals on the contribution level	-0.017 (0.034)	-0.058 (0.055)
1e	Propose to rotate or explicitly designate contributors		0.067*** (0.016)
1f	Push for consensus on the contribution level	0.188** (0.078)	-0.253* (0.135)
2	Appeal to fool the other group across periods (e.g., be unpredictable)	0.027** (0.014)	0.026 (0.042)
3	Make choices by reasoning from the other group's point of view	-0.112 (0.099)	0.041 (0.079)
4	Discussion about benefits for own group	0.034 (0.042)	-0.051 (0.048)
6	Reference to previous choices for the other group	0.011 (0.032)	-0.116** (0.056)
7	Reference to the previous choices of own group	0.104 (0.147)	-0.030 (0.040)
8	Reference about the size asymmetry	-0.050 (0.068)	0.329*** (0.080)
9	Reference to the game rules	-0.007 (0.011)	
10	Appeal to play safe	0.116 (0.091)	0.386*** (0.086)
	1/period	-0.250 (0.748)	-1.706 (2.117)
	Lag1 dummy (1 if large group contributed 4 tokens in the last period)		-0.274*** (0.020)
	Lag1 dummy (1 if small group contributed 3 tokens in the last period)	0.244 (0.286)	0.172 (0.119)
	Lag1 dummy (1 if small group contributed 0 tokens in the last period)	-0.070 (0.108)	0.317 (0.208)
	Lag 1: Propose to rotate or explicitly designate contributors	0.001 (0.114)	0.018 (0.013)
	Lag 1: Appeal to fool the other group across periods		-0.080** (0.032)
	Lag 2: Propose to rotate or explicitly designate contributors	0.004 (0.009)	0.008 (0.016)
	Lag 2: Appeal to fool the other group across periods		-0.148*** (0.035)
	Lag 3: Propose to rotate or explicitly designate contributors	-0.007 (0.010)	0.038** (0.019)
	Lag 3: Appeal to fool the other group across periods		-0.065*** (0.019)
	Number of observations	0.022 (0.014)	68.00
	Log likelihood	66.00	-20.86

Notes: marginal effects; Robust standard errors in parentheses, clusters on groups.
Statistical significance *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 7: Probit regressions on small group contribution decisions

