Communication and Efficiency in Competitive Coordination Games

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Abstract

Costless pre-play communication has been found to effectively facilitate coordination and enhance efficiency in games with Pareto-ranked equilibria. We report an experiment in which two groups compete in a weakest-link contest by expending costly efforts. Allowing intra-group communication leads to more aggressive competition and greater coordination than control treatments without any communication. On the other hand, allowing inter-group communication leads to less destructive competition. As a result, intra-group communication decreases while inter-group communication increases payoffs. Our experiment thus provides an example of an environment where communication can either enhance or damage efficiency. This contrasts sharply with experimental findings from public goods and other coordination games, where communication always enhances efficiency and often leads to socially optimal outcomes.

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1. Introduction

Considerable resources are spent on inherently unproductive activities such as advertising campaigns, lobbying for government favors, political elections, and R&D competitions to produce products that are not substantially better than the less expensive existing products.[1] Economic researchers often employ contests or rent-seeking models to analyze the effect of this excessive, unnecessary and wasteful spending. Contestants are usually modeled as unitary players, which rules out within-group conflict.[2] In practice, however, groups such as boards of directors, legislatures, committees and lobbying groups are competing rather than individuals. In these group-based contests, the group's respective success in coordinating within-group efforts often determines the outcome of the between-group competition.

One of the most effective ways to improve coordination is communication, even when it is merely nonbinding "cheap talk." Many experimental studies have shown that cheap talk can facilitate coordination on the efficient equilibrium in experimental games with Pareto-ranked equilibria (Cooper et al., 1992; Charness, 2000; Charness and Grosskopf, 2004; Duffy and Feltovich, 2002, 2006). For example, Van Huyck et al. (1993) demonstrate that pre-play communication is efficiency-enhancing in coordination games. Blume and Ortmann (2007) find that costless nonbinding messages, even those with minimal information content, can facilitate quick convergence to the Pareto-dominant equilibrium. Communication also enhances efficiency

[1] For example, advertising expenses by American hospitals, clinics and medical centers amount to $717.2 million in the first half year of 2011 although most of the ads have no impact on consumers' choice of their health care provider (Bevolo, 2011; http://www.nytimes.com/2011/09/13/business/health-care-ad-spending-rises-advertising.html?_r=2, accessed February 10, 2012). Many of the R&D competitions aiming to produce new drugs simply results in new "me too" brand-name drugs that add little clinical advantage over existing drugs (Kelly, 2009; http://www.factsforhealthcare.com/whitepaper/HealthcareWaste.pdf, accessed February 10, 2012).

[2] See Konrad (2009) for an excellent review of the contest model literature.

in intergenerational coordination experiments (Chaudhuri et al., 2009).[3] One reason that communication is so effective is that it apparently reduces strategic uncertainty about other players' behavior (Riechmann and Weimann, 2008). Since many economic interactions can be modeled as coordination games, this finding may have a very important general implication: improving communication in coordination games can increase efficiency and social welfare.

This paper departs from the conventional coordination game literature and provides a simple counterexample by embedding the coordination game in a competition between groups. Nonbinding and costless communication improves coordination but generates negative externalities on competing groups' payoffs. In this experimental environment, two groups compete in a weakest-link lottery contest by expending costly efforts in order to win a prize. The framework combines features of a cooperative weakest-link game (Van Huyck et al., 1990) and a competitive rent-seeking contest (Tullock, 1980). One key characteristic of this type of group contest is that coordination on higher efforts increases the probability of winning the prize, and thus expected payoff within that group, but it also reduces expected payoffs of the competing group. Thus, from social point of view effort expenditures are wasteful. The experimental literature on the Tullock lottery contest, started by Millner and Pratt (1989), paints even bleaker picture since subjects often exert efforts that exceed the equilibrium prediction. This previous literature, however, has almost exclusively considered individual contestants.

[3] The early literature on coordination games with Pareto-ranked equilibria documents that coordination failure is common in the laboratory (Van Huyck et al., 1990, 1991; Cooper et al., 1990, 1992). This important finding has been interpreted as relevant for environments ranging from individual organizations to macroeconomies, and has led to an active research agenda to investigate possible mechanisms to resolve this coordination failure. Besides cheap talk communication, experiments have studied whether coordination improves through repetition and fixed-matching protocols (Clark and Sefton, 2001), full information feedback (Brandts and Cooper 2006), introduction of between group competition (Bornstein et al., 2002; Riechmann and Weimann, 2008), sequential play (Camerer et al., 2004), behavioral spillovers (Cason et al. 2012), the use of entrance fees (Cachon and Camerer, 1996), gradual increases in group size (Weber, 2006), and group decision making (Feri et al., 2010).

We study contests between groups when efforts are aggregated within each group using a weakest-link production technology, so the effective group effort equals the lowest effort expended by an individual in the group. The weakest-link feature of this contest competition resembles many real life competitions where the performance of the entire group depends on the worst performer (Hirshleifer, 1983). For example, in many teamwork competitions each member of the team is responsible for a specific task. If any of the members performs his or her task poorly then the team loses the competition. Certain R&D competitions and team projects have such characteristics, such as a software development project where one bad coding bug can make the entire project fail. Also, in terrorist attacks and in some military battles, the attacker's objective is often to successfully attack one target, so success is determined by the defense of the minimally-protected target (Clark and Konrad, 2007).

Although it has strong coordination incentives, a key feature of this competitive coordination game is that efforts are socially wasteful so efficiency increases when players coordinate on lower effort levels. This is a key difference between our environment and Sutter and Strassmair (2009), who study a similar underlying game (a contest between groups) and features a similar experimental design (treatments involving different forms of communication). The main feature that distinguishes our study from theirs, as well as from Nalbantian and Schotter (1997), is that in our experiment higher efforts lead to lower efficiency due to the negative externality imposed to the competing group. This unique feature allows the design to determine whether intra-group communication, which usually increases efforts and efficiency, can actually damage efficiency and decrease social welfare. There are also other differences. First, in our study, we reward the prize according to a probabilistic contest success function rather than giving to the group with higher (stochastic) effort. Second, the effective group effort is determined by a weakest link game which gives a rational individual the veto power to effectively lower the group effort instead of noisy additive effort game. Third, we implement a richer experimental design involving both contests between groups and contests between individuals which allows for a direct comparison between individual and group decision making.

Without communication, we find that group members achieve a modest level of coordination within each group. Allowing only intra-group communication before expending any efforts leads to significantly greater coordination and higher efforts, but it also results in more aggressive competition and substantially lower payoffs. In this communication treatment group efforts actually exceed the highest equilibrium level. On the other hand, allowing inter-group communication leads to significantly lower efforts and higher payoffs. Since intra-group and inter-group communication have opposite effects, in another treatment with both types of communication permitted we find that the level of competition and payoffs are not significantly different from a no-communication baseline treatment.

Our experiment thus provides an example of an environment where communication can either enhance or damage efficiency. This result contrasts with experimental findings from standard public goods and coordination games, where communication always enhances efficiency and often leads to socially optimal outcomes.[4] Although as in all studies cited above we also find that intra-group communication increases coordination and effort, here it actually damages efficiency and decreases social welfare.[5] The main reason behind this result is that in

[4] See Isaac and Walker (1988) and Ledyard (2005) for the efficiency enhancing effect of communication in public goods games.

[5] The finding that communication may reduce efficiency echoes the recent finding of Abbink et al. (2010), who show that by allowing intra-group punishment in inter-group contests leads to excessive and inefficient contest expenditures. In this study, we find that allowing intra-group communication in weakest-link contests leads to excessive effort expenditures. The crucial difference is that communication, commonly perceived to enhance efficiency, may cause inefficiency in a coordination game. Cooper et al. (1989) also find that more communication (two-way rather than one-way) in the battle-of-the-sexes game can reduce efficiency, since it increases miscoordination. The design of Sutter and Strassmair (2009) does not include this efficiency-reducing effect of

the weakest-link contest higher efforts are wasteful, and thus they lower efficiency. Therefore, our experiment makes a clear point: communication is a good coordination-enhancing mechanism, but it should not be interpreted generally as an efficiency-enhancing mechanism.

2. The Model

Consider a contest between two groups A and B. Each group consists of N risk-neutral players. All players simultaneously and independently expend irreversible and costly individual efforts x_{iA} and x_{iB}. Players within the winning group each receive the valuation of a prize v. Players within the losing group receive no prize. The total effective effort of each group depends on the lowest effort chosen by a member within the group – the so-called weakest-link. Group efforts determine winning probabilities using the widely-used Tullock (1980) lottery contest success function (CSF). Therefore, the probability of group A winning the prize is defined as:

$$p_A(x_{iA}, x_{-iA}) = \frac{\min\{x_{1A},\dots,x_{NA}\}}{\min\{x_{1A},\dots,x_{NA}\} + \min\{x_{1B},\dots,x_{NB}\}} \quad (1)$$

That is, each group's probability of winning depends on the lowest effort within that group relative to the sum of the lowest efforts by both groups (groups win with equal probability if they both have a lowest effort equal to 0). There are a number of reasons for choosing this probabilistic CSF. First, the lottery CSF (1) arises naturally from a reasonable set of axioms about contests between groups (Münster, 2009). Second, the equivalence theorem of Baye and Hoppe (2003) shows that the lottery-type contest is equivalent to a class of innovation games such as innovation tournaments and patent races. Finally, due to the "sufficient" noise produced by the lottery CSF, the equilibrium in lottery-type contests is often in pure strategies

communication. As in oligopolistic competition, communication facilitates coordination and collusion and causes inefficiency (Isaac et al., 1984; Davis and Holt, 1998; Engel, 2007), but in oligopoly environments this inefficiency arises from reduced consumer surplus as colluding sellers charge higher prices and increase their own payoffs. In contrast, in our study intra-group communication reduces the payoffs of parties involved in the communication.

