Communication in Asymmetric Group Competition over Public Goods

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Abstract

This paper examines whether and how cheap talk communication can facilitate within-group coordination when two unequal sized groups compete for a prize that is shared equally among members of the winning group, regardless of their (costly) contributions to the group's success. We find that allowing group members to communicate before making contribution decisions improves coordination. To measure how much miscoordination remains, we employ a control treatment where miscoordination is eliminated by asking group members to reach a unanimous contribution decision. Average group contributions are not significantly different in this control treatment. Cheap talk communication thus completely solves miscoordination within groups and makes group members act as a single agent. Furthermore, it is the larger group that benefits from communication at the expense of the smaller group. Finally, content analysis of group communication reveals that after the reduction of within-group strategic uncertainty, groups reach self-enforcing agreements on how much to contribute, designate specific contributors according to a rotation scheme, and quickly discover the logic of the mixed-strategy equilibrium.

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1. Introduction

The notion of public good provision in group competitions 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 which are distributed among members of the winning group, regardless of the extent of their contributions to the group's success. Hence, individual members face the following trade off: within a group, there is an incentive to free ride on other members' costly effort and between groups, there is an incentive to compete for the benefit.

In these competitions, communication among group members is natural and important because the group's respective success in solving the within-group dilemma determines the outcome of the between-group competition. This motivates us to explore the role of within-group cheap talk communication in this environment.[1] Although cheap talk communication is non-binding and costless, previous experimental studies have demonstrated that communication can nevertheless significantly improve cooperation, facilitate coordination and enhance efficiency in various experimental settings.[2] Social psychologists have identified several means by which communication influences behavior: (1) provides information and facilitates understanding of the game; (2) promotes coordination of cooperative actions; (3) reduces strategic uncertainty about other players' behaviors; (4) elicits social norms such as trust, commitment, promise-keeping; and (6) induces conformity due to peer pressure or increased group identity (Kerr and Kaufman-Gilliland, 1994 and Bicchieri 2002). Yet, with a few exceptions that we will review in section 2, these documented effects are observed in situations where strategic interaction is present only within a group.

We are interested in examining how communication affects behavior when strategic interactions take place both within and between groups.[3] Moreover, competing groups of

[1] All discussions about communication hereafter refer to within-group cheap talk communication, unless otherwise stated. The role of other communication channels such as between-group communication is discussed in the conclusion section and will be addressed in future research.

[2] For example, communication improves cooperation in public goods games (Ledyard, 1995), common pool resource games (Hackett et al., 1994; Ostrom et al. 1994), and trust games (Charness and Dufwenberg, 2006, 2011). Communication facilitates coordination and enhances efficiency in games with Pareto-ranked equilibria (Van Huyck et al., 1992).

[3] Many papers have investigated multi-level strategic interactions without the influence of communication. For example, in the strand of literature on voter participation, there are Schram and Sonnemans (1996a), Bornstein et al.

different sizes may make use of the opportunity to communicate in different ways and to different extents. This paper thus focuses on the role of within-group communication in asymmetric conflicts (in terms of relative group size) which has received much less attention than symmetric situations in economic research. Attractive as it is for theoretical analysis symmetry is the exception rather than the rule as asymmetric conflicts are most common in real life. Asymmetry may result in different types of messages exchanged in groups and the same type of messages may shape behavior differently.

Rapoport and Bornstein (1989) is the only paper we are aware of studying the effect of communication in asymmetric group competitions. There are several notable differences between our study and theirs. First, we study a repeated game instead of a one shot game which allows us to observe the dynamic evolution of the effect of communication on group behavior. Second, our design presents a more sever coordination problem for large groups relative to small groups so that large groups value the opportunity to communicate much more than small groups do. This in turn generates some interesting patterns in the way messages are used. Third, besides measuring how much within-group miscoordination is reduced via communication we also measure how much miscoordination still remains in groups. Lastly, instead of face to face communication, subjects in our experiment could send free-form non-binding messages to each other through a chat window at the beginning of each period which enables us to see how subjects respond to the history of the play or layout and adjust a plan across periods, as they articulate in the chat.[4] We then adopt content analysis to systematically translate the qualitative information of the chats into quantitative measures and relate them to outcomes in the experiment. Thus we not only document whether communication affects decision making, but also explicitly reveal why and how communication has such an impact.

The environment we examine resembles the following situation. When a group of people, such as boards of directors, legislatures, committees, or lobbying groups need to reach a decision, communication usually takes place within subgroups before individual votes are cast.

(2005), Cason and Mui (2005), Levine and Palfrey (2007), Duff and Tavits (2008), Kugler et al. (2010), etc. (see Palfrey, 2009 for a detailed review). In the contest literature, there are Nalbantian and Schotter (1997), Abbink et al. (2010), Ahn et al. (2011), to name a few. All these papers do not examine the effect of communication.

[4] Compared to face-to-face communication, chat-room communication preserves anonymity and excludes facial expressions and other non-verbal stimuli as the chat program assigned subjects an id number in the order 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).

The final decision tends to favor the subgroup with more votes. We construct an experiment around the workhorse model of voter participation involving two unequal-sized groups which was first introduced by Palfrey and Rosenthal (1983, hereafter P&R). Each group member decides whether or not to cast a private vote at some cost. The group with the highest turnout gets the prize which is evenly distributed among all members in the winning group. It is a winner-takes-all election which can be seen as a step-level public goods game played within groups, with the threshold determined by the turnout of the opponent group. P&R prove that Nash equilibrium with positive turnout exists. And in some cases, the large group turns out less heavily than the small group. This environment departs from the classic single-group public goods game by introducing between-group conflict. It also differs from the traditional literature on contest games where the competitors are modeled as unitary players, which rules out within-group conflict.

To investigate the effect of cheap talk communication in this game, we employ four treatments in a between-subject design. The voting decision was presented as whether or not to contribute endowed tokens to the group account. The stage game was played for 20 periods in the no communication treatment. In the communication treatment, subjects can exchange messages with other group members at the beginning of each period before making individual contribution decisions. Besides the communication and no communication treatments, two control treatments are conducted. In one treatment, within-group conflict is eliminated by asking individual members to reach a unanimous group decision on how much to contribute and share the contribution cost equally. By comparing the outcomes of this control treatment to those in the original communication treatment, we are able to isolate how much miscoordination still remains in the communication treatment. In the other treatment, two groups of unequal sizes are replaced with two individuals with unequal endowments competing for the prize. This contributes to the discussion of whether groups behave differently than individuals in strategic tasks.

When there is no communication, we identify a particular mixed strategy Nash equilibrium from other multiple mixed strategy equilibria as the most behaviorally relevant equilibrium, where the contribution rate is higher in small groups than in large groups. Large groups win only about half of the time despite the size advantage. When within-group cheap talk communication is allowed, it promotes large group contribution and deters small group contribution. Large groups win around 88% of the time. Relative to small groups, large groups benefit more from communication precisely because they face more severe coordination problem and they understand that they shall use communication as a coordination device to the full extent to achieve an optimal outcome. Anticipating this, small groups are discouraged from competing with large groups. More surprisingly, behavior in the communication treatment is well approximated by a different mixed strategy Nash equilibrium which models the small group and the large group each as one agent in the game. Outcomes in the communication treatment are not significantly different from the control treatment featuring unanimous group decisions. Similar outcomes are also observed in another control treatment in which two individuals are competing with each other. Communication therefore completely eliminates miscoordination 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 large groups to coordinate is to explicitly designate specific contributors (or non-contributors) following a rotation scheme. Small groups rely more on making choices by reasoning from the opponent group's point of view. Both small groups and large groups emphasized the need to be unpredictable in their contribution decisions in the chats which reflects their understanding of the essence of mixed strategy equilibrium.