<i>Dependent variables:</i> Model 1: 1= the small group contributed 0 tokens in a given period, 0= otherwise		Treatment 1x1 G	Treatment 3x5 C	Treatment 1x1 G	Treatment 3x5 C
Model 2: 1= the small group contributed 3 tokens in a given period, 0= otherwise		Model 1 (0 tokens)	Model 1 (0 tokens)	Model 2 (3 tokens)	Model 2 (3 tokens)
<i>Independent variables</i>					
<i>Coding categories</i>					
1a	Propose how many people to contribute to the group account	-0.197 (0.303)	0.124 (0.297)	0.168*** (0.044)	0.022 (0.095)
1b	Ask for the opinions of other group members	0.269 (0.231)	0.100 (0.165)	-0.040 (0.115)	-0.008 (0.129)
1c	Disagree with group members' proposals	0.100 (0.093)	-0.098 (0.152)	-0.191*** (0.035)	-0.111 (0.075)
1d	Agree with group members' proposals on the contribution level	-0.127*** (0.033)	-0.139*** (0.044)	0.083*** (0.018)	0.106*** (0.018)
1e	Push for consensus on the contribution level		-0.140* (0.082)		-0.028 (0.072)
2	Appeal to fool the other group across periods	-0.321*** (0.053)	-0.121*** (0.014)	0.080 (0.058)	0.167*** (0.065)
3	Make choices by reasoning from the other group's point of view	-0.532*** (0.112)	-0.125*** (0.048)	0.159*** (0.054)	0.256*** (0.061)
4	Discussion about benefits for own group	-0.197*** (0.028)	-0.058** (0.017)	0.279*** (0.020)	0.024 (0.028)
6	Reference to previous choices for the other group	-0.106** (0.050)	-0.004 (0.101)	0.018 (0.025)	-0.029 (0.043)
7	Reference to the previous choices of own group	-0.104 (0.597)	-0.005 (0.042)	0.278*** (0.076)	0.014 (0.030)
8	Reference about the size asymmetry	-0.027 (0.081)	0.142 (0.092)	-0.023* (0.013)	-0.141** (0.065)
9	Reference to the game rules	0.005 (0.014)	-0.065 (0.040)	-0.008 (0.016)	-0.003 (0.022)
10	Appeal to play safe	0.222 (0.136)		-0.128** (0.055)	
11	Appeal to take risks	-0.300 (0.525)	-0.242** (0.098)	-0.005 (0.239)	0.196*** (0.056)
	1/period	-2.815 (2.385)	-2.553** (1.040)	0.190 (1.237)	0.383 (0.588)
	Lag1 dummy (1 if small group contributed 0 tokens in the last period)	0.441** (0.223)	0.224 (0.153)	-0.149 (0.141)	-0.143 (0.251)
	Lag1 dummy (1 if small group contributed 3 tokens in the last period)	-0.261 (0.305)	-0.288 (0.274)	0.030 (0.124)	-0.033 (0.099)
	Lag1 dummy (1 if large group contributed 4 tokens in the last period)	0.554*** (0.077)	0.394*** (0.065)	-0.305*** (0.096)	-0.268** (0.129)
	Lag 1: Appeal to fool the other group across periods	-0.004 (0.082)	-0.250 (0.165)	-0.008 (0.028)	0.072 (0.078)
	Lag 2: Appeal to fool the other group across periods	0.038 (0.067)	-0.006 (0.078)	-0.047*** (0.011)	0.026 (0.023)
	Lag 3: Appeal to fool the other group across periods	0.269** (0.105)	0.080 (0.056)		0.015 (0.028)
	Number of observations	67.00	68.00	71.00	68.00
	Log likelihood	-19.90	-23.53	-19.89	-21.01

Notes: marginal effects; Robust standard errors in parentheses, clusters on groups.
Statistical significance *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

6. Conclusion

This paper conducts an experimental study on the effects of communication in a competition between two unequal sized groups over a public good. When group members make a binary decision on whether or not to contribute, we find that communication significantly increases contributions in the large group and deters contributions in the small group. This is because communication makes group members act as one agent in their strategic interactions. Moreover, group level contributions are not significantly different in the presence or the absence of the free-riding incentives as long as groups have the opportunity to communicate. Integrating research methods drawn from sociology and economics, we analyze the content of communication to provide insights into behavior as subjects articulate their strategies in the chat. We find that the categories of messages that help groups to achieve the group outcome and avoid free-riding include messages proposing to rotate or explicitly designating contributors; messages appeal to fool the other group across periods and messages regarding making choices by reasoning from the other group's point of view.

We focus on binary decisions on whether or not to contribute in this study. Yet, the propensity of lowering the level of contributions, but not necessary to contribute zero can only be observed when a continuous strategy space is allowed. We report the effects of communication in a more general form of intergroup competition in Zhang (2009). Group members are asked to make a continuous contribution decision on how much to contribute and an all-pay auction contest success function is used to determine the winner group. Besides documenting similar effects of communication on group contribution decisions, we find that both groups on average contribute less and earn more when they decide how much to contribute rather than whether or not to contribute.

Another interesting extension to explore is how much communication is needed to achieve and maintain coordination in the inter-group competition. Cason and Khan (1999) report that face to face communication dramatically improves subjects' ability to efficiently provide the public good in a single group. They focus on examining the impact of imperfect monitoring in both communication and non-communication settings where subjects can't learn others' public goods contributions instantaneously but every six periods. They show that contributions are increased by communication even with imperfect monitoring. However, improved contribution monitoring alone cannot increase contributions without communication.