(Szidarovszky and Okuguchi, 1997).[6] Given the lottery contest success function (1), the expected payoff for player i in group A can be written as:

$$\pi_{iA}(x_{iA}, x_{-iA}) = p_A(x_{iA}, x_{-iA})v - x_{iA}. \quad (2)$$

Maximizing (2) with respect to x_{iA} and solving the (symmetric) best response functions simultaneously gives the theoretical predictions for this contest. Since this game is a coordination game, there exist multiple pure-strategy Nash equilibria in which the players within the same group match their efforts at the same level while best responding to the effort of the other group (Sheremeta, 2011; Lee, 2012). In particular, in any equilibrium, all players in each group best respond to the effort of the other group according to the following best-response functions: $x_A \leq \sqrt{x_B v} - x_B$ and $x_B \leq \sqrt{x_A v} - x_A$. Moreover, because of the weakest-link technology for aggregating individual efforts, in equilibrium all players in each group must match their effort levels, i.e. $x_{iA} = x_A$ for all i and $x_{jB} = x_B$ for all j. The full set of pure strategy Nash equilibria is illustrated by the shaded area in Figure 1.

Two specific equilibria of interest are the *group Pareto dominant* equilibrium and the *Pareto efficient* equilibrium. The group Pareto dominant equilibrium may be focal because the players within a group have incentives to coordinate with each other to increase their effort levels at any other equilibrium within the shaded area. At the group Pareto dominant equilibrium all players expend efforts of $v/4$ and no group has any incentive to deviate. On the other hand, the Pareto efficient equilibrium is when all players expend 0. In this equilibrium there is no dead

[6] An alternative to the lottery CSF is a deterministic CSF, which is often used in all-pay auctions (Baye et al., 1996). However, the equilibria in contests with deterministic functions are in mixed strategies, and thus it may be difficult for subjects to find one of such equilibria. Moreover, deterministic contests between groups are difficult to analyze theoretically because the mixed strategies have to be aggregated on the group level, and often such models can be characterized theoretically only in some very restricted cases (Baik et al., 2001). Another alternative to the lottery CSF is a proportional-prize structure (Cason et al., 2010). The benefit of using proportional-prize structure is that it eliminates probabilistic noise, which may help subjects to find an equilibrium faster. However, the proportional-prize structure is not as common in practice and it has not been thoroughly investigated. Given these considerations, we decided to use a lottery CSF in our theoretical analysis and experimental design.

weight loss from competition and each group is equally likely to win the contest. Note that any symmetric or asymmetric equilibrium within the shaded area in Figure 1 is more efficient than the group Pareto dominant equilibrium and less efficient than the Pareto efficient equilibrium.

3. Experimental Design and Procedures

Our principal research question concerns the impact of communication in this competitive coordination game, so our experiment employs six treatments in a between-subjects design as shown in Table 1. In four group treatments (NOCOMM, INTRA, INTER, and INTRA+INTER), there are N=3 players in each group and all players within the winning group receive the prize of v=60 (equivalent to $2). The stage game was played for 30 periods. Subjects were placed into group A or B at the beginning of the first period, and they stayed in the same group for the duration of the experiment. They also competed against the same opposing group for all 30 periods. We chose this fixed matching protocol to allow subjects an opportunity to coordinate with each other on one of the many different equilibria. Therefore, the 48 subjects in each group treatment generate 8 statistically independent, 30-period, 6-player supergames.[7] At the beginning of each period, each subject received 60 experimental francs as an endowment. Effort choices were framed in the instructions using the standard labels from public good provision experiments: subjects were informed that by allocating 1 franc to their individual account they would earn 1 franc, while by allocating 1 franc to their group account they could increase the chance of their group receiving the reward. Subjects could contribute any integer number of francs between 0 and 60.

[7] Subjects were informed that the session would last for exactly 30 periods, so the stage equilibrium prediction also holds for this finitely repeated game. As noted above, we conjectured that groups or individuals might coordinate on Pareto-improving outcomes in the repeated game, since this is frequently observed in the experimental literature even in finitely-repeated games with a unique equilibrium (e.g., Selten and Stoecker, 1986).

The baseline treatment NOCOMM implements a group contest without communication. In treatments with communication, before subjects made their allocation decisions they had an opportunity to communicate with other participants via chat windows. In treatment INTRA, subjects in both groups could send messages to the two other members of the own group anonymously via a "3-person chat" window for 60 seconds each period. In treatment INTRA+INTER, besides the "3-person chat" window, messages could also be sent in a "6-person chat" window which would be viewed by all six subjects in the two groups. In treatment INTER, only the "6-person chat" window was available.[8] Finally, in the two individual treatments (INDIVIDUAL-INTER and INDIVIDUAL-NOCOMM), two groups were replaced with two individual players who competed for a prize of v=60. This is similar to the tournament treatment in Harbring (2006), except that earlier study used a deterministic rather than lottery contest success function. In the INDIVIDUAL-INTER treatment the two players could communicate using a chat window for 60 seconds during each period, while no communication was allowed in the INDIVIDUAL-NOCOMM treatment. For all chat communications we asked subjects to follow two basic rules: (1) to be civil to one another and not to use profanity, and (2) not to identify themselves in any manner. Messages were recorded.

After the chat period, all subjects simultaneously made their effort (allocation) decisions, and then a random draw determined the winning group. A simple lottery was used to explain how the computer chose the winning group.[9] At the end of each period subjects were informed of group *A*'s and *B*'s effective efforts (i.e., the minimum effort in each group); or in the case of the individual treatment, they learned both individuals' effort choices. Subjects were paid for 5

[8] In these two treatments, the chat windows were active for 120 seconds at the beginning of the first 10 decision-making periods. From the 11th through 20th periods the chat time was set at 90 seconds, and for the final 10 periods the communication lasted for 60 seconds.

[9] Probabilities were explained in the instructions as a number of tokens placed in a bingo cage based on effort choices, and then one randomly drawn token determined the winning individual or group.

randomly-drawn periods at the end of the experiment.

A total of 224 subjects participated in 18 sessions, generating 48 independent observations: eight groups of six in each of the treatments NOCOMM, INTRA, INTER, and INTRA+INTER and eight pairs of subjects each in treatments INDIVIDUAL-INTER and INDIVIDUAL-NOCOMM (Either 12 or 16 subjects participated in the lab for each data collection period – 2 sessions of 6 subjects for the group treatments, or all 16 subjects in the individual treatments). Subjects were undergraduate students who participated in only one session of this study. Some students had participated in other economics experiments that were unrelated to this research.

The computerized experimental sessions were run using z-Tree (Fischbacher, 2007). At the beginning of each part subjects were given the written instructions, shown in the Appendix, and the experimenter also read the instructions aloud. Before the subjects played 30 periods of the stage game, we elicited subjects' risk attitudes using multiple price list of 15 simple lotteries, similar to Holt and Laury (2002).[10] At the end of the session, one of the 15 lottery decisions was randomly selected for payment.

Earnings were converted into US dollars at the rate of 30 francs to $1. Subjects earned about $21 on average and sessions lasted about 60 to 90 minutes.

4. Group Identity and Predictions

One important factor influencing group decision making is group identity. Inspired by Akerlof and Kranton's (2000, 2005) pioneering work to incorporate social identity into the

[10] Subjects were asked to state whether they preferred safe option A or risky option B. Option A yielded $1 payoff with certainty, while option B yielded a payoff of either $3 or $0. The probability of receiving $3 or $0 varied across all 15 lotteries. The first lottery offered a 0% chance of winning $3 and a 100% chance of winning $0, while the last lottery offered a 70% chance of winning $3 and a 30% chance of winning $0.

principal-agent model, experimenters have studied the effect of salient group identity on individual behavior in nonstrategic tasks with induced out-groups (Chen and Li, 2009), nonstrategic tasks without out-groups (Sutter, 2009) and in strategic tasks such as public goods games (Eckel and Grossman, 2005), bargaining games (McLeish and Oxoby, 2007), prisoner's dilemma and battle of the sexes games (Charness, Rigotti and Rustichini, 2007).

According to social identity theory (Tajfel and Turner, 1979), a salient group identity can cause a blurring of the boundaries between personal and group welfare and produce behavior that is contrary to personal self-interest and is instead in the interest of group benefit. In intergroup relations, individuals put themselves and others into different categories based on perceived similarities and differences (categorization), identify others as in-group or out-group members (identification), and compare their groups with other groups, discriminating in favor of the in-group and against the out-group (comparison). Individuals also tend to prefer their own identity to be both distinct and better than other groups (psychological distinctiveness).

Various methods have been used to induce saliency of group identity in economics experiments.[11] Along with assigning a group task, associating individual decisions with payoff consequences for other group members, or revealing individual decisions to group members, exchanging nonbinding messages with other group members can effectively induce saliency (Sutter, 2009). The multiple group boundaries in our competitive coordination game allow us to manipulate communication channels to explore how individual and group behavior differs depending on the perception of individual, in-group and out-group membership.[12]

[11] Another set of economics experiments studies the effect of group identity, using primed group identity such as gender, ethnicity, native social groups, natural groups, and village communities. Chen and Li (2009) provide an excellent literature review on group identity.

[12] Besides increasing group identity, communication also (1) provides information and facilitates understanding of the game; (2) promotes coordination of cooperative actions; (3) alters the expectations about other players' behaviors; and (4) elicits social norms such as trust, commitment, promise-keeping (Bicchieri, 2002). The purpose

Compared to the no communication treatment (NOCOMM), when intra-group communication is allowed in both groups (treatment INTRA), communication may shift individuals' self-categorization from the individual to the 3-person group level. The inter-group competition can also lead subjects to identify the 3 people in the opponent group as out-group members, resulting in in-group favoritism that leads to greater coordination with in-group members and more intense competition with out-group members. Intra-group communication may even lead all individuals within the 3-person group to act cooperatively as one player (Sutter and Strassmair, 2009; Zhang, 2009). In this case it is appropriate to model all players within a group as trying to maximize their joint payoff instead of their individual payoff (2), and so the objective function of player i in group A can be written as:

$$\pi_{iA}^{c}(x_{iA}, x_{-iA}) = p_A(x_{iA}, x_{-iA})Nv - \sum_{i=1}^{N} x_{iA} \quad (3)$$

Maximizing (3) with respect to x_{iA} and solving the best response functions simultaneously gives us a unique Nash equilibrium where all players in each group match their efforts at the same level of $v/4$=15. Note that this is exactly the same as the group Pareto dominant equilibrium in the case with no communication, and is also the standard equilibrium in the two-player Tullock contest. The group Pareto dominant equilibrium is also a coalition-proof Nash equilibrium (Bernheim et al., 1987). Therefore, if intra-group communication indeed helps members within each group to improve coordination, they may select a more competitive (higher effort) equilibrium. Thus, the introduction of intra-group communication may cause inefficiency.