The remainder of the paper is organized as follows. Section 2 briefly reviews related experimental literature. Section 3 characterizes the structure of the game. Section 4 describes the experimental design and procedures. Section 5 reports the results. Section 6 elaborates on content analysis, and section 7 concludes.

2. Related Literature

Schram and Sonnemans (1996b) and Rapoport and Bornstein (1989) are most closely related to our study. Both papers study face to face communication. In Schram and Sonnemans (1996b), a participation game is played between two groups of 6 subjects. They report that communication significantly increases the turnout rates of both groups. A point worthy to note here is that they use within-subject design with the same subjects play 20 periods of the game in no communication treatment followed by 5 minutes face-to-face communication and then another 5 periods of the game without further communication. Thus the reported communication effect might be confounded with learning effect.

Rapoport and Bornstein (1989) analyze the effect of communication in a one-shot participation game. Their results show that communication increases the contribution rate in large groups but not in small groups. They do not provide game-theoretical predictions for rational individuals. The prize in their experiment is a "pure" public good—the value of the prize to each individual does not decrease as group size rises. In contrast to the "perfect non-rivalry" characteristic of the "pure" public good, the prize in our study is an "impure" public good— the value of the prize to each individual is smaller in large groups than in small groups. Our design thus presents a more sever coordination problem for large groups relative to small groups. [5]

Several recent studies have examined the effect of chat messages in group competitions, but all of them analyzed competition between equal-sized groups and none of them measures how much miscoordination still remains after the use of within-group communication as a tool to reduce any internal conflict.

Sutter and Strassmair (2009) evaluate the role of communication in a tournament that involves two teams competing for a fixed prize which is paid by the losing team and shared equally in the winning team. They find that communication within teams increases contributions and leads to higher efficiency. This is consistent with experimental findings from public goods and other coordination games which document that communication always enhances efficiency. By contrast, when groups competing in a weakest-link contest, Cason et al. (2010) report that although within-group communication improves coordination it significantly reduces efficiency. This is because communication creates strong in-group favoritism that increases their utility of winning and leads to excessive and wasteful efforts. The efficiency-reduction effect of within-group communication is also documented by Buckley et al. (2009) in common pool resource games with individual appropriators share their output in groups of optimal size.

Besides the communication and no communication treatments, we also compare results from a competition between two individuals and a competition between two unitary groups. This contributes to the literature investigating whether group behavior is different from individuals.

Literature in social psychology and economics has provided compelling evidence that groups behave differently from individuals in games with no strategic interactions. [6] In

[5] In a single-group public goods game, Isaac and Walker (1988) find that more members free ride as group size increases in the provision of an "impure" public good but not in the provision of a "pure" public good.

[6] For example, groups make faster and better decisions than individuals facing a statistical problem (Blinder ad Morgan, 2005); groups gain higher expected payoffs at a significant lower risk in investment games (Rockenbach, et

strategically interactive games, an excellent literature review by Kugler et al., (2012) reveals that groups seem to better comply with theoretical predictions than individuals.

Regarding the performance of groups in inter-group 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). Mixed evidence is 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, leading to more overbidding and less profit than individuals in a common value auction experiment. Sutter et al. (2009) document that groups stay longer in an ascending sealed-bid English auction and thus earn less than individuals. Gillet et al. (2009) report that common pool resource extraction by groups of appropriators is more competitive than by individual appropriators. On the other hand, Sheremeta and Zhang (2010) show that groups bid less aggressively and receive significantly higher payoffs than individuals in group-based Tullock contests, and Cheung and Palan (2011) find that groups are less prone to create bubbles than individuals in a double auction asset market.

3. 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 all of 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 between the two groups, each group gets half of the prize. The contributions are non refundable. The prize is then shared equally among group members in the winning group 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 $r_G = \frac{R}{n_G}$. In addition to the share of the group's benefit, each member in both groups earns any endowment that is not contributed to the group. The ordinal relation between

al., 2007); groups make substantially fewer errors than individuals in probability judgment and Bayesian updating (Charness et al., 2007, 2010); groups fall prey less to the winner's curse problem (Casari et al., 2010). Research on whether groups are more or less risky than individuals in lottery choices provides mixed results (See Zhang and Casari, 2011 for a review).

the payoff parameters for an individual player in the model satisfies the inequality $r_G > \frac{r_G}{2} + e$, where e is the cost of the contribution (equals to the endowment), r_G is the utility of a win and $\frac{r_G}{2}$ 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 $\frac{r_G}{2} > e$. This ensures that a payoff maximizing player has an incentive to contribute when his or her contribution is critical to tying the game. There is no pure strategy Nash equilibrium for this game. There are 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. This paper thus focuses on the second class of Nash equilibria. [7]

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: $EV_{\mathrm{i}}^{A}(Contribute) = EV_{\mathrm{i}}^{A}(Not\ to\ Contribute)$, which is a function of two unknowns p, q and can be simplified to $\frac{(P_1+P_2)}{2} = \frac{e}{r_A}$ where P_1 is the probability that the contribution of player i can change a losing situation into a tie and P_2 is probability that the contribution of player i can break a tie and lead to a win. Thus if $\frac{(P_1+P_2)}{2} > \frac{e}{r_A}$, 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 $EV_{\mathrm{i}}^{B}(Contribute) = EV_{\mathrm{i}}^{B}(Not\ to\ Contribute)$. With two functions and two unknowns, we can analytically solve for the mixed strategy equilibria.[8]

[7] Recent papers also focus on quasi-symmetric equilibrium (for instance, Levine and Palfrey (2007), Duffy and Tavits (2008), Battaglini et al. (2010)).
[8] The expected payoff functions are discussed in detail in Appendix I.

4. Experimental Design and Procedures

Our experiment consists of 35 statistically independent competitions between two groups (or individuals) with a total of 184 subjects across four different treatments, as summarized in Table 1.

Table 1: Summary of Experimental Design

Treatment	# of Competitions	# of subjects per competition	Communication	Decision	Miscoordination
3x5 NC	6	8	No	Individual	Yes
3x5 C	6	8	Yes	Individual	Yes
1x1 G	7	8	Yes	Group	No
1x1 I	16	2	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 game. Each member is endowed with one token and decides whether to contribute the token to the group account or keep it for him or herself. [9] 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 coordination problem within groups because only the contributors bear the cost of contribution. No form of communication is permitted.

Treatment 3x5 C: This treatment adds to the treatment 3x5 NC, the opportunity for group members to communicate with one another at the beginning of each period. Group members have 90 seconds to send free-form messages through a chat window before deciding whether to contribute the endowed token. Communication is non-binding—group members (who make their contribution decisions independently and anonymously) are not constrained to keep any agreement that they may have reached during the chat period. Subjects were informed that their messages would be recorded and they would be required to follow several simple rules: be civil to each other, use no profanity and do not identify themselves.

Treatment 1x1 G: This treatment differs from treatments 3x5 NC and 3x5 C in the way that tokens are endowed. Tokens are distributed collectively, to the entire group, instead of

[9] The asymmetric competition is between a small group of three members and a large group of five members. With at least three members, coalitions can be formed and some kind of organization is present. Also, in the treatment 1x1 G, 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. That is, the un-refundable cost of contribution equals one.

separately to each individual. The large (small) group decides how many of the 5 (3) endowed tokens to contribute. The group with higher contributions wins a prize. Group members share the prize and the retained endowment equally. There are no miscoordination issues because the cost of contribution is born by every group member and groups are asked to make a joint decision. Again, 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. Every period, each group has up to 10 rounds with no further communication 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.