Also, adding between-group communication would be a natural extension of our study. Bornstein (1992) investigates between-group communication in a one-shot inter-group public goods game played between two 3-player groups. They show that the possibility of communication with out-group members considerably lowers the in-group member's ability to solve the internal free rider problems. Sutter and

Strassmair (2009) examine the effects of communication on effort-choices in team tournaments. The tournament is repeated for 10 rounds with fixed groups. They find that in the case of between-group communication where any messages are public to both groups, there is significant decrease in efforts due to collusion relative to effort levels when within-group communication is allowed. It is interesting to see how individual and group decisions would alter by the ways the communication infrastructure within and between groups are implemented in our games.

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Appendix I: Expected Payoffs in 3x5 Game

The expected payoff of contributing $EV_i^A(\textit{Contribute})$ for any player i in Group A is:

$$EV_i^A(Contribute) = \frac{r_A}{2} \sum_{j=0}^{n_A-1} \binom{n_A-1}{j} p^j (1-p)^{n_A-j-1} \binom{n_B}{j+1} q^{j+1} (1-q)^{n_B-j-1} \\ + r_A \sum_{j=0}^{n_A-1} \binom{n_A-1}{j} p^j (1-p)^{n_A-j-1} \binom{n_B}{j} q^j (1-q)^{n_B-j} + r_A \sum_{j=1}^{n_A-1} \sum_{k=0}^{j-1} \binom{n_A-1}{j} p^j (1-p)^{n_A-j-1} \binom{n_B}{k} q^k (1-q)^{n_B-k}$$

This expression is the sum of three components. The first component is the expected payoff associated with a tie, i.e., by contributing, player i will change a losing situation into a tie and get $r_A/2$; the second is the expected payoff associated with winning the contest, i.e., by contributing, player i can break the tie and lead his or her group to a victory and get r_A units of rewards; and the third is the expected payoff associated with a wasted contribution, i.e., excluding player i , the number of contributors in Group A has already exceeded the number of contributors in Group B. Player i 's decision of contributing or not will have no effect on the outcome of the contest.

The expected payoff of NOT contributing $EV_i^A(NContribute)$ for any player in Group A is:

$$EV_i^A(NContribute) = e \sum_{j=0}^{n_A-1} \sum_{k=j+2}^{n_B} \binom{n_A-1}{j} p^j (1-p)^{n_A-j-1} \binom{n_B}{k} q^k (1-q)^{n_B-k} + e \sum_{j=0}^{n_A-1} \binom{n_A-1}{j} p^j (1-p)^{n_A-j-1} \binom{n_B}{j+1} q^{j+1} (1-q)^{n_B-j-1} \\ + (e + \frac{r_A}{2}) \sum_{j=0}^{n_A-1} \binom{n_A-1}{j} p^j (1-p)^{n_A-j-1} \binom{n_B}{j} q^j (1-q)^{n_B-j} + (r_A + e) \sum_{j=1}^{n_A-1} \sum_{k=0}^{j-1} \binom{n_A-1}{j} p^j (1-p)^{n_A-j-1} \binom{n_B}{k} q^k (1-q)^{n_B-k}$$

This expression is the sum of four components. The first two components are the expected payoff associated with a loss when player i chooses not to contribute: in the first case, Group A will lose the contest even with player i 's input; in the second case, player i will miss the opportunity to tie the game if he or she chooses not to contribute. The third component is the expected payoff associated with the case when excluding player i , the number of contributors in Group A has already tied the number of contributors in Group B. By not contributing, player i saves his endowment e and gets to share half of the prize $r_A/2$ for a tie. The last component is the expected payoff associated with the case when player i avoids wasting his endowment by not contributing because excluding player i the number of contributors in Group A has already exceeded the number of contributors in Group B.