Hypothesis 1: Intra-group communication improves coordination within groups compared to the no communication treatment and leads to more intense competition (higher effort) between groups, which results in lower payoffs.

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of this study is not to identify which of these factors has the strongest explanatory power on the effect of communication, but to investigate how individual and group behavior can differ depending on the availability of different communication channels.

When messages are exchanged and viewed by all 6 individuals in the contest and no private messages can be exchanged between subsets of individuals (treatment INTER), according to social identity theory the 6-person collective boundary is more likely to be used as the basis for self-categorization. This attenuates the competitiveness between the two 3-person groups, leading all 6 individuals to act as one player trying to maximize their joint payoff. It is easy to verify that the joint payoff of all players is strictly decreasing in individual effort, i.e. $\sum_{i=1}^{N} \pi_{iA} + \sum_{i=1}^{N} \pi_{iB} = Nv - \sum_{i=1}^{N} x_{iA} - \sum_{i=1}^{N} x_{iB}$. In treatments INTER and INDIVIDUAL-INTER, if subjects can coordinate on the most efficient equilibrium they should all choose efforts equal to the group Pareto efficient equilibrium of 0. Therefore, inter-group communication may help to reduce wasteful effort expenditures and achieve higher efficiency.

Hypothesis 2. Inter-group communication improves coordination within groups and leads to less intense competition (lower effort) between groups compared to treatments without inter-group communication, and this results in higher payoffs.

By contrast, when both public messages and private messages for each of the 3-person groups are allowed (treatment INTRA+INTER), group behavior may be more complex and depend on whether the communication strengthens the 3-person or 6-person group boundaries. The public messages could make the 6-person group membership more salient. Alternatively, if the 3-person group membership is more salient, individuals may strategically send misleading public messages to the opposing group and coordinate on higher effort levels in their private chat window. Although we expect higher coordination in INTRA+INTER than in NOCOMM treatment, social identity theory has ambiguous implications for the comparison between effort levels in treatments INTRA+INTER and NOCOMM. In these treatments all subjects within each group should coordinate on the same effort level, but this level can vary across groups and there is no strong reason to expect a particular equilibrium effort level between 0 and 15.

Hypothesis 3. Allowing both intra- and inter-group communication improves coordination within groups compared to the no communication treatment.

5. Experimental Results

5.1. Within-Group (INTRA) Communication

Figure 2 displays the time series of the average group effective (minimum) effort in the six treatments. In the NOCOMM treatment, average individual effort should be between 0 and 15. As shown in Table 2, the actual average effort is 11.18, indicating that subjects learn to coordinate their efforts at a substantial level. To measure the extent of coordination, we examine how much effort is wasted due to unequal effort choices within groups. We define *mean wasted effort* in a group by taking the average of the differences between individual effort and the group minimum effort within each group (Riechmann and Weimann, 2008).[13] Complete coordination is reached when the group wasted effort equals zero. Figure 3a indicates that subjects in the NOCOMM treatment substantially reduced their miscoordination in the second half of the experiment relative to the first half (Wilcoxon signed-rank test, p-value < 0.05, n=8).[14]

The minimum effort does not decline to zero with repetition in this treatment without communication, and generally remains above 8 until the final period. This finding stands in sharp contrast to previous findings for the minimum effort coordination game (Blume and Ortmann,

[13] Although these efforts above the minimum are always wasteful in the static game environment, they may not be wasteful in a dynamic setting. In some cases higher effort (which would be wasted in the short term) might be beneficial if they signal to others that efforts should be increased. Such "strategic teaching" could be particularly useful in the no communication treatments, when arguments for or against specific effort choices are not possible.

[14] All non-parametric tests employ only the independent observations of six subjects in group treatments and two subjects in individual treatments.

2007; Devetag and Ortmann, 2007), and could be due to our use of relatively small (three-person) groups or the competition between groups.[15] To summarize:

Result 1. Even without communication, substantial but incomplete coordination exists within groups.

When intra-group communication is allowed, as in treatment INTRA, the overall average effort is 20.13. The average effective (*minimum*) effort within groups is higher than 15 in 28 out of 30 periods (Figure 2a), and the mean effective effort (18.86) is significantly greater than the highest equilibrium level of 15 (Wilcoxon signed-rank test, p-value < 0.05, n=8). Moreover, the average effective effort in the INTRA treatment is not significantly different from the INDIVIDUAL-NOCOMM treatment, suggesting that intra-group communication leads all subjects within the 3-person group to act as one player (Mann-Whitney test, p-value = 0.60, n=m=8).[16]

Blume and Ortmann (2007) and Sutter and Strassmair (2009) document that intra-group communication leads to significantly higher coordination and efforts. Consistent with these previous studies and predictions from social identity theory discussed above, the average and minimum efforts in the INTRA treatment are significantly higher than the average and minimum efforts in the NOCOMM treatment (Mann-Whitney test, p-value < 0.05, n=m=8).

[15] Van Huyck et al. (1990) find that with two-person groups, subjects usually choose high efforts and achieve very substantial coordination levels. By contrast, previous studies of coordination games with three-person groups report that in the final period of the experiment about 30% of subjects choose the lowest possible effort level (Camerer and Knez, 1994; Knez and Camerer, 2000). In contrast, in the final period of our experiment only 4% of subjects choose the lowest effort level. Therefore, we conjecture that the main reason driving substantial coordination in the NOCOMM treatment is not that we have three-person groups but the fact that in our experiment we have competition between groups.

[16] Although we do not find a significant difference between INTRA and INDIVIDUAL-NOCOMM treatments, one has to be careful in interpreting this finding. It is possible that failure to reject a null hypothesis is due to lack of power, but since the observed differences in this case are small a much larger sample size might be required to identify statistical differences. Based on the empirical means and standard deviations observed in the two treatments, a simple power calculation indicates that these means would be statistically different with a sample of 701 independent observations per treatment.

Figure 4 displays the average minimum effort for each group or individual pair in the last 10 periods of the experiment by treatment. Each bar represents one independent observation, either a group of six (two groups of three) interacting subjects in the NOCOMM, INTRA, INTER and INTRA+INTER treatments, or an interacting pair of subjects in the INDIVIDUAL-NOCOMM and INDIVIDUAL-INTER treatments. Although considerable heterogeneity exists across groups, note that the distributions of average minimum efforts in the INTRA and NOCOMM treatments are very different.

Result 2. Relative to no communication, intra-group communication increases average and minimum group efforts.

Further comparison of the INTRA and NOCOMM treatments indicates that intra-group communication allows subjects coordinate better (Figure 3a). The amount of wasted effort is lower in the INTRA treatment in almost all periods, and is significantly different from the NOCOMM treatment (Mann-Whitney test, p-value < 0.05; $n=m=8$).

Result 3. Intra-group communication improves coordination.

Recall that the Pareto efficient equilibrium occurs when all players expend 0 efforts. At this equilibrium there is no deadweight loss from competition, and each group is equally likely to win the prize of 60. Because of the over-contribution of efforts in treatment INTRA the average payoff is substantially lower than the payoff in treatment NOCOMM. As shown in Table 2, pooled across periods the average payoff in NOCOMM is about double that in INTRA. This treatment difference is statistically significant (Mann-Whitney test, p-value < 0.05, $n=m=8$).

Result 4. Intra-group communication decreases payoffs and efficiency.

This result contrasts with experimental findings from public goods, team production, and coordination experiments, where communication enhances efficiency and leads to socially optimal outcomes. Jointly, Results 2-4 provide strong empirical support for Hypothesis 1. To summarize, intra-group communication improves coordination and increases individual efforts. However, this increase in individual efforts reduces payoffs and is inefficient. Not only are efforts under communication higher than the efficient equilibrium effort of 0, but they also exceed the highest possible equilibrium effort of 15. Note that 15 is the maximum rationalizable effort level for monetary payoff maximizers; i.e., given any effort level chosen by the opponents, 15 is the maximum effort that a rational player should expend (cf. Figure 1).[17] As a result of this over-contribution of efforts, the average payoff in the NOCOMM treatment is twice as high as the average payoff in the INTRA treatment. These observed differences between the NOCOMM and INTRA treatments are consistent with implications of social identity theory outlined in the previous section. It appears that the INTRA communication promotes in-group favoritism and leads to greater coordination with in-group members and more intense competition with out-group members. Subjects choose significantly higher effort levels in the INTRA treatment, and these higher efforts generate a positive externality to in-group members and a negative externality towards out-group members.

5.2. Between-Group (INTER) Communication

In INDIVIDUAL-INTER and INTER treatments, the group Pareto dominant equilibrium is for all players to choose an effort of 0, although any effort level between 0 and 15, where all players within each group coordinate on the same effort level, is consistent with other equilibria. The actual average effort in treatment INDIVIDUAL-INTER is 5.33 and in treatment INTER is

[17] It is important to emphasize, however, that efforts above 15 may not necessarily be irrational. For example, if the event of winning carries some utility (i.e. Sheremeta, 2010) then 15 is no longer the appropriate maximum benchmark. In fact, analyzing the chat messages in the INTRA treatment, we find evidence that winning is an important element that enters subjects' utilities. On average 29% of chat room discussions in the INTRA treatment contain "explicit indication and appeal to WIN and to beat the other group".

5.81, and both of these are significantly lower than 15 (Wilcoxon signed-rank test, *p*-value <0.05, *n*=8 for both treatments). Efforts are not significantly different between these two treatments, and neither are payoffs (Mann-Whitney test, *p*-value = 0.60 for effort and *p*-value = 1.00 for payoffs, *n*=*m*=8).[18] The average and minimum effort in the INTER treatment is also significantly lower than the average and minimum effort in the NOCOMM treatment (Mann-Whitney test, *p*-value = 0.06, *n*=*m*=8). This finding provides initial support for Hypothesis 2.

Result 5. Relative to no communication, inter-group communication decreases average and minimum group efforts.

Although substantial intra-group coordination exists with and without inter-group communication, comparing INTER and NOCOMM treatments indicates that inter-group communication allows subjects to coordinate better. In particular, Figures 3a and 3b show that the *mean wasted effort* is lower with inter-group communication than without inter-group communication, and this difference becomes marginally significant in later periods (Mann-Whitney test, *n*=*m*=8; *p*-value = 0.14 pooled over all periods and *p*-value = 0.06 over last 10 periods).