Treatment 1x1 I: Two individuals instead of groups compete 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 conflict is thus eliminated in this treatment. No communication is permitted.

The effectiveness of communication in solving miscoordination problem within groups is examined in pair-wise comparisons of the first three treatments: 3x5 NC, 3x5 C and 1x1 G. More specifically, the treatment 1x1 G should be equivalent to the case where communication completely eliminates miscoordination. The difference between the treatments 3x5 NC and 3x5 C allows us to measure the degree to which miscoordination is reduced by communication, while the difference between treatments 3x5 C and 1x1 G reveals the extent to which miscoordination still remains. The comparison between treatments 1x1 G and 1x1 I indicates whether individual choices differ from group decisions.

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 treatments 3x5 NC, 3x5 C and 1x1 G, 16 subjects were randomly and anonymously placed into either a 3 or 5-person group. Each 3-person group was then paired with one of the 5-

person groups to form a cohort of 8 subjects. Group compositions remained the same for the first 10 periods. Before the start of period 11, subjects were regrouped.[10] After the regrouping, another 10 periods were played. Subjects were informed of their own group decision, the decision of the opponent group, individual earnings for each period and the cumulative earnings at the end of each period. Similarly, in the treatment 1x1 I, 16 subjects were randomly split into 8 pairs and assigned to two roles: Person A (endowed with 3 tokens) or Person B (endowed with 5 tokens). The subjects' roles were fixed for 10 periods and switched for another 10 periods.

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. Subjects earned about $18 on average and sessions lasted about 45 to 75 minutes.

5. Predictions and Results

Our parameters are chosen to generate 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 the treatment 3x5 NC pooling across all periods and all sessions.

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%

In both equilibria, the small group contributes at a higher rate than the large group. The large group loses most of the time (80.7%) in the Type L equilibrium because they rarely contribute. In the Type H equilibrium, groups compete aggressively with individual contribution rates of 0.91 in the small group and 0.74 in the large group. Despite the size advantage, the large group is only able to win the competition about 67.1% of the time.

[10] The regrouping was used to reduce the difference in earnings. The regrouping occurred separately within the two cohorts of 8 subjects. Wilcoxon sign tests indicate no significant difference before and after the regrouping in all the treatments. Thus we use all 20-period data in the following analyses. For more detail please see Figure A1 in Appendix which shows the average group contribution over the first 10 periods and last 10 periods in all treatments.

The theoretical prediction highlights the fact that small group members contribute more often than large group members. This leads to the following prediction.

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

Result 1: Prediction 1 is supported.

The data in the treatment 3x5 NC are different from point predictions from both types of equilibrium (Table 2). But if we focus on the relative contribution rates and the outcomes of the competition on the group level, the data are much closer to the Type H equilibrium than the Type L equilibrium. Large groups never contributed 0 tokens.[11] Average individual contribution rates are significantly lower than the predictions in both groups.[12] The average individual contribution rate is higher in small groups than in large group.[13] Groups were competing aggressively. Averaging across six sessions, large groups only won the game 56.7% of the time and tied the game 25.8% of the time.

To form a set of testable hypotheses for the communication treatment, we consider the extreme benchmark where communication completely eliminates miscoordination within groups. In this case, members of each group are able to reach an agreement to coordinate their individual choices and act as a single 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; correspondingly, we refer to the original group competition as 3x5 game). A small player endowed with 3 tokens and a large player endowed with 5 tokens each decide how many tokens to contribute to the group account. Contributions are not refundable. The player with higher contribution wins a prize of 18 tokens and the player who

[11] We compare the mixed strategy prediction with the aggregate group level not the individual level behavior because clearly individual subjects didn't contribute with the same fixed probability at each period. The observation that a mixed strategy does not characterize individual behavior, but rather the aggregate data is well documented in experimental literature (Camerer, 2003).

[12] One sample Wilcoxon signed-rank test, p-value=0.028 for small groups, p-value= 0.027 for large groups. This is consistent with Levine and Palfrey (2007) documenting that the turnout rates for the smallest electorate with one voter in a group and two in the other group are lower than theoretical predictions. Yet they also reported that turnout rates for larger electorates with 9 voters in total (either 3 in one group and 6 in the other or 4 in one group and 5 in the other) are approximately equal to the Nash equilibrium value, whereas turnout rates for the largest electorates with 27 or 51 voters in total are higher than predicted by theory.

[13] The difference is statistically significant at 10% (p-value=0.076) based on a probit regression, where the dependent variable is the individual binary contribution decision and the independent variables are a constant, a period trend, a group-type dummy and session dummies. Standard errors are adjusted for 48 clusters at the individual level to account for the multiple decisions made by individuals. On the other hand, the difference is not significant based on group level data (Mann-Whitney test, n=m=6, p-value=0.63, t test, *p*-value=0.32).

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 and 5 members each (1x1 G).

Table 3 Payoff Matrix and Mixed Strategy Nash Equilibria for the 1x1 Game

Contributions	0	1	2	3	4	5
0	12,14	3,22	3,21	3,20	3,19	3,18
1	20,5	11,13	2,21	2,20	2,19	2,18
2	19,5	19,4	10,12	1,20	1,19	1,18
3	18,5	18,4	18,3	9,11	0,19	0,18

Table 3 presents the payoff matrix for the 1x1 game designating the strategies of the small player and the large player as rows and columns, respectively. There is no pure strategy Nash equilibrium for this game. [14] Given the payoff structure, it is straightforward to solve the mixed strategy Nash equilibria (Rapoport and Amaldoss, 2000).

Figure 2 compares the predicted probability mass function of group contributions in the 3x5 game and in the 1x1 game. In the 1x1 game, there are two sets of mixed strategy Nash equilibrium for the small player. They are very similar and behaviorally indistinguishable. We only present one of them in Figure 2.[15] The mixed strategy Nash equilibrium 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 equilibrium because the data are completely at odds with the Type L equilibrium. In the 1x1 game, the small player abstains from the competition about 78% of the time while the large player contributes 4 tokens 78% of the time. Thus the large group almost always wins the game (96% of the time). This is very different from the prediction in the 3x5 game, where the small group contributes 3 tokens most of the time while the large group contributes 4 tokens less than 40% of the time resulting in a 30% decrease in the chances of

[14] The large player can guarantee himself to win the prize by contributing 4 tokens. Anticipating that, the small player would abstain to save the endowment. If, however, the large player anticipates that the small player would contribute nothing, he is better of contributing 1 token. But then the small player has incentives to increase contribution to tie or win the prize. Thus no pure strategy equilibrium exists in this game. Note the 1x1 game with unequal endowment is typically used to model patent race between a strong and a weak players.

[15] In one equilibrium, the small player never contributes 2 tokens and randomizes over actions of contributing 0, 1, and 3 tokens with the following probability vector (0.778, 0.111, 0.111). This is the one depicted in Figure 2. In the other equilibrium, the small player never contributes 1 token and randomizes over actions of contributing 0, 2, and 3 tokens with the following probability vector (0.833, 0.056, 0.111).

winning. Note in the 3x5 game, the large group is expected to contribute 5 tokens about 22% of the time, although, only four tokens are needed for the large group to win. This highlights the sever miscoordination problem within the large group.