Similarly, we can get another function of p, q for players in Group B such that $EV_i^B(Contribute) - EV_i^B(NContribute) = 0$, where the expected payoff of contributing $EV_i^B(Contribute)$ for any player i in Group B is:

$$EV_i^B(Contribute) = \frac{r_B}{2} \sum_{j=0}^{n_B-1} \binom{n_B-1}{j} q^j (1-q)^{n_B-j-1} \binom{n_A}{j+1} p^{j+1} (1-p)^{n_A-j-1} \\ + r_B \sum_{j=0}^{n_B-1} \binom{n_B-1}{j} q^j (1-q)^{n_B-j-1} \binom{n_A}{j} p^j (1-p)^{n_A-j} + r_B \sum_{j=1}^{n_B-1} \sum_{k=0}^{j-1} \binom{n_B-1}{j} q^j (1-q)^{n_B-j-1} \binom{n_A}{k} p^k (1-p)^{n_A-k}$$

And the expected payoff of NOT contributing $EV_i^B(NContribute)$ for any player in Group A is:

$$EV_i^B(NContribute) = e \sum_{j=0}^{n_B-1} \sum_{k=j+2}^{n_A} \binom{n_B-1}{j} q^j (1-q)^{n_B-j-1} \binom{n_A}{k} p^k (1-p)^{n_A-k} + e \sum_{j=0}^{n_B-1} \binom{n_B-1}{j} q^j (1-q)^{n_B-j-1} \binom{n_A}{j+1} p^{j+1} (1-p)^{n_A-j-1} \\ + (e + \frac{r_B}{2}) \sum_{j=0}^{n_B-1} \binom{n_B-1}{j} q^j (1-q)^{n_B-j-1} \binom{n_A}{j} p^j (1-p)^{n_A-j} + (r_B + e) \sum_{j=1}^{n_B-1} \sum_{k=0}^{j-1} \binom{n_B-1}{j} q^j (1-q)^{n_B-j-1} \binom{n_A}{k} p^k (1-p)^{n_A-k}$$

With two functions and two unknowns, we can numerically solve the mixed strategy equilibria.

Appendix II: Proof of the Nash equilibria in 1x1 Game

In the case of two-person nonzero-sum game,

	Person B	q_0	q_1	q_2	q_3	q_4	q_5
Person A	Strategies	0	1	2	3	4	5
p_0	0	12,14	3,22	3,21	3,20	3,19	3,18
p_1	1	20,5	11,13	2,21	2,20	2,19	2,18
p_2	2	19,5	19,4	10,12	1,20	1,19	1,18
p_3	3	18,5	18,4	18,3	9,11	0,19	0,18

Note in the large group, action q_5 is strictly dominated by q_4 . Strictly dominated action can not be part of Nash equilibrium. Therefore, probability of playing q_5 is equal to zero. Note also that action q_0 is strictly dominated by q_3 and q_4 and thus by the same logic can not be a part of Nash equilibrium.

By elimination of the strictly dominated strategies, we have reduced our problem to a simple 4 by 4 game.

	q_1	q_2	q_3	q_4
p_0	3,22	3,21	3,20	3,19
p_1	11,13	2,21	2,20	2,19
p_2	19,4	10,12	1,20	1,19
p_3	18,4	18,3	9,11	0,19

To make the small group be indifferent among all the actions of the large group, the large group should set the probabilities so that $E_0 = E_1 = E_2 = E_3$ where E_i is the expected payoff for the small group to choose *Strategy_i*

$$E_0 = 3q_1 + 3q_2 + 3q_3 + 3q_4$$

$$E_1 = 11q_1 + 2q_2 + 2q_3 + 2q_4$$

$$E_2 = 19q_1 + 10q_2 + q_3 + q_4$$

$$E_3 = 18q_1 + 18q_2 + 9q_3$$

By equalizing the above 4 equations, we can solve 4 unknowns. Thus the equilibrium mixed strategies for the large group is to play each strategy at the following probabilities: $q_0 = 0, q_1 = 0.111, q_2 = 0, q_3 = 0.778, q_4 = 0$.