Figure 5 illustrates between-group coordination using a histogram of the difference between the two groups' effective efforts. The strong mode on 0 for the INTER treatments reflects the effective between-group coordination. When inter-group communication was allowed, groups spent a lot of time discussing the procedurally fair (but not allocatively fair) coin-flip determination of the winner. Subjects made statements such as, "lets all pick the same amount… that way its a 50-50 on who gets the bonus" or "if everyone is willing to collude and put 0 in the group account each time we're guaranteed at least 60 each time with a 50/50 shot of

[18] Based on the empirical means and standard deviations observed in the two treatments, a simple power calculation indicates that these means would be statistically different with a sample of 2921 independent observations per treatment.

getting the other sixty". As a result, everyone chose the same effort level 70% of the time in the INTER treatment, compared to only 28% of the groups who matched effective efforts in NOCOMM treatment. Among these tied contests in treatment INTER, groups matched efforts at 0 in 23% of the contests, and at 1 in 56% of the contests. The comparisons between treatments INDIVIDUAL-INTER and INDIVIDUAL-NOCOMM generate similar results. In the INDIVIDUAL-INTER treatment, 60% of the contests had tied effort choices, and among these contests 20% were tied at effort of 0 and 53% were tied at effort of 1. Although positive efforts are inefficient, we conjecture that some groups struck agreements to match effort levels at 1 rather than 0 because such agreements are less susceptible to defection. Agreements at positive effort levels have a lower expected deviation payoff since higher effort choices are not sure to win.

Figure 4 further indicates that 7 out of 8 paired groups in the INTER treatment learned to coordinate on an effort level less than 5. Only one pair of groups competed aggressively by exerting on average effort of 18. Because of the lower efforts in the INTER treatment, subjects earn average payoffs that are significantly higher than the payoffs in the NOCOMM treatment (Mann-Whitney test, p-value = 0.06, n=m=8). Similarly, efforts are lower (and payoffs higher) in the INDIVIDUAL-INTER than the INDIVIDUAL-NOCOMM treatment (Mann-Whitney test, p-values < 0.01, n=m=8). These finding further support Hypothesis 2.

Result 6. Relative to no communication, inter-group communication improves both intra-group and inter-group coordination, and also increases payoffs and efficiency.

Compared to the INTRA treatment, with inter-group communication subjects not only achieved similar levels of intra-group coordination (the *mean wasted effort* is 1.41 versus 1.27; Mann-Whitney test, p-value = 0.67, n=m=8), but they also reduced effective efforts significantly via inter-group coordination (Mann-Whitney test, p-value < 0.01, n=m=8). Subjects in the INTER treatment thus earned significantly more (Mann-Whitney test, p-value < 0.01, n=m=8). To summarize, inter-group communication improves coordination and decreases individual efforts. This decrease in individual efforts increases payoffs. These treatment effects are consistent with social identity theory. The ability to communicate with the opponent group apparently leads subjects to identify with the 6-person group and lowers effort levels. To illustrate from the chats, subjects make statements such as “it's help 6 people instead of 3” and “please be kind to the group”.

5.3. Within- and Between-Group (INTRA+INTER) Communication

When both intra- and inter-group communication were allowed, some groups tried to mislead the opponent group. For example, in their private (3-person) chat one group wrote, “why not we betray them. LOL”; “we could mess with them and go really high”; “are they telling us one thing and then doing another to get us”. These and similar messages were classified as “trying to fool or cheat the other group” in 10% of the chat rooms by our content analysis coders, discussed in Section 5.5. Other groups recognized the benefit of coordinating with the opponent group, as reflected in the following: “what if we try to strike a deal with the other group where you only allocate between 1-10 that could maximize both our profits”; “its best for both teams in the long run”. Figure 4 indicates that in the INTRA+INTER treatment, 4 out of 8 pairs of competing groups apparently identified themselves with the large, 6-person group and achieved almost perfectly efficient outcome, similar to the observed behavior in the INTER treatment. The other 4 pairs seemed to identify with the small 3-person group because they behaved very similar to the INTRA treatment.

Statistically, the differences in mean wasted effort, effective group effort and payoffs between INTRA+INTER and INTER are not significant, although this may be due to insufficient statistical power.[19] The two distinctive patterns in the INTRA+INTER treatment, with half of the groups competing aggressively and the other half choosing low efforts, leads to a significantly higher mean coefficient of variation in this treatment relative to INTER (Mann-Whitney test, *p*-value=0.03). Differences in outcomes are more systematically different, however, between treatments INTRA+INTER and INTRA. In particular, relative to the INTRA treatment, adding inter-group communication improves coordination (the *mean wasted effort* is 0.60 versus 1.27; Mann-Whitney test, p-value = 0.06, n=m=8), decreases group effort (9.69 versus 18.86; Mann-Whitney test, p-value = 0.01, n=m=8), and increases payoffs (19.70 versus 9.87; Mann-Whitney test, p-value = 0.01, n=m=8). These differences are consistent with the findings summarized in Results 5 and 6.

To summarize, we find that, consistent with Hypothesis 1, intra-group communication leads to greater coordination (Result 3), more aggressive competition (Result 2) and lower payoffs (Result 4). Also, consistent with Hypothesis 2, inter-group communication leads to greater coordination, but less competition (Result 5) and higher payoffs (Result 6). Note that intra- and inter-group communications both enhance coordination. However, these types of communication have opposite impacts for competition and payoffs in this competitive coordination game. Consequently, a comparison between treatments INTRA+INTER and NOCOMM reveals no significant differences in group effort or payoffs. The only significant difference is that coordination in INTRA+INTER treatment is significantly better than in

[19] Based on the empirical means and standard deviations for these two treatments, the difference between effective efforts would have been significant with 51 independent observations per each treatment. So, the conclusion about the no difference between treatments INTRA+INTER and INTER should be taken cautiously.

NOCOMM treatment (the *mean wasted effort* is 0.60 versus 2.89; Mann-Whitney test, p-value < 0.01, n=m=8). This provides support for Hypothesis 3.

Result 7. Relative to no communication, adding both inter- and intra-group communication improves coordination; however, it neither changes efforts nor payoffs.

5.4. Cournot Beliefs and Best Response Functions

As shown in Figure 1, for efforts less than $v/4$ (15 in our experiment with v=60) the best response functions are upward sloping, and for efforts above this threshold the best response functions are downward sloping. If subjects best respond to their beliefs about the other group's effort, these slopes imply a positive (negative) relationship between their own effort and beliefs about the opponents effort when the opponent is expected to choose efforts less (greater) than 15.

While estimation of a structural belief-learning model is beyond the scope of this paper, consider the simple assumption that subjects form beliefs using Cournot expectations, which is a common approximation used in theoretical and empirical learning models (e.g., Ho, 2008). In other words, suppose subjects tend to believe that a higher effort by the opponent in the previous period is likely to be followed by a similar, high effort in the current period. Review of the recorded chat messages provides evidence for such Cournot expectations.[20] Table 3 reports results from a random effects model of individual effort choices ($effort_t$) that condition on previous period effective (minimum) effort chosen by the competing group ($othergroup\text{-}effort_{t-1}$)

[20] The content analysis, described in more detail in Section 5.5, provides evidence that subjects often look back one period while discussing their current decisions. For example, in the treatment INTRA, 10% of chat rooms contain discussions about previous period decisions. Some typical messages used in the treatment INTRA are: "I think we stick to 25, because they seem to stick to 21" (session 081110 group 2, period 7); "wow… they went for 30? let's go for 31 then" (session 090311 group 4, period 3); "hmm…i guess they are just going 20…ya…how about we try 25?" (session 090303, group 4, period 11); "they are still at 30…suggestions? … 30…group consensus, yes?" (session 090331, group 1, period 11). Unfortunately, our coders did not classify backward-looking messages at a high statistical reliability.

and the previous period effective effort squared (*othergroup-effort*$_{t\text{-}1}$^2), to account for the inverted U-shaped best response reaction function illustrated in Figure 1.[21] These models also control for the risk attitudes inferred from the separate lottery choice task (*risk*; see footnote 10), the effective effort chosen by that group in the previous period (*group-effort*$_{t\text{-}1}$) and a nonlinear time trend (1/*period*).

The coefficient estimate on *othergroup-effort*$_{t\text{-}1}$ shown in the top row is positive and significant in all specifications. The coefficient estimate on *othergroup-effort*$_{t\text{-}1}$^2 is negative, indicating an inverted U-shaped reaction function. However, it is significant only in specifications (3) and (4) for the INTER and INTRA+INTER treatments. The point estimates for the coefficients of *othergroup-effort*$_{t\text{-}1}$ and *othergroup-effort*$_{t\text{-}1}$^2 imply reaction functions for the treatments INTER and INTRA+INTER that peak close to the equilibrium (approximately 18 to 22, compared to the equilibrium of 15). However, since the *othergroup-effort*$_{t\text{-}1}$^2 coefficient is insignificant and effectively zero in specifications (1) and (2) for the NOCOMM and INTRA treatments, the reaction functions in these cases are always increasing in the effort of the competitors. Based on this maintained assumption of Cournot belief updating, it appears that without any communication, subjects are best responding to the opponents' efforts because nearly all efforts are below 15. Adding only intra-group communication, however, causes subjects either to not recognize the incentive to reduce efforts in response to above-equilibrium efforts chosen by their competitors, or this communication creates strong in-group identity and favoritism that increases their utility of winning and thus leads to more intense competition.

In our view the "group irrationality" explanation seems less likely given the rich and nearly free-form communication within groups permitted by the chat windows, as well as the

[21] The estimates in the INTER treatment exclude the first 6 periods of one session (out of the 8 total sessions in this treatment) because during that learning phase subjects chose some very high outlier effort choices. After period 6 their behavior in that session closely resembled the low, cooperative effort choices observed in the other 7 sessions.

previous literature that suggests groups often make more rational decisions than individuals (Cooper and Kagel, 2005; Kocher and Sutter, 2005). This explanation is also less likely because each member of the group has “veto” power to lower effective group effort in this minimum-effort game, and more rational individuals can employ this power when the group effort is unreasonably high. Individuals do not take advantage of the opportunity to unilaterally lower their group’s effective effort, however. Instead, an informal review of the chat data suggest that subjects’ competitive tendencies are strengthened by their communications, consistent with a “group identity” explanation for the above-equilibrium efforts. For example, subjects’ mention of the word “win” often corresponds to a discussion about the effort level of at least 15, such as: “okay 30.. we will win” or “this is bad.. it has to be 40.. or we won’t win..” This suggests that many groups focus on winning the contest as a group, even when their efforts already exceed the maximum equilibrium level. To further and more formally analyze what kind of messages impact individual behavior we use content analysis.