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

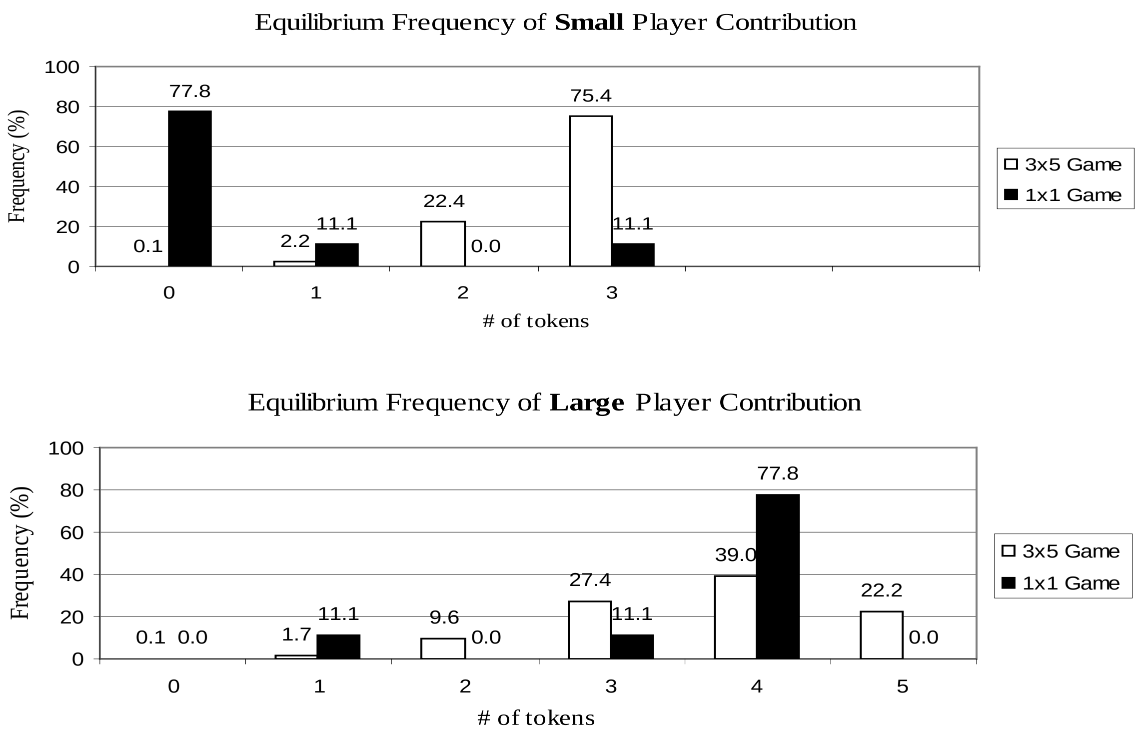


Table 4 presents the predicted average group contributions, average group earnings and the probability the large group wins, ties and loses the game in the 3x5 game and the 1x1 game along with the data we observed in four treatments. Both the Kruskal Wallis test on the equality of medians and the F test on the equality of means indicate that there is a statistically significant difference across all four treatments in both groups (p-value<0.01 for all comparisons).

Table 4: Theoretical predictions and observed data across treatmtents

	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	4.06	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%	7.8%
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 coordination problem and each group act as one agent in the game. Based on the theoretical comparison between the 3x5 game and the 1x1 game, we form the following predictions:

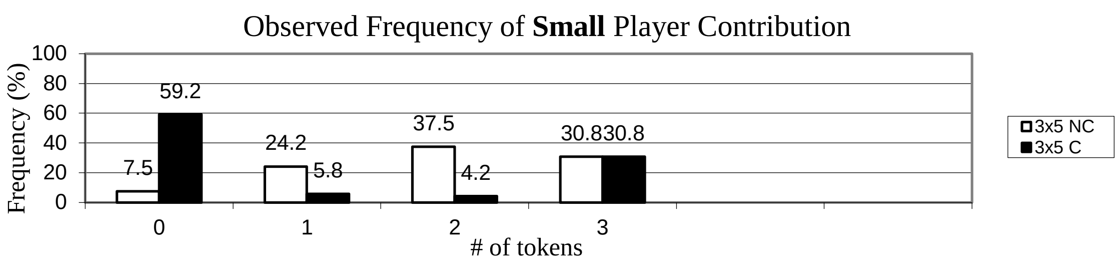
Prediction 2: Within-group communication (treatment 3x5 C) reduces miscoordination. The small group almost always abstains from contributing and the large group is able to win the game most of the time. This leads to relatively higher earnings for the large group and lower earnings for the small group compared to the no communication case (treatment 3x5 NC).

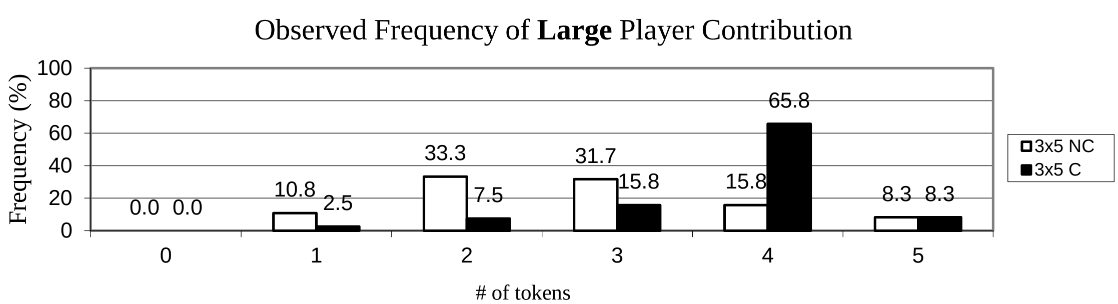
Result 2: Prediction 2 is supported.

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

Result 3: Prediction 3 is supported.

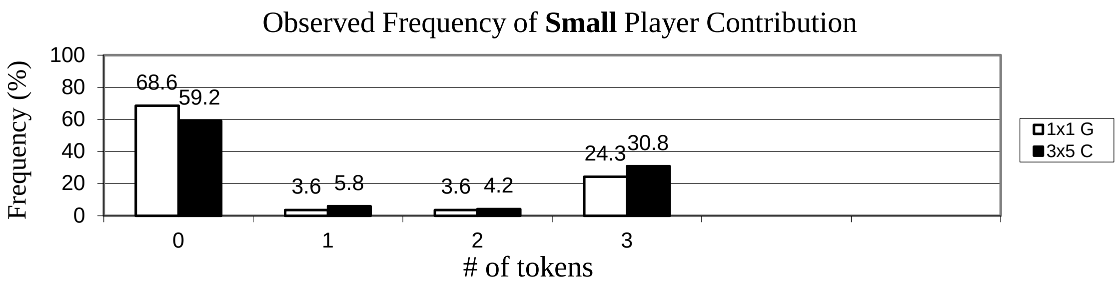
Figure 3: Data comparison between 3x5 NC sessions and 3x5 C sessions

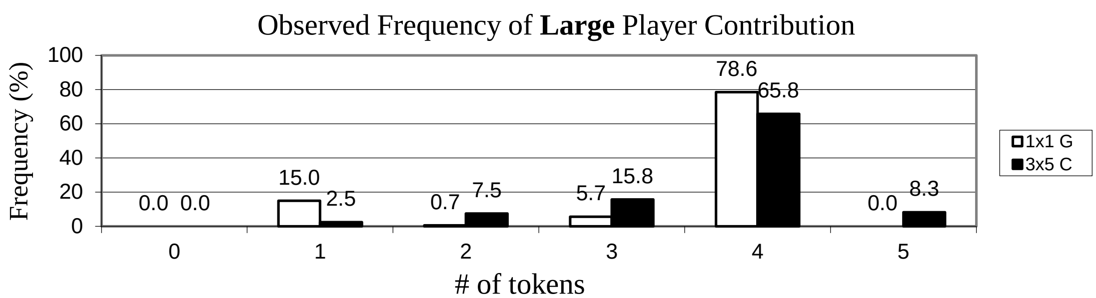




When we permit communication, the behavior is well approximated by the 1x1 Game that models the small group and the large group each as one agent in the competition. The average large group contributions and the outcome of the game are not significantly different from the 1x1 Game predictions. The average small group contributions are significantly higher than the prediction though which may reflect some non-monetary utility that is not captured by the standard economic model.[16] The average individual contribution rate and the average earnings and the probability of winning the game are significantly higher in large groups than in small groups, consistent with the predictions. The winning percentage of large groups increases from 56.7% in the 3x5 NC treatment to 88.3% in the 3x5 C treatment. The observed distributions of contributions in these two treatments are quite different (Figure 3). Based on the group level data, relative to the treatment 3x5 NC, with communication, average contributions and average earnings decrease significantly in small groups and increase significantly in large groups.[17]