Similarly, to make the large group be indifferent among all the actions of the small group, Small group should set the probabilities so that $\pi_1 = \pi_2 = \pi_3 = \pi_4$ where π_i is the expected payoff for the large group to choose *Strategy_i*

$$\pi_1 = 22p_0 + 13p_1 + 4p_2 + 4p_3$$

$$\pi_2 = 21p_0 + 21p_1 + 12p_2 + 3p_3$$

$$\pi_3 = 20p_0 + 20p_1 + 20p_2 + 11p_3$$

$$\pi_4 = 19p_0 + 19p_1 + 19p_2 + 19p_3$$

By equalizing the above 4 equations, we can solve 4 unknowns. We get two sets of mixed strategies for the small group: $p_0 = 0.778, p_1 = 0.111, p_2 = 0, p_3 = 0.111$ or $p_0 = 0.833, p_1 = 0, p_2 = 0.056, p_3 = 0.111$

Mixed Strategy NE		B	0	0.111	0	0.111	0.778	0
A (1)	A (2)	# of tokens contributed	0	1	2	3	4	5
0.778	0.833	0	12,14	3,22	3,21	3,20	3,19	3,18
0.111	0	1	20,5	11,13	2,21	2,20	2,19	2,18
0	0.056	2	19,5	19,4	10,12	1,20	1,19	1,18
0.111	0.111	3	18,5	18,4	18,3	9,11	0,19	0,18

Plug the equilibrium probabilities into the expected payoffs, we get

$$E_0 = E_1 = E_2 = E_3 = 3 \text{ for the small group.}$$

For the large group, if we consider the first set of mixed strategies

$$(p_0 = 0.778, p_1 = 0.111, p_2 = 0, p_3 = 0.111), \pi_1 = \pi_2 = \pi_3 = \pi_4 = 19.$$

Yet, for the second set ($p_0 = 0.833, p_1 = 0, p_2 = 0.056, p_3 = 0.111$),

$\pi_1 = \pi_3 = \pi_4 = 19, \pi_2 = 18.50$. The large group gets lower payoffs by contributing 2 tokens. That is why the large group never contributes 2 tokens in equilibrium.

Appendix III

General Instructions

This is an experiment in the economics of multi-person strategic decision making. Various research agencies have provided funds for this research. If you follow the instructions and make appropriate decisions, you can earn an appreciable amount of money. The currency used in the experiment is tokens.

Your tokens will be converted to U.S. Dollars at a rate of 4 tokens to one dollar. At the end of today's experiment, you will be paid in private and in cash.

It is very important that you remain silent and do not look at other people's work. If you have any questions, or need assistance of any kind, please raise your hand and an experimenter will come to you. If you talk, laugh, exclaim out loud, etc., you will be asked to leave and you will not be paid. We expect and appreciate your cooperation.

Please pay careful attention during these instructions. When the instructions are completed, you will take a short quiz on your computer to verify your understanding. The computer will record how many quiz questions you answer correctly, and you will be paid **2 tokens** for every correct answer.

The experiment is composed of **two** parts and each part consists of **10** decision-making periods. The payoffs of all **20** periods determine your total earnings.

Now we are reading the instructions for part one.

Instructions-Part One (Treatment 1x1 G)

There are **10** periods in part one. Before we start, the **16** participants in today's experiment will be randomly and anonymously placed into either a **3-person group** or a **5-person group**. You will know how many participants are in your group but you will have no way of knowing which of the participants are assigned to which group. Each **3-person group** will then be paired with one of the **5-person** groups to form a set of **8** participants. The compositions of your group and other groups will remain the same in this part of the experiment. The groups' compositions (or other aspects of the experiment) may or may not change in the second part of the experiment.

Your Decision:

If you are in the **3-person group**, EACH period your group will be given an endowment of **3** tokens. If you are in the **5-person group**, EACH period your group will be given an endowment of **5** tokens. You will be asked to decide **how many** tokens out of your endowment to be allocated to the **group account**. These endowed tokens can NOT be saved for later periods. An example of your decision screen is shown below.