5.5. Content Analysis of Communication

Our results show that communication impacts individual behavior by inducing greater coordination but it can either enhance or reduce efficiency depending on how communication boundaries are defined. We therefore use some exploratory content analysis to examine what kinds of messages are associated with different effort choices made by individuals. This analysis is challenging because the qualitative information exchanged in chats is difficult to quantify objectively.

The procedure that we used is becoming standard in the emerging experimental economics literature that explicitly analyzes how chat communication affects behavior. First, we randomly selected a session to develop a coding scheme. The scheme was based on the types of messages exchanged and conjectures based on group identity and learning, resulting in the 21 categories shown in Table 4. Then we employed two individuals to code independently all chat room discussions into the coding categories. The unit of observation for coding was all messages in a given period within each chat room. If a unit of observation was deemed to contain the relevant category of content, it was coded as 1 for that category and 0 otherwise. Each unit was coded under as many or few categories as the coders deemed appropriate. The coders were not informed about any hypotheses of the study, although they read the experiment instructions provided to subjects so that they understood the strategic environment the subjects faced.

Coding is subjective so the coders do not always agree on the message classification. To assess whether a particular type of message meaning is reliably coded, we follow Henning-Schmidt et al. (2008) and Cooper and Kühn (2010) in using a standard approach from content analysis methodology to adjust the reliability statistic to account for the number of categories that coders can use for classification. Agreement between the coders can occur by chance, especially if there are few categories for classification. Cohen’s Kappa (Krippendorff, 2004; Cohen, 1960) is a scaled measure of agreement that 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). Many of our message categories were not coded at the “Moderate” or “Substantial” agreement, particularly for the INTRA treatment, and are thus not considered sufficiently reliable. We do include some classifications that were classified moderately below the threshold of 0.4 but above 0.3, as indicated by “*” in Table 4, and in these cases we interpret results with caution.

Table 4 displays the average frequency that the coders classified chat room discussions in specific categories. In the INTRA treatment, the most common category coded is "agreement reached within group" (category C2a), suggesting that 79% of time group members coordinate by reaching agreement. The fact that subjects often reach agreement is consistent with Result 3, which documents that intra-group communication improves coordination. Most of the other categories are not coded reliably for this treatment, unfortunately, indicating some difficulty in objectively quantifying the content of some wide-ranging chat discussions. A considerable fraction of coded chat rooms (18%) did include discussions indicating that subjects made choices when reasoning from the other group's point of view, and some featured "verbal bullying or punishment" of fellow group members.

Many more of the relevant categories were reliably coded in the other treatments. In the INTER treatment, the most common and reliably coded categories are for agreement or no agreement reached between groups (categories C3a and C3b) and the "proposal that both groups choose the same effort" (category C3c). These categories reflect frequent inter-group coordination. Messages indicating "proposal that both groups choose 0" (category C3d) for efficient coordination are not as frequent. In the INDIVIDUAL-INTER treatment, where groups are replaced by individuals, there are more proposals to take turns to win and a similar number of proposals to choose the same effort. Overall, it appears that in both treatments INTER and INDIVIDUAL-INTER, groups/individuals frequently use messages to coordinate their efforts, which can explain why inter-group communication decreases group efforts (Result 5) and consequently increases payoffs (Result 6).

Messages used in the treatment INTRA+INTER are also often coded reliably, and many reflect intra-group coordination as well as inter-group coordination. This is consistent with our finding that adding both inter- and intra-group communication improves coordination (Result 7). Nevertheless, about 10% of messages in the within-group chat rooms indicate attempts to fool or cheat the other group (category C2c) and 4% of statements reflect mistrust towards the other group (category C2i).

Table 5 reports results from random effects models of individual effort choices ($effort_t$) on the same explanatory variables as in Table 3, augmented with the reliably-coded categories of communication from Table 4. Column (1), corresponding to the INTRA treatment, indicates that messages that belong to category C1c (reasoning from the other group's point of view) are associated with lower individual efforts, while verbal bullying or punishment (category C4a) is associated with greater effort, suggesting that this punishment is intended to restore higher efforts in the next period. Also, we find that greater intra-group chat volume, summarized by the number of words typed per subject in each chat room, is associated with lower efforts.

Column (2), corresponding to the INTER treatment, reveals that groups who reach agreement (C3a) and do not reach agreement (C3b) both have higher effort choices than those whose chat discussions do not explicitly indicate agreement or disagreement (a likelihood ratio test rejects the hypothesis that these coefficients are equal ($\chi^2_{1\ d.f.}$=20.61; p-value<0.01) in favor of the alternative that not reaching agreement (C3b) raises efforts more). Subjects in the INTER treatment who propose that both groups choose the same effort (category C3c) or that both groups choose zero effort (category C3d) choose lower efforts. This is also the case for the INDIVIDUAL-INTER treatment, where groups are replaced with individuals (column 4), although the only statistically significant category is the proposal for the same effort choices. In the INDIVIDUAL-INTER treatment, we also find that greater inter-group chat volume is associated with lower effort choices.

In the INTRA+INTER treatment subjects could communicate both within and between groups, and the results shown in column (3) indicate a more complex and rich relationship between messages and efforts. In this treatment more message categories were reliably coded and many are associated significantly with different effort levels. As in the INTER treatment, messages that reveal agreements (C2a), but this time within rather than between groups, are associated with significantly higher effort. Attempts to fool or cheat the other group (C2c) or mistrust of the other group (C2i) are also associated with higher efforts. The classifications associated with attempts to cooperate, and not compete with the other group, through mechanisms such as choosing the same effort level or taking turns winning, are all associated with lower effort choices. These types of communications, quite intuitively, appear to provide the mechanism through which social identity may increase cooperation in the INTER and INTRA+INTER treatments that feature inter-group communication.

6. Conclusion

Previous research has shown that communication in coordination games induces greater coordination, improves efficiency and increases individual payoffs. This study provides a counterexample of an environment where communication may decrease efficiency. Specifically, in a weakest-link contest between groups, we find that although both intra- and inter-group communication enhance coordination, these types of communication have opposite impacts for efficiency and payoffs. Introducing intra-group communication leads to more aggressive competition and lower payoffs. On the other hand, inter-group communication leads to greater coordination across groups, less competition and higher payoffs.

Although our main finding is novel, it is consistent with the broad literature discussed in the introduction highlighting the positive effects of communication in public goods and related games. We also find that both intra- and inter-group communication improves coordination and reduces free-riding within groups. The key point that our experiment adds is that this improved coordination occurs even when it reduces, rather than enhances, efficiency (treatment INTRA). An interpretation drawing on social identity is that intra-group communication increases subjects' identification with their group and shifts their self-categorization from the individual to the group level, leading them to coordinate better with their group and compete more with the opponent group. Therefore, one way to enhance efficiency in such contexts is to restrict intra-group communication (treatment NOCOMM). When intra-group communication is unavoidable, one way to offset its efficiency-reducing effect is to also allow communication across competing groups (treatment INTRA+INTER). The most effective way to improve efficiency in these environments with wasteful effort expenditures is to allow inter-group communication (INTER). This appears to lead group members to shift their self-categorization from individual to the larger (inter-) group level and increase joint payoff.[22]

The experimental environment implemented the classical Tullock model of rent-seeking, which has been widely used to model incentives for competing interest groups to influence public policy. While more confident conclusions await further research, we can note preliminary implications of our results for this setting. In particular, our findings indicate that intra-group communication results in greater wasteful rent-seeking. Drawing on results from Sutter and Strassmair (2009) and Sheremeta (2011), we conjecture that other mechanisms to aggregate

[22] Similar effects of intra-group and/or inter-group communication were documented by Bornstein et al. (1989, 1992) in an intergroup step-level public goods game where the group with higher contributions wins a prize that is shared equally among all members in the winning group regardless of their individual contributions. This earlier research considers different games and also differs from ours in many dimensions, such as its focus on the one-shot game and by aggregating group contributions through the sum of individual contributions. Our experiment provides subjects a more favorable environment to reduce possible detrimental effect of communication: 1) subjects had opportunity to learn over time in a repeated game; 2) subjects could unilaterally lower the group effort by reducing their individual effort due to the weakest-link effort aggregation rule; and 3) communication was implemented via online chat instead of face to face communication, which preserves anonymity and excludes non-verbal stimuli so that the social cost of using this veto power is attenuated.

individual efforts into group contests would also result in increased efforts when groups can communicate. Our general conjecture is that in group rent-seeking contests, similar to the one studied in this paper, mechanisms such as communication that lead to better within-group coordination will reduce efficiency. Future research can investigate how robust our findings are when the best-shot or summation (perfect-substitutes) technology is used within groups instead of the weakest-link effort aggregation rule (Abbink et al., 2010; Sheremeta, 2011; Chowdhury et al., 2011). Two pilot sessions we have conducted suggest that the general conclusion of our experiment stands: intra-group communication also improves coordination but reduces efficiency in the best-shot and perfect-substitutes contests. We chose to focus on the weakest-link rule in the present study, since it affords subjects the ability to unilaterally reduce their group's choice, increasing the chances that some group members would reduce the excessive effort expenditures and improve efficiency. Groups uniformly fail to take advantage of this opportunity, and so our experiment makes a clear point: communication is a good coordination-enhancing mechanism, but it should not be interpreted generally as an efficiency-enhancing mechanism.