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





Thus communication does significantly improve coordination. Is there any miscoordination left? Comparing treatments 3x5 C and 1x1 G, Mann-Whitney tests report no significant difference in average group contributions, average group earnings in both types of groups and the probability that the large group wins the competition.[18] Also, the observed

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[16] One sample Wilcoxon signed-rank test against the 1x1 Game prediction, p-value= 0.249 for large group contributions, p-value= 0.115 for the probability that large groups win the game, p-value=0.027 for the average small group contributions and p-value=0.463 for the average small group earnings.

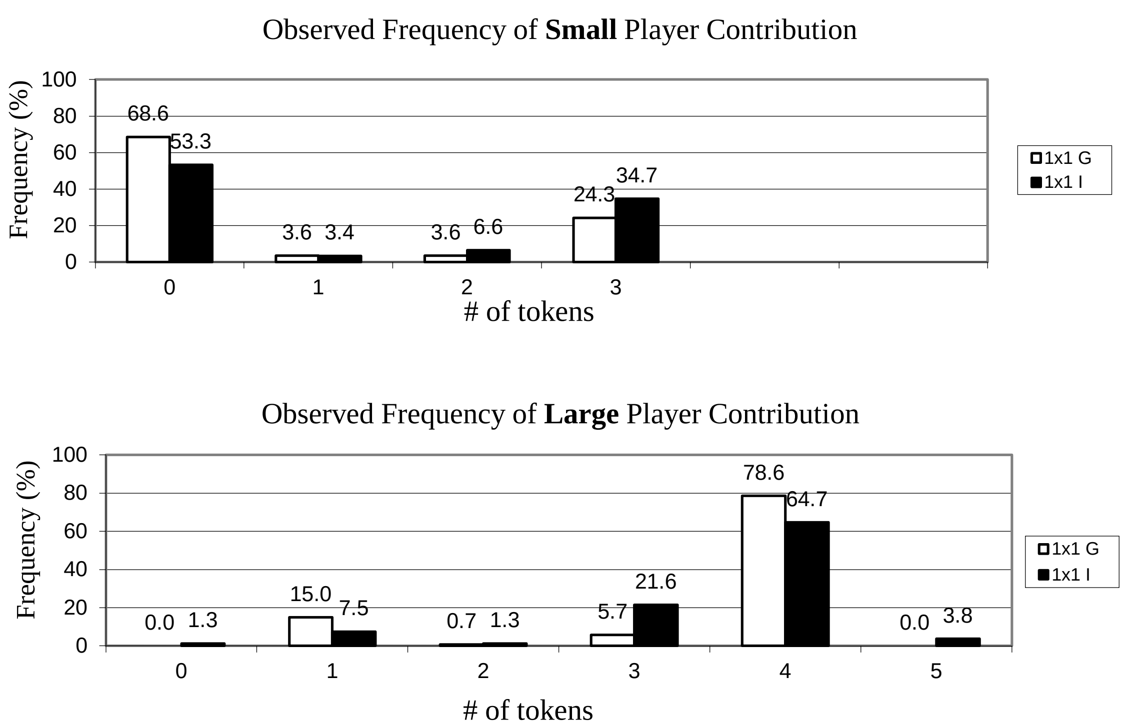
[17] Comparing small groups and large groups in the 3x5 C treatment, Mann-Whitney tests (m=n=6) report significant difference on average individual contribution rate, average earnings and winning percentage (p-value <0.01 for all comparisons). Relative to the treatment 3x5 NC, there is significant increase in contributions, earnings for the large group and significant decrease in average contributions and average earnings in small groups (Mann-Whitney tests m=n=6, p-value<0.02 for all comparisons).

[18] Mann-Whitney tests, n=7, m=6, *p*-value=0.67 for small group average contributions, *p*-value=0.17 for large group average contributions, *p*-value=0.39 for small group average earnings, *p*-value=1.00 for large group average

distributions of contributions in both groups in treatment 1x1 G and treatment 3x5 C line up closely (Figure 4). Thus group decisions are not significantly different in the presence or absence of the internal conflict as long as groups have the opportunity to communicate. In other words, communication is so effective that it completely solves the miscoordination problem within groups.

The comparison between the treatment 1x1 I and the treatment 1x1 G allows us to examine whether groups behave differently from individuals. Although early research provides compelling evidence that group decisions are different from individuals, the question of whether groups are more competitive than individuals is still unresolved. The last prediction follows.

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



Prediction 5: Contribution decisions made by groups in treatment 1x1 G are different from those made by individuals in treatment 1x1 I.

Result 5: Prediction 5 is not supported.

earnings, *p*-value=0.88 for the probability that the large group wins the competition. All the results hold if we use t-tests with unequal variances or robust rank order tests here.

On average, no difference, in terms of group contributions, group earning and the outcome of the game, is observed when two individuals instead of two groups played the game.[19] The similarity of the frequencies of contribution in the two treatments (Figure 5) provides additional support of this result.

To further support our results, we estimated panel regressions for each group type, where the dependent variable is group contribution per period in specifications (a) and (b) and group earnings per period in specifications (c) and (d) (Table 5). The independent variables are always a constant, a period trend, and treatment dummies. Estimation assumes random effects at the group level and uses robust standard errors. The constant captures the mean group contribution (or mean group earnings) in the treatment 3x5 C.

Consistent with the results based on non-parametric analyses, mean group contributions and mean group earnings in the treatment 3x5 NC are significantly different from the other three treatments. All the other pairwise comparisons report no significant difference.

Table 5: Random effects regressions on group contribution and earnings

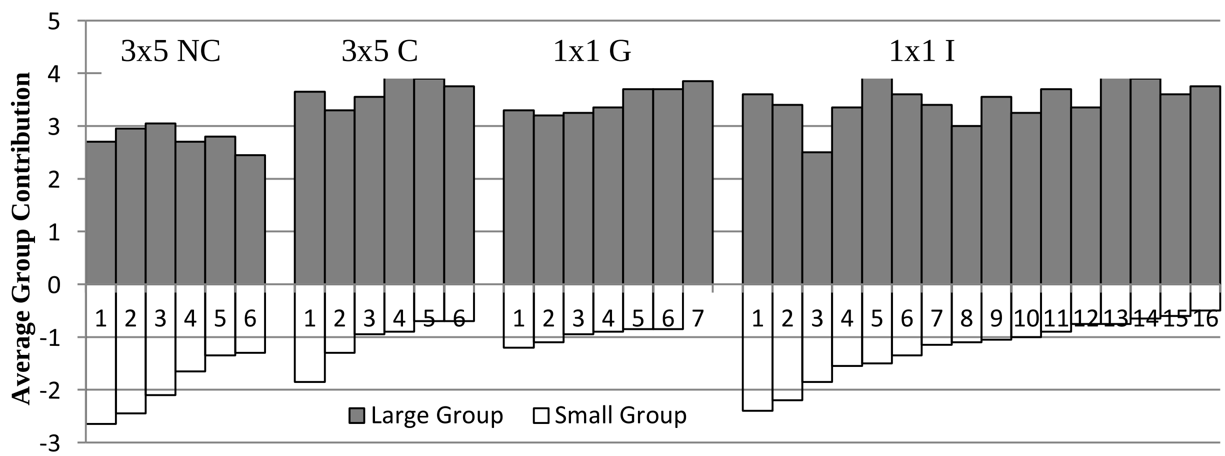
Dependent variable	Small Group Contribution (a)	Large Group Contribution (b)	Small Group Earnings (c)	Large Group Earnings (d)
1x1 G	-0.23	-0.22	0.48	-0.02
	(0.218)	(0.137)	(0.467)	(0.497)
1x1 I	0.14	-0.18	0.09	-0.06
	(0.218)	(0.145)	(0.457)	(0.451)
3x5 NC	0.85**	-0.93**	3.20**	-3.12**
	(0.274)	(0.128)	(0.652)	(0.783)
1/period	0.13	0.55**	-1.64**	0.97
	(0.300)	(0.169)	(0.603)	(0.515)
Constant	1.04**	3.60**	3.65**	17.70**
	(0.187)	(0.110)	(0.364)	(0.370)
Observations	700	700	700	700
No. of groups	35	35	35	35