Period 1 out of 1 Remaining time 66

Participant ID: 8

You are in the 5-person group .

Your group is endowed with 5 tokens.

How many tokens do you want to allocate to the group account?

OK

Decision Screen

Before you are asked to make the allocation decision you will have an opportunity to communicate with the members of your own group in a chat window. You will have 90 seconds to chat with each other anonymously. Although we will record the messages that you send, only you and your group members will see them. Note, in sending messages back and forth between you and the other members we request that you follow two simple rules: (1) Be civil to each other and use no profanity and (2) Do not identify yourself.

A sample screen with the chat window is shown on the next page.

Chat Window

You can open your chat window by clicking on the [messenger] tab in the task bar and you can switch back to the decision screen by simply clicking on the decision screen.

Please do not close any windows on the computer during the experiment. Accidentally close the window will cause a delay for about 10 minutes.

When the chat time is over, all group members then make their actual decisions simultaneously. After you make your decision, you will be informed about the actual allocation decisions of your group members. The **unanimous** decision selected by all people in your group will be implemented as your group decision as shown in the **information screen 1** on the next page. A unanimous decision is 3 equal allocation decisions in the 3-person group, or 5 equal allocation decisions in the 5-person group.

In case a group does not have the same allocation decision, a decision screen followed by an information screen will ask all group members to anonymously make their allocation decisions again **without** the access to the chat window (please see **information screen 2** and **decision screen 2** on the next pages). In other words, communication is only allowed once at the beginning of each period.

Groups have up to **10** rounds to reach a unanimous decision. If no unanimous decision is reached in the 10th round, the choice of allocating “0” tokens to the group account will be implemented as the “group decision”.

Period	1 out of 20	Remaining time 14
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Participant ID: 2

Your group members' allocation decisions are:

3
3
3

Your **group** allocation decision reached by the unanimity rule is:

3

Please wait until the other group reaches their group allocation decision.

OK

Information Screen 1: A unanimous decision is reached.

Period	Remaining time 29
<p>Participant ID: 8</p> <p>Your group members' allocation decisions are:</p> <div style="display: flex; justify-content: center; gap: 10px;"> 54555 </div> <p>Your group allocation decision has NOT been reached by the unanimity rule.</p> <p>You have 7 more rounds to make your allocation decisions.</p>	
<input type="button" value="OK"/>	

Information Screen 2: A unanimous decision has not been reached.

Period	Remaining time 111
<p>Participant ID: 8</p> <p>Your group allocation decision has NOT been reached by the unanimity rule.</p> <p>You are in the 5-person group .</p> <p>Your group is endowed with 5 tokens.</p> <p>How many tokens do you want to allocate to the group account?</p> <div style="display: flex; justify-content: center; align-items: center; margin: 10px 0;"> <input style="width: 50px; height: 20px; border: 1px solid black;" type="text"/> </div>	
<input type="button" value="OK"/>	

Decision Screen 2

Your Earnings:

You will share your group earnings **equally** with all other members in your group for each period. Given the decisions that your group and the other group in your set make, your group earnings are calculated in the following way:

- (a) If the total number of tokens in your group account **exceeds** the total number of tokens in the other group account, your group earns a prize of **18** tokens and the other group receives nothing, and vice versa. If the total numbers of tokens in the two group accounts are **equal**, both groups earn a prize of **9** tokens.
- (b) Any endowed group tokens that are allocated to the group account are **NOT** refundable even if you get a prize of **0** tokens.
- (c) Any endowed group tokens that are **NOT** allocated to the group account are directly added to your group earnings.

Here are two examples illustrating the calculations of your period earnings.

Example 1:

The unanimous decision reached by the **3-person group** is to allocate **all** the endowed tokens to the group account while the **5-person group** decides unanimously to allocate **1** token out of 5 in the group account (please see Table 1 below). The number of tokens in the **3-person group** account **exceeds** the number of tokens in the **5-person group** account, thus the **3-person group** earns a prize of **18** tokens and the **5-person group** gets nothing. The group period earnings are the sum of the prize earned from the allocation decision and any endowed tokens that are not allocated to the group account. Your individual earnings are the equal share of your group earnings.