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Tables and Figures

Figure 1: The Pure-Strategy Nash Equilibria of the Game

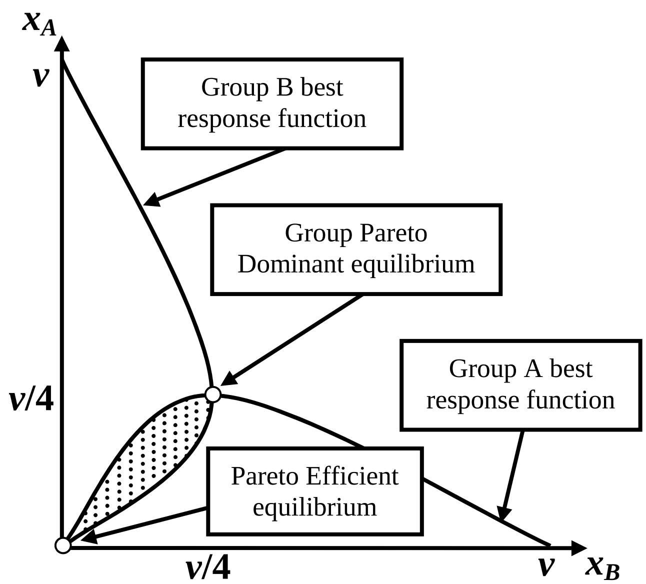


Figure 2a: Effective Group Effort

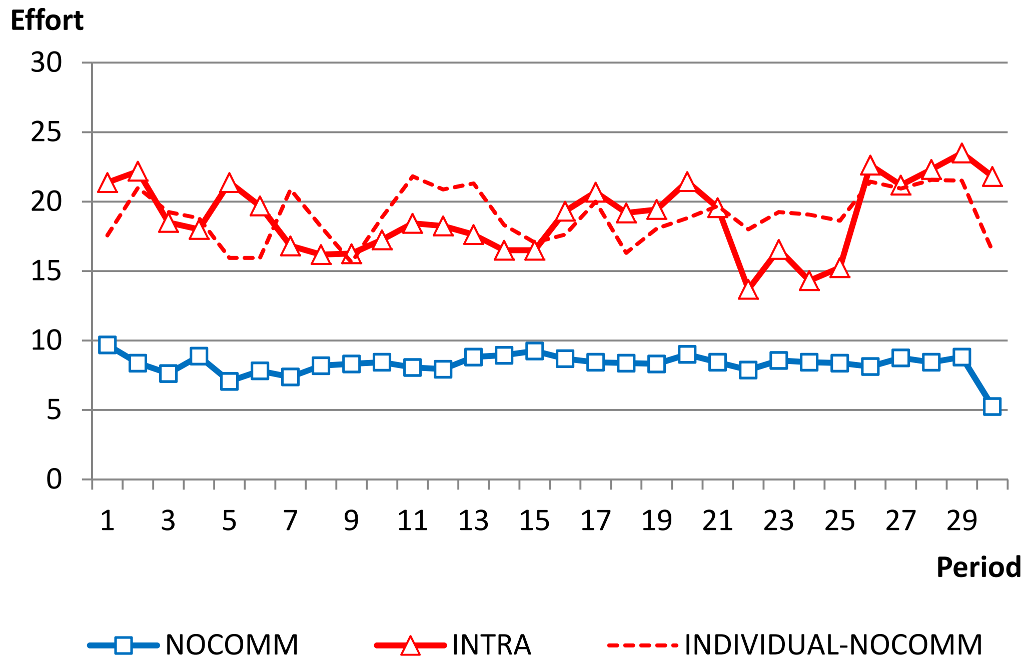


Figure 2b: Effective Group Effort

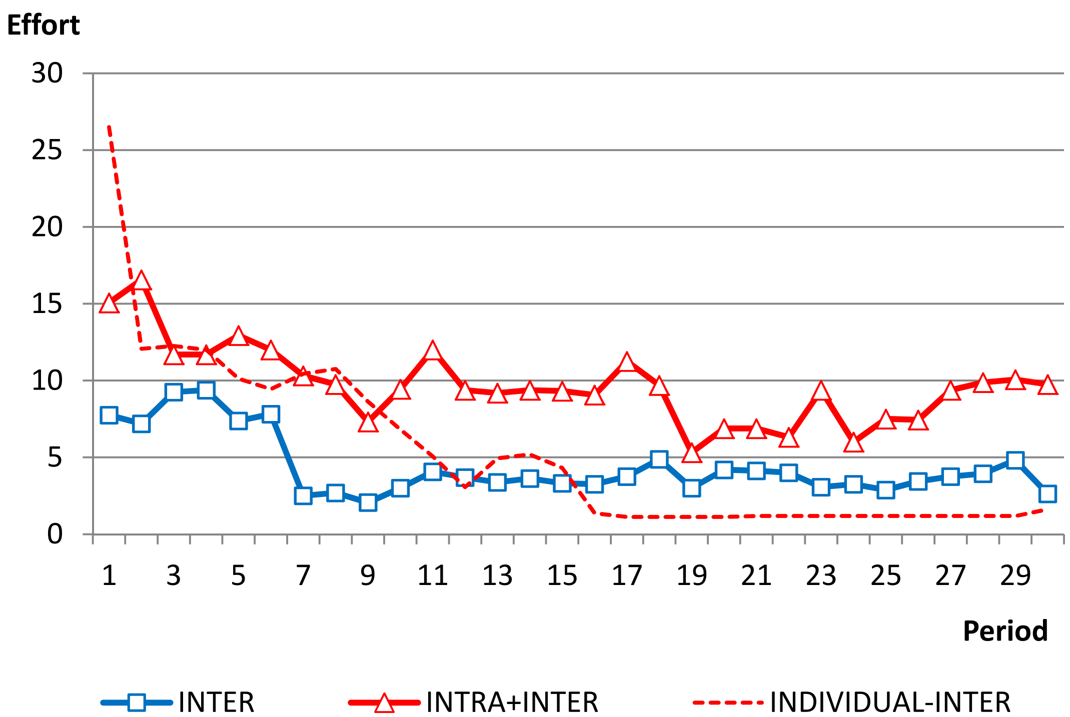


Figure 3a: Mean Wasted Effort

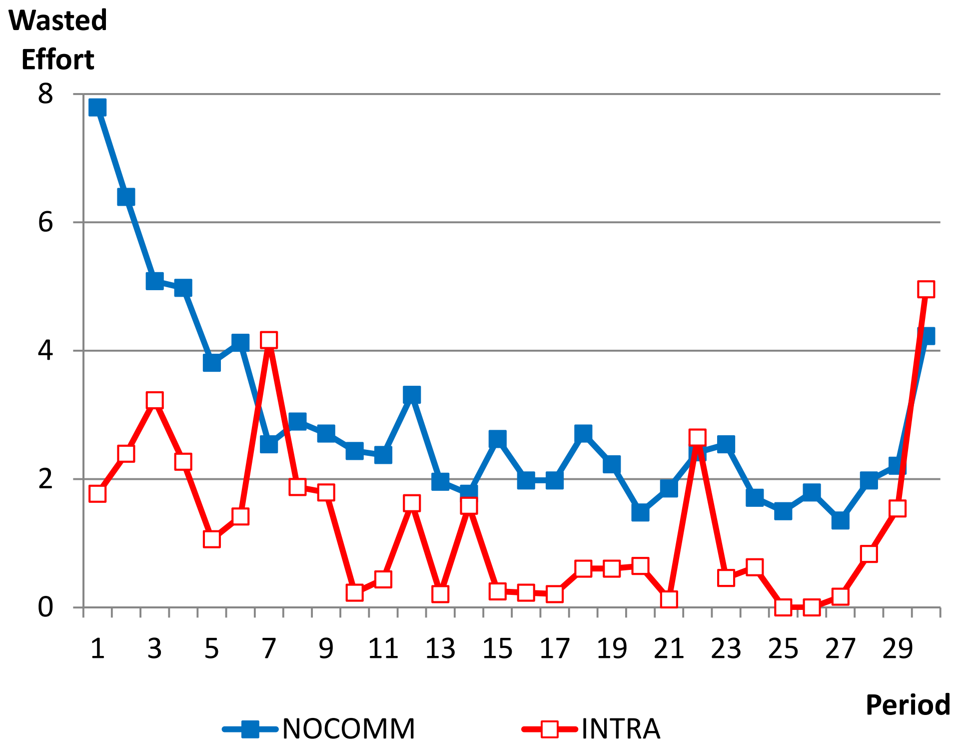


Figure 3b: Mean Wasted Effort

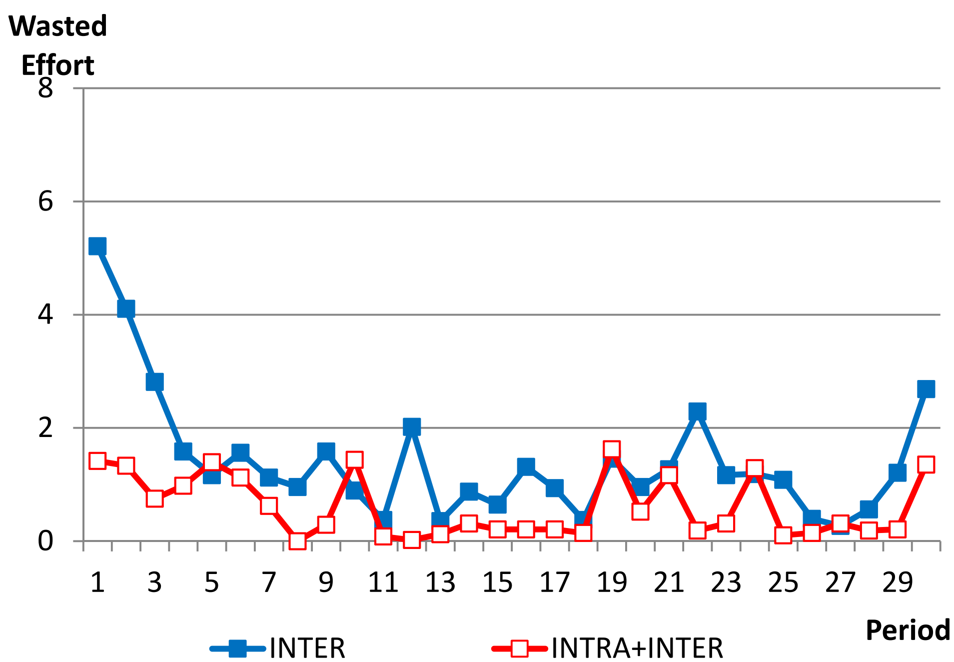


Figure 4: Average Minimum Effort per Group or Individual Pair (Last 10 Periods)