Note: Robust standard errors in parentheses, clusters on groups.
*Statistical significance ** p<0.01, * p<0.05.*

[19] Mann-Whitney test, n=16, m=7, *p*-value= 0.30 for small group contributions, *p*-value= 0.57, for large group contributions, *p*-value= 0.26 for small group earnings, *p*-value= 0.89 for large group earnings, *p*-value= 0.71 for the probability that the large group wins. Results hold if we use parametric t tests or robust rank order tests here.

Even though average group contributions do not differ between the 3x5 C, 1x1 G and 1x1 I treatments, group behavior might be more heterogeneous in some treatments than others because of different group dynamics. Figure 6 displays the average group contribution across 20 periods for each group or individual pair by treatment. Each bar represents one independent observation, either a competition between two groups in the 3x5 NC, 3x5 C and 1x1 G treatments, or a competing pair of subjects in the treatment 1x1 I. Although considerable heterogeneity exists across groups, note that the distribution of average large group contributions in the 3x5 NC barely even overlaps with the other three treatments. Pairwise comparisons of coefficients of variations indicate that there is more (less) heterogeneity across large (small) groups in the treatment 3x5 NC compared to others (Mann Whitney tests, $p<0.05$). No significant difference is observed between the 3x5 C, 1x1 G and 1x1 I treatments.

Figure 6: Heterogeneity across groups by treatment



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6. Content Analysis

At this point we know that communication reduces miscoordination 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? Do large groups exchange different messages than small groups? Does same type of messages shape behavior differently in large groups than in small groups? We use content analysis to answer this question.

We implemented the following procedure to systematically quantify the recorded messages. First, we randomly selected a test sample from the pilot sessions to develop a coding scheme which classifies messages into different categories. Second, we employed two undergraduate coders, trained separately, to independently read and classify all messages according to the coding scheme. They were not informed about any of the hypotheses of the study. 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. Category 1 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 reliability of coding, which quantifies agreement as the proportion of the difference attained between perfect agreement and chance agreement. Kappa takes a value of 0 when the agreement is consistent with random chance, and 1 when the coders agree perfectly. Kappa values between 0.41 and 0.60 are considered moderate agreement and those above 0.60 indicate substantial agreement (Landis and Koch, 1977). Except two categories (category 1e and category 11, Table 6) that are rarely coded, Kappa indicates either substantial or moderate agreement in our coding. The two categories that are below the moderate agreement threshold are not included in the regression analyses.

Table 6 reports the frequency of codings under each category in the treatments 3x5 C and 1x1 G, average across two coders. 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 adopted to coordinate their members' behavior. In the treatment 1x1 G, large groups typically used majority rule to reach the unanimous decision as shown in the following quotes: "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) and category 1f (Push for consensus on the contribution level) in the treatment 1x1 G relative to the treatment 3x5 C. None of the groups in our experiment failed to reach a unanimous decision and groups took at most 3 attempts to reach the unanimous decision. This supports Goeree and Yariv (2011)'s finding that once communication is available, outcomes are similar between majority and unanimity voting rules in jury decision.

Table 6: Comparison of coding frequencies by treatments and group types[20]

	Coding Category Description	1X1 G		3x5 C	
		Large	Small	Large	Small
1	Coordination on the contribution level for the current period	43.6%	36.4%	52.1%	41.3%
1a	Propose a specific contribution level	6.7%	8.9%	3.5%	11.8%
1b	Ask for the opinions of other group members	1.5%	2.9%	3.3%	4.3%
1c	Disagree with group members' proposals	4.2%	2.6%	2.8%	1.9%
1d	Agree with group members' proposals	28.7%	19.1%	13.4%	20.7%
1e	Propose to rotate or explicitly designate contributors and (or) non-contributors	N/A	N/A	29.8%	0.4%*
1f	Push for concensus on the contribution level	3.0%	3.0%	1.4%	1.8%
2	Appeal to fool the other group across periods (be unpredictable, to trick others, pretend to be predictable)	7.0%	9.3%	6.5%	7.4%
3	Make choices by reasoning from the other group's point of view	7.0%	11.6%	4.5%	13.0%
4	Discussion about benefits for own group	8.4%	7.9%	5.5%	6.5%
5	Discussion about benefits for the other group	1.2%	1.7%	0.8%	1.2%
6	Reference to the previous choices of own group	3.4%	4.5%	2.1%	6.0%
7	Reference to the previous choices of the other group	2.4%	3.0%	7.1%	4.9%
8	Reference about the size asymmetry	4.8%	2.0%	3.1%	1.7%
10	Appeal to play safe	2.1%	3.9%	2.5%	3.8%
11	Appeal to take risks	0.7%*	1.5%*	0.4%*	0.4%*
12	Other Messages	29.0%	28.6%	19.0%	24.2%
Number of Observations		3146	2029	2104	1432

*Note: * Codes did not reach the 0.41 Cohen's Kappa reliability threshold and are excluded from the regression analyses.*

On the other hand, in the treatment 3x5 C, each large group proposed a rotation strategy to designate contributors and/or non-contributors in the first period. This strategy was implemented in the first period in 4 out of 6 groups, in the second period in one group and in the third period in the other group. The following messages were sent in a large group in the first period: "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

[20] 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 which appeal to take risks under category 10 mean to increase contributions in the small group and decrease contributions in the large group.

period 4. After successfully discouraged the small group from contributing anything, in period 5 a new idea was brought up: "hey…for this round only 1 person should put it into the group account…everyone else the other…coz they are always 0". The large group decided to contribute 1 token instead of 4 to optimize group earnings and they rotated to be the only contributor to equalize individual earnings. By contrast, small groups rarely rotated or explicitly designated contributors and/or non-contributors. Small groups contributed everything 57% of the time and nothing 32% of the time.

Another common strategy adopted by both types of groups is to fool the other group across periods. A typical quote from large groups in the 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 typical quote from small groups 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 understood the essence of mixed strategy equilibrium and tried to implement their decisions in an unpredictable way across periods.

To decide the contribution level, groups spent a fair amount of time reasoning from the other group's point of view in both treatments (category 3). For example, in the treatment 1x1 G, after observing a "1 token" choice of a small group in the last period, 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, 2007b).

Note, in both treatments, proportional to all the messages exchanged, small groups sent more messages about being unpredictable and reasoning from the other group's point of view relative to the large groups. [21] Thus to compensate for the size disadvantage, small groups relied more on being strategic and best responding to other group's decisions.