Table 1

Group type	Tokens in the group account	Endowed tokens left	Prize earned	Group earnings	Individual earnings
3-person	3	0	18	$0+18=18$	$18/3=6.0$
5-person	1	4	0	$4+0=4$	$4/5=0.8$

Example 2:

Both the **3-person group** and the **5-person group** make the unanimous decision of allocating **0** tokens to the group accounts (please see Table 2 below). The numbers of tokens in the two group

accounts are equal, thus both groups earn **9** tokens addition to their group endowments that are leftover. Again, your earnings are the **equal** share of your group earnings.

Table 2

Group type	Tokens in the group account	Endowed tokens left	Prize earned	Group earnings	Individual earnings
3-person	0	3	9	$3+9=12$	$12/3=4.0$
5-person	0	5	9	$5+9=14$	$14/5=2.8$

The End of the Period

After both groups in the same set have reached a group decision by the unanimity rule you will be automatically switched to the outcome screen, as shown below. This screen displays your group decision as well as the decision of the other group in your set. It also shows your individual earnings for this period and your individual earnings for the experiment so far.

Period

1 out of 20

Remaining time 28

Participant ID: 8

You are in the **5-person** group.

Total tokens in your group account:

5

Total tokens in the other group account:

3

Your period individual earnings:

3.60

Your cumulative individual earnings:

3.60

OK

Please record the results on your **Personal Record Sheet** under the appropriate headings. Then click on the **OK** button to move to the next period.

Before we start the experiment, please fill out the quiz on the computer. There are a total of **8** questions, each worth **2 tokens**. Thus you can earn **16 tokens** in total if you answer all the questions correctly. Please feel free to refer back to the instructions as you answer the quiz questions. Also feel free to raise your hand to summon an experimenter if you do not understand the explanation for a wrong

answer. Please do not say anything before the experimenter comes to you, as the experimenter will answer your question in private.

Instructions-Part Two

Part two consists of **10** decision-making periods. The rules for this part of the experiment are the same as part one EXCEPT that:

At the beginning of this part of the experiment, you may be **re-assigned** to a different group in your set. Your re-assignment is completely unrelated with your past decisions. Group composition will remain the same for all **10** periods after the reassignment.

Coding Instructions

Purpose: To study how communication affects the play of the game.

Game: Refer to the attached instructions for the experiment.

Coding Rules:

- (1) If a message is deemed to contain the relevant category of content, enter the code for the category in the relevant column beside the message.
- (2) Each message can be coded under as many or few categories as you deem appropriate. Enter the additional codes in columns to the right.
- (3) A number of the categories have sub-categories. You are free to code a message under as many or few sub-categories as you desire. Enter the code(s) of the subcategories in the relevant columns. You do not need to write the super category (for example, if you code a message as 1d, you do not need to also code it as 1).
- (4) It will sometimes be important to look at the timing and context of a message to properly interpret and code it. Sometimes, a particular message is covered across multiple lines, and may also be “interrupted” by others’ messages. The unit of observation is the message, not the line. Enter the code(s) for multi-line messages at the last line of the message, and leave the earlier lines of that message blank.
- (5) You should **independently** code all messages. Do not discuss with anyone about which statements should fall into which categories.
- (6) Your job is to capture what had been said rather than why it was said or what effect it had. Think of yourself as a “coding machine.”
- (7) If you find messages that cannot be coded under any categories, code them as “other.”
- (8) Code the sessions in the chronological order that the sessions were conducted, as explained and presented by your coding supervisor.
- (9) For each period, indicate how many tokens each group agreed to contribute to the group account at the end of the conversation. Put this information on the last line of that period at the last column of the spreadsheet.

Please track the time you spend on coding the messages and training. You will be paid **\$12** for each hour working on this project.

Thanks a lot for your participation in the coding task!