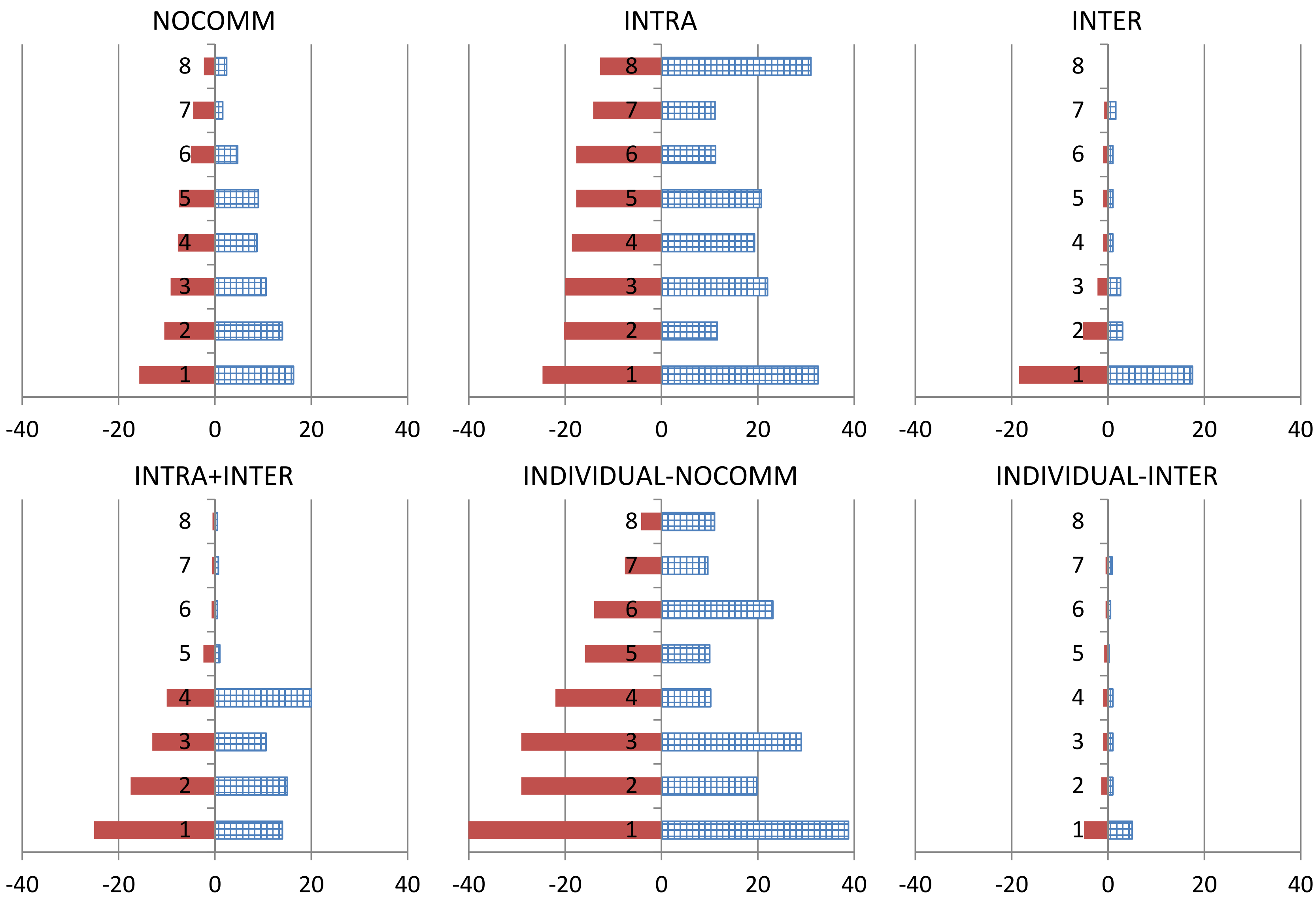


Figure 5: Coordination Between Groups

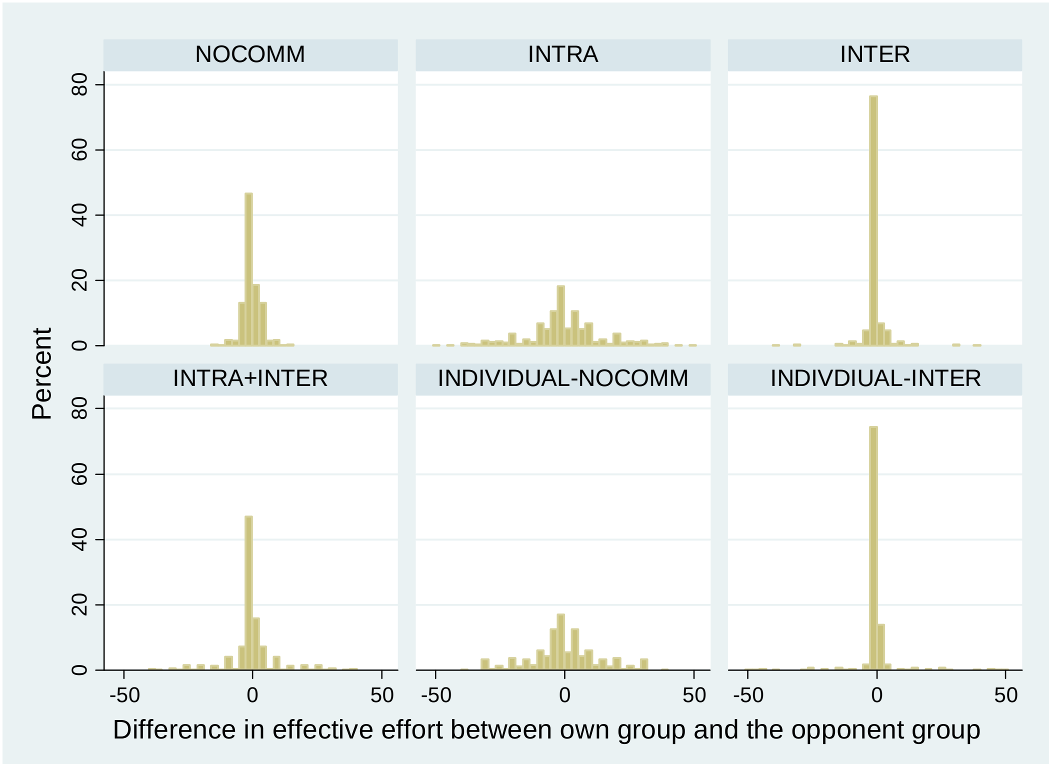


Table 1: Experimental Design and Treatment Labels (224 Total Subjects)

		Private Communication Within Three-Person Groups		Individuals
		None	Both Groups	
Communication Between Contestants	No	NOCOMM (8 sessions, 48 subjects)	INTRA (8 sessions, 48 subjects)	INDIVIDUAL-NOCOMM (8 pairs, 16 subjects)
	Yes	INTER (8 sessions, 48 subjects)	INTRA+INTER (8 sessions, 48 subjects)	INDIVIDUAL-INTER (8 pairs, 16 subjects)

Table 2: Summary Statistics by Treatment (All Periods)

Treatment	Average Group Effective Effort	Average Individual Effort	Average Wasted Effort	Average Individual Payoff
NOCOMM	8.29	11.18	2.89	18.82
	(0.12)	(0.20)	(0.16)	(0.81)
INTRA	18.86	20.13	1.27	9.87
	(0.30)	(0.31)	(0.14)	(0.78)
INTER	4.40	5.81	1.41	24.19
	(0.19)	(0.24)	(0.13)	(0.82)
INTRA+INTER	9.69	10.29	0.60	19.71
	(0.27)	(0.28)	(0.08)	(0.81)
INDIVIDUAL-NOCOMM		18.96		11.04
		(0.55)		(1.37)
INDIVIDUAL-INTER		5.33		24.68
		(0.47)		(1.41)

Standard errors shown in parentheses.

Table 3: Reactions to Previous Group Efforts Based on Individual Effort Choices

	Treatment and Data Subset			
Dependent variable, $effort_t$	NOCOMM	INTRA	INTER	INTRA+ INTER
Model	(1)	(2)	(3)	(4)
$othergroup\text{-}effort_{t-1}$	0.46**	0.21**	0.86**	0.78**
[effective effort of other in t-1]	(0.172)	(0.062)	(0.121)	(0.125)
$othergroup\text{-}effort_{t-1}$^2	-0.01	-0.00	-0.02**	-0.02**
[squared effective effort of other in t-1]	(0.009)	(0.002)	(0.004)	(0.003)
risk	0.21	-0.04	0.08	0.13
[number of risky options B]	(0.246)	(0.134)	(0.135)	(0.109)
$group\text{-}effort_{t-1}$	0.26**	0.58**	0.38**	0.46**
[effective group effort in t-1]	(0.075)	(0.041)	(0.076)	(0.084)
1/*period*	8.90**	4.20*	-0.50	1.47
[inverse of period number t]	(3.017)	(1.877)	(2.066)	(2.321)
constant	2.91	8.42**	-0.36	0.13
	(1.537)	(1.905)	(0.689)	(0.842)
Observations	1,392	1,392	1,362	1,392
Number of Subjects	48	48	48	48

* significant at 5%, ** significant at 1%.

Standard errors robust to general heteroscedasticity are shown in parentheses. All models include a random effects error structure, with individual subject effects. Session dummies are not reported in the interest of space. INTER treatment estimates drop the first 6 periods of one session (out of the 8 total sessions in this treatment) with outlier effort choices.