[21] Comparing small groups and large groups in both treatments, two sample tests of proportion report significant difference in percentage of messages falling into categories 2 and 3 (p-value<0.01) except category 2 in the 3x5 C treatment.

Discussions about monetary benefits were coded under categories 4 and 5. Groups discussed more about their own group benefits than the other groups.[22] They specified payoffs associated with all potential strategies. For example, a large group member in the treatment 1x1 G said: "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 a 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 and Roth, 1998).

Moreover, the reference to the previous choices made by the other group (category 7) suggests that subjects updated beliefs about what other group would do based on history and used those beliefs to determine which strategies are the best. Typical quotes in large groups 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 capture the data better, given this direct evidence that players look back at what other players have done previously and also give weights to forgone payoffs from un-chosen strategies (Crawford, 1995). When groups referred to their own choices in the previous rounds (category 6), they either cheered for the success, "our group rocks" or regretted the decision, "Damn it, I told you guys 1 wouldn't work, stick with 4." This echoes the impact of communication on the saliency of group identity (Sutter, 2009).

Just because a category of messages is used frequently doesn't necessarily mean it accomplishes much. We estimated probit regressions on the contribution decisions made in large groups and small groups, augmented with the reliably-coded categories of communication from Table 6. The dependent variables is whether or not large groups contributed 4 tokens (Table 7), small groups contributed 3 tokens (Table 8, Model 1) or 0 tokens (Table 8, Model 2) in a given period. The independent variables are the total value of codings of the messages coded under each category in a given period. Specifically, the value of 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 and 0.5 if two coders disagreed with each other. We also include three lagged variables. They are the opponent groups' contribution decisions in the last

[22] Two sample tests of proportion report significant difference in percentage of messages falling into categories 4 and 5 in both treatments and both groups (p-value<0.01).

period, and the value of codings of category 2 “Appeal to fool the other group across periods” in the last two periods. Session dummies and a time trend variable (expressed as 1/period) is included as well. Standard errors are corrected for clustering at the group level. Let us first discuss the marginal effects of the messages exchanged upon large groups’ decisions of contributing 4 tokens. In the treatment 1x1 G, messages about being unpredictable to fool the other group across periods (category 2) are associated with higher likelihood of choosing 4 tokens. In the treatment 3x5 C, the contribution decisions are not affected by those messages sent in the current period but from two periods ago. The significantly negative coefficient of the 2-period lag variable captures a typical multi-period strategy that large groups followed: “let us do 4 for 2 to 3 rounds and then drop to 1.” In the 3x5 C treatment, coordination via the rotation scheme (category 1e) and the reference about the size asymmetry (category 8) are effective in reducing miscoordination and making groups act as one agent.

Table 8 reports the marginal effects of messages on small groups’ decisions of contributing 3 tokens and 0 tokens. When small groups appeal to fool the opponent (category 2), they don’t increase their contributions immediately but rather wait for a period (Model 2 in 1x1 G). In treatment 3x5 C, the more time small groups spent on reasoning from the other group’s point of view (category 3), the less often they contributed 3 tokens and the more often they contributed 0 tokens.

Several other categories of messages have significant impact on groups’ decisions across treatments. Large groups who reach agreement (category 1d) are less likely to contribute 4 tokens, suggesting that explicit agreement is elicited for reducing contribution levels and groups who appeal to play safe (category 10) are more likely to contribute 4 tokens to secure a win (Table 7). As expected, these messages related to small group decisions in an exact opposite way: explicit agreement is elicited for competing aggressively (category 1d) and appeal to play safe (category 10) leads to abstain more from competition (Table 8). Also, discussions about monetary benefits (categories 4 and 5) increase small group contributions but reduce large group contributions. This is because these discussions emphasized the fact that the individual share of the prize in small groups is bigger than in large groups.

Table 7: Probit regressions on large group contribution decisions

	Dependent variables: **1= the large group contributed 4 tokens in a given period, 0= otherwise**	**1x1 G**	**3x5 C**
	Independent variables:		
	Coding Categories		
1a	Propose a specific contribution level	-0.007	0.180*
		(0.014)	(0.079)
1b	Ask for the opinions of other group members	-0.096	-0.136
		(0.059)	(0.076)
1c	Disagree with group members' proposals	0.035	(0.018)
		(0.019)	(0.067)
1d	Agree with group members' proposals	-0.032**	-0.100**
		(0.008)	(0.024)
1e	Propose to rotate or explicitly designate contributors and (or) non-contributors		0.024*
			(0.011)
1f	Push for consensus on the contribution level	-0.023	-0.082
		(0.036)	(0.078)
2	Appeal to fool the other group across periods	0.068**	0.017
		(0.013)	(0.030)
3	Make choices by reasoning from the other group's point of view	-0.025	-0.009
		(0.021)	(0.032)
4	Discussion about benefits for own group	-0.026	-0.012
		(0.020)	(0.051)
5	Discussion about benefits for the other group	-0.065	-0.473**
		(0.054)	(0.173)
6	Reference to the previous choices of own group	-0.009	-0.024
		(0.021)	(0.023)
7	Reference to the previous choices of opponent group	0.001	-0.102
		(0.050)	(0.080)
8	Reference about the size asymmetry	-0.012	0.128**
		(0.024)	(0.035)
10	Appeal to play safe	0.041**	0.267**
		(0.013)	(0.102)
11	Other Messages	0.009	-0.03
		(0.007)	(0.015)
	1/period	1.000*	1.008
		(0.494)	(0.690)
	Small group contribution in the last period	0.085**	0.023
		(0.023)	(0.031)
	1-period lag: Appeal to fool the other group across periods	0.002	-0.051
		(0.015)	(0.031)
	2-period lag: Appeal to fool the other group across periods	0.011	-0.131**
		(0.017)	(0.037)
	Number of observations	126	108
	Log likelihood	-48.77	-44.5

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

Table 8: Probit regressions on small group contribution decisions

	Dependent variables: **Model 1: 1= the small group contributed 3 tokens in a given period, 0= otherwise** **Model 2: 1= the small group contributed 0 tokens in a given period, 0= otherwise**	**1x1 G** **Model 1 (3 tokens)**	**3x5 C** **Model 1 (3 tokens)**	**1x1 G** **Model 2 (0 tokens)**	**3x5 C** **Model 2 (0 tokens)**
1a	Propose a specific contribution level	0.109**	-0.053	-0.104**	0.021
		(0.038)	(0.028)	(0.037)	(0.061)
1b	Ask for the opinions of other group members	0.032	0.115	-0.172*	-0.086
		(0.075)	(0.066)	(0.079)	(0.127)
1c	Disagree with group members' proposals	-0.015	-0.147*	0.023	-0.215**
		(0.079)	(0.061)	(0.100)	(0.048)
1d	Agree with group members' proposals	0.03	0.083**	-0.046	-0.052**
		(0.016)	(0.019)	(0.033)	(0.020)
1f	Push for consensus on the contribution level	0.015	-0.23	-0.056	0.263
		(0.046)	(0.139)	(0.085)	(0.208)
2	Appeal to fool the other group across periods	-0.048*	-0.118**	0.083*	0.041
		(0.022)	(0.043)	(0.035)	(0.062)
3	Make choices by reasoning from the other group's point of view	-0.024	-0.093*	0.024	0.157*
		(0.028)	(0.048)	(0.029)	(0.080)
4	Discussion about benefits for own group	0.043*	0.042	-0.071**	-0.101
		(0.021)	(0.028)	(0.020)	(0.053)
5	Discussion about benefits for the other group	0.048	0.217**	-0.088**	-0.005
		(0.033)	(0.056)	(0.030)	(0.079)
6	Reference to the previous choices of own group	0.037	-0.002	-0.003	0.001
		(0.024)	(0.023)	(0.017)	(0.028)
7	Reference to the previous choices of the opponent group	-0.025	0.066**	0.001	-0.127**
		(0.023)	(0.021)	(0.024)	(0.043)
8	Reference about the size asymmetry	-0.007	-0.102	0.062	0.004
		(0.017)	(0.071)	(0.041)	(0.107)
10	Appeal to play safe	-0.023	-0.155**	0.037	0.129*
		(0.033)	(0.041)	(0.041)	(0.054)
11	Other Messages	0.001	-0.011	0.004	0.013
		(0.015)	(0.008)	(0.015)	(0.009)
	1/period	-0.1	0.383	0.69	-1.290**
		(0.352)	(0.560)	(0.699)	(0.454)
	Large group contribution in the last period	0.019	-0.205**	-0.042	0.318**
		(0.029)	(0.048)	(0.045)	(0.057)
	1-period lag: Appeal to fool the other group across periods	0.03	0.048	-0.053**	-0.09
		(0.019)	(0.034)	(0.014)	(0.055)
	2-period lag: Appeal to fool the other group across periods	0.019	0.034	-0.022	-0.036
		(0.014)	(0.034)	(0.026)	(0.052)
	Number of observations	126	108	126	108
	Log likelihood	-55.87	-38.7	-53.12	-49.62

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

7. Conclusions

This paper examines the effects of within-group cheap talk communication in a competition between two unequal-sized groups over a public-good prize. We find that without communication, large groups could only win the game about half of the time despite its size advantage. This is because members of large groups had problems coordinating on who was going to contribute since they only needed 4 out of 5 members to contribute to win. Once within-group communication was available, even though it is cheap talk, it significantly increases contributions in large groups and deters contributions in small groups, leading to large groups winning 90% of the time. Moreover, outcomes in the communication treatment are not significantly different when the within-group conflict was removed by asking groups to make a unanimous decision on how much to contribute and share the cost of contribution equally. Thus communication is so effective that it completely eliminates miscoordination and makes group members act as one agent.

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. The categories of messages that have significant impact on groups' ability to solve internal conflict and strategize against the opponent groups include messages proposing to rotate or explicitly designating contributors; messages appealing to fool the other group across periods and messages regarding making choices by reasoning from the other group's point of view.

While more confident conclusions await further research, we can note preliminary implications of our results for this setting. In particular, our findings indicate that when individual and group incentives can be aligned toward the competition against opponent groups, within-group cheap talk communication is an effective mechanism to coordinate behavior and make group members act as one agent in decision-making. However in asymmetric competitions, the small group is worse off with this powerful tool because its ability to solve internal conflict helps the large group to exploit more of the size advantage. Thus the large group benefits from communication at the expense of the small one.

This paper opens up several avenues for further research.

First, the experimental environment implemented the classical voter participation game, which has been widely used to model two levels of conflicts faced by competing groups to influence public policy or political outcome. Can communication be as effective in other types of group competitions? For example, will we observe similar effects when group members are asked to decide how much to contribute instead of whether or not to contribute? Pilot sessions we have conducted suggest that the general conclusion of our paper stands. After generalizing the binary strategy space to continuous strategy space, group contest literature provides a natural test bed to check the robustness of our results. Will the introduction of communication change behavior in a similar way in the following environments: group contests with different prize structure (a pure public good, a private good or a mixture of private and public goods, Nitzan and Ueda 2009, 2010), different contest success function (Tullock probability function, Tullock 1980), different types of asymmetry (randomly and publicly select one group beforehand to be the winning group in the case of a tie, Bornstein et al., 2005), etc..

Second, we report no difference between our unanimous group decision treatment 1x1 G and individual decision with communication treatment 3x5 C. This novel comparison allows us to observe that communication not only improves coordination but to the extent that there is no miscoordination left. This is a much stronger result than the ones documented in the experimental literature. It is important to understand what drives this strong effect. In our experiment, the size asymmetry and the "impure" public good prize — the value of the prize to each individual is smaller in the large group than in the small group — create a more severe coordination problem for the large group. Thus the large group has more incentives to increase the effectiveness of communication as a coordination device. This contributes to the discussion about the group-size paradox which posits that large groups are less effective to provide public good because of the more severe free-riding problems (Olson 1965). Our findings suggest that larger groups exploit the effect of communication to the full extent precisely because of the more severe coordination problems. With communication, small groups are actually worse off. When the provision of a coordination device is a choice that would be adopted upon the agreement by every competing group, small groups may deliberately choose to limit the access to it.

Third, without communication, Levine and Palfrey (2007) report that the experimental data confirm the comparative statics predictions about the "size", "underdog" and "competition" effects of the Palfrey and Rosenthal (1983) model. Depending on the degree of asymmetry in group sizes, communication may attenuate or exacerbate the "underdog" effect, i.e the tendency of small group members to participate more frequently than large group members. Likewise communication may reinforce "the competition" effect that predicts increased participation rates when the degree of group-size asymmetry becomes smaller. It would be interesting to identify the critical relative size difference that would sustain the group size advantage with communication. Communication may also interact with the “size” effect, which predicts that keeping fixed the relative group sizes, participation rates fall when groups get bigger.

Last, another factor that might hinder the effectiveness of communication is the availability of other communication channels. Bornstein et al. (1989, 1992) investigate 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) find that with between-group communication, there is significant decrease in effort levels due to collusion in team tournament, relative to effort levels when within-group communication is allowed. How individual and group decisions would alter according to within and between group communication infrastructures appears a promising topic for future research.

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Appendix I: Expected Payoffs in the 3x5 Game

The expected payoff of contributing $EV_i^A(Contribute)$ 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 $\frac{r_A}{2}$; 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 $EV_i^A(Not\ to\ Contribute)$ for any player in Group A is:

$$EV_i^A(Not\ to\ Contribute) = e\sum_{j=0}^{n_A-1}\sum_{k=j+2}^{n_B}\binom{n_A-1}{j}p^j(1-p)^{n_A-j-1}\binom{n_B}{k}q^k(1-q)^{n_B-k}$$

$$+e\sum_{j=0}^{n_A-1}\binom{n_A-1}{j}p^j(1-p)^{n_A-j-1}\binom{n_B}{j+1}q^{j+1}(1-q)^{n_B-j-1}$$

$$+\left(e+\frac{r_A}{2}\right)\sum_{j=0}^{n_A-1}\binom{n_A-1}{j}p^j(1-p)^{n_A-j-1}\binom{n_B}{j}q^j(1-q)^{n_B-j}$$

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

This expression is the sum of 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 $\frac{r_A}{2}$ 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 $EV_i^B(Contribute) - EV_i^B(Not\ to\ Contribute) = 0$, 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 $EV_i^B(Not\ to\ Contribute)$ for any player i in Group B is:

$$EV_i^B(Not\ to\ Contribute) = e\sum_{j=0}^{n_B-1}\sum_{k=j+2}^{n_A}\binom{n_B-1}{j}q^j(1-q)^{n_B-j-1}\binom{n_A}{k}p^k(1-p)^{n_A-k}$$

$$+e\sum_{j=0}^{n_B-1}\binom{n_B-1}{j}q^j(1-q)^{n_B-j-1}\binom{n_A}{j+1}p^{j+1}(1-p)^{n_A-j-1}$$

$$+\left(e+\frac{r_B}{2}\right)\sum_{j=0}^{n_B-1}\binom{n_B-1}{j}q^j(1-q)^{n_B-j-1}\binom{n_A}{j}p^j(1-p)^{n_A-j}$$

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

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

Figure A1: Average Group Contribution by Treatments in Part 1 and Part 2