Table 4: Categories for Coding Messages and Observed Frequency in Chat Rooms

Category	Description	Relative frequency of coding: INTRA	INTER	INTRA+ INTER	INDIVIDUAL- INTER
C1	Learning and Best Response				
C1a	look back one period	0.10	0.00	0.02	N/A
C1b	look back at all or some (multiple) past periods, not just last period	0.13	0.00	0.01	N/A
C1c	make choices by reasoning from the other group's point of view	0.18*	0.01	0.05	N/A
C1d	changing strategy to be unpredictable	0.03	0.01	0.01	N/A
C2	Communication Within Group				
C2a	agreement reached within group	0.79***	N/A	0.46***	N/A
C2b	no agreement reached within group	0.14***	N/A	0.08***	N/A
C2c	try to fool or cheat the other group	0.10	N/A	0.10*	N/A
C2d	try to coordinate and cooperate with the other group	0.01	N/A	0.04**	N/A
C2e	explicit indication and appeal to WIN and to beat the other group	0.29	N/A	0.15	N/A
C2f	appeal to not compete, or lower effort within group	0.06	N/A	0.02**	N/A
C2g	compare own group with the other group and try to earn more than the other group	0.15	N/A	0.07	N/A
C2h	maximize everyone's payoff from both groups	0.01	N/A	0.02*	N/A
C2i	do not cooperate with other group because of mistrust	0.00	N/A	0.04*	N/A
C2j	cooperate until the other group defects or until the last period to defect	0.01	N/A	0.06*	N/A
C3	Communication Between Groups				
C3a	agreement reached between groups	N/A	0.23***	0.13***	0.31***
C3b	no agreement reached between groups	N/A	0.35***	0.05***	0.09**
C3c	proposal that both groups choose the same effort	N/A	0.22**	0.06**	0.18***
C3d	proposal that both groups choose 0	N/A	0.05***	0.01***	0.06***
C3e	proposal to take turns to win	N/A	0.03	0.09*	0.13**
C4	Other				
C4a	verbal bullying or punishment	0.05*	0.16	0.02	0.00
C4b	nothing relevant or fits	0.06***	0.41***	0.25***	0.59***

Note: Entries without asterisk indicate codes that did not reach the 0.3 Cohen's Kappa reliability threshold.
* denotes codes with Cohen's Kappa reliability between 0.3 and 0.4.
** denotes codes with Cohen's Kappa reliability between 0.4 and 0.6.
*** denotes codes with Cohen's Kappa reliability above 0.6.

Table 5: Effects of Communication on Individual Effort Choices

	Treatment and Data Subset			
Dependent variable, *effort*$_t$	INTRA	INTER	INTRA+ INTER	INDIVIDUAL-INTER
Model	(1)	(2)	(3)	(4)
othergroup-effort$_{t-1}$	0.19**	0.75**	0.63**	0.76**
[effective effort of other in *t*-1]	(0.060)	(0.111)	(0.092)	(0.139)
othergroup-effort$_{t-1}$^2	-0.00	-0.02**	-0.01**	-0.01**
[squared effective effort of other in *t*-1]	(0.001)	(0.004)	(0.002)	(0.003)
risk	-0.02	0.02	0.18*	-0.04
[number of risky options B]	(0.124)	(0.115)	(0.088)	(0.098)
group-effort$_{t-1}$	0.60**	0.35**	0.47**	0.36**
[effective group effort in *t*-1]	(0.038)	(0.068)	(0.060)	(0.087)
1/*period*	3.97*	0.35	4.66*	-3.47
[inverse of period number *t*]	(1.937)	(2.198)	(2.164)	(8.613)
Constant	9.89**	-0.78	1.09	1.34
	(1.758)	(0.772)	(0.736)	(1.004)
intra-group chat volume	-0.19**		0.01	
[average words per subject in chat]	(0.060)		(0.030)	
inter-group chat volume		0.01	0.01	-0.13**
[average words per subject in chat]		(0.016)	(0.030)	(0.024)
C1c	-1.40*			
[make choices reasoning from other's view]	(0.629)			
C2a	-0.13		1.48**	
[agreement reached within group]	(0.708)		(0.529)	
C2b	-1.53		1.35	
[no agreement reached within group]	(1.198)		(0.969)	
C2c			2.60**	
[try to fool or cheat the other group]			(1.008)	
C2d			-4.26**	
[try to coordinate/cooperate w/other group]			(0.971)	
C2f			-13.68**	
[appeal not to compete, lower effort in group]			(2.064)	
C2h			-4.63*	
[maximize everyone's payoff in both groups]			(2.140)	
C2i			5.29**	
[do not coop. with other group due to mistrust]			(1.467)	
C2j			-3.71**	
[coop. with other group until they defect]			(0.748)	
C3a		1.81**	-0.62	0.70
[agreement reached between groups]		(0.533)	(0.687)	(1.206)
C3b		3.29**	0.61	-0.03
[no agreement reached between groups]		(0.480)	(0.879)	(1.857)
C3c		-0.95	-3.88**	-4.90*
[propose both groups choose same effort]		(0.574)	(0.896)	(2.190)
C3d		-4.57**	-1.41	0.78
[propose both groups choose 0]		(0.710)	(1.021)	(1.120)
C3e			-3.52**	-0.82
[propose to take turns to win]			(0.797)	(1.593)
C4a	7.93**			
[verbal bullying or punishment]	(2.339)			
Observations	1,392	1,362	1,392	464
Number of Subjects	48	48	48	16

* significant at 5%, ** significant at 1%.

Standard errors robust to general heteroscedasticity are shown in parentheses. All models include a random effects error structure, with individual subject effects. Session dummies are not reported in the interest of space. INTER treatment estimates drop the first 6 periods of one session (out of the 8 total sessions in this treatment) with outlier effort choices.

Not for Publication: Appendix – Experiment Instructions for the INTRA+INTER treatment

GENERAL INSTRUCTIONS

This is an experiment in the economics of strategic decision making. Various research agencies have provided funds for this research. The instructions are simple. If you follow them closely and make appropriate decisions, you can earn an appreciable amount of money.

The experiment will proceed in two parts. Each part contains decision problems that require you to make a series of economic choices which determine your total earnings. The currency used in Part 1 of the experiment is U.S. Dollars. The currency used in Part 2 of the experiment is francs. Francs will be converted to U.S. Dollars at a rate of **_30_** francs to **_1_** dollar. At the end of today's experiment, you will be paid in private and in cash. **12** participants are in today's experiment.

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.

INSTRUCTIONS FOR PART 1

YOUR DECISION

In this part of the experiment you will be asked to make a series of choices in decision problems. How much you receive will depend partly on **chance** and partly on the **choices** you make. The decision problems are not designed to test you. What we want to know is what choices you would make in them. The only right answer is what you really would choose.

For each line in the table in the next page, please state whether you prefer option A or option B. Notice that there are a total of **15 lines** in the table but just **one line** will be randomly selected for payment. You ignore which line will be paid when you make your choices. Hence you should pay attention to the choice you make in every line. After you have completed all your choices a token will be randomly drawn out of a bingo cage containing tokens numbered from **1 to 15**. The token number determines which line is going to be paid.

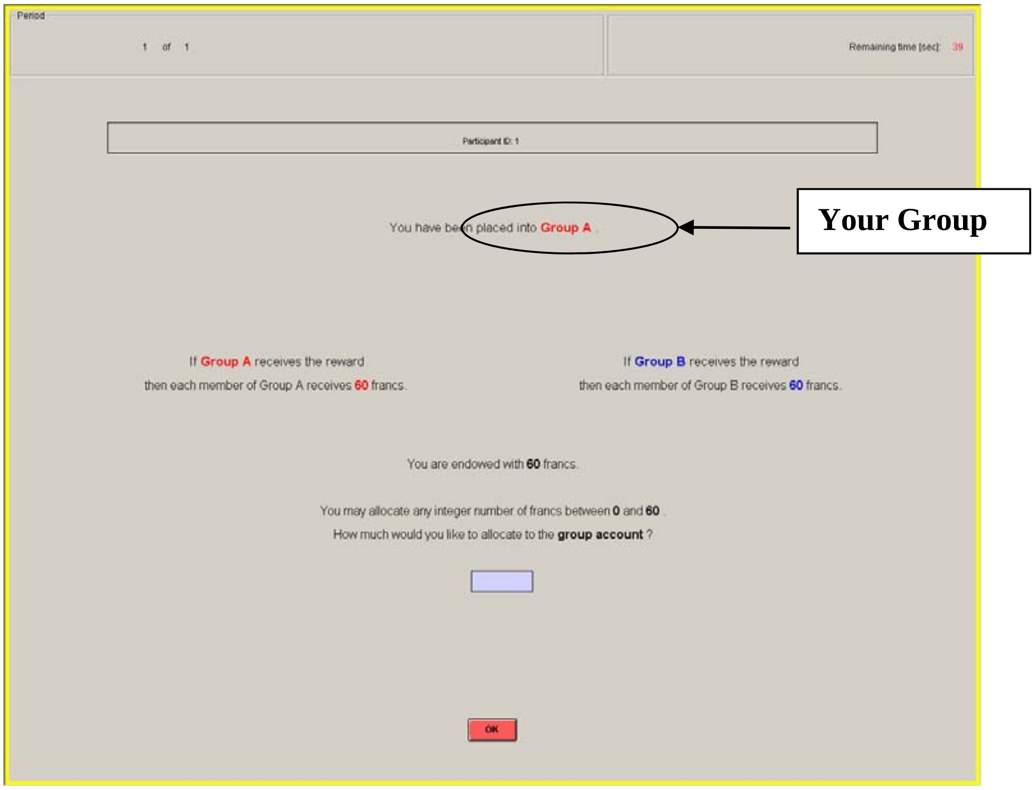
Your earnings for the selected line depend on which option you chose: If you chose option A in that line, you will receive **$1**. If you chose option B in that line, you will receive either **$3** or **$0**. To determine your earnings in the case you chose option B there will be second random draw. A token will be randomly drawn out of the bingo cage now containing twenty tokens numbered from **1 to 20**. The token number is then compared with the numbers in the line selected (see the table). If the token number shows up in the left column you earn $3. If the token number shows up in the right column you earn $0.

Decision no.	**Option A**	**Option B**		Please choose A or B
1	**$1**	**$3** never	**$0** if 1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20	
2	**$1**	**$3** if 1 comes out of the bingo cage	**$0** if 2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20	
3	**$1**	**$3** if 1 or 2	**$0** if 3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20	
4	**$1**	**$3** if 1,2,3	**$0** if 4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20	
5	**$1**	**$3** if 1,2,3,4,	**$0** if 5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20	
6	**$1**	**$3** if 1,2,3,4,5	**$0** if 6,7,8,9,10,11,12,13,14,15,16,17,18,19,20	
7	**$1**	**$3** if 1,2,3,4,5,6	**$0** if 7,8,9,10,11,12,13,14,15,16,17,18,19,20	
8	**$1**	**$3** if 1,2,3,4,5,6,7	**$0** if 8,9,10,11,12,13,14,15,16,17,18,19,20	
9	**$1**	**$3** if 1,2,3,4,5,6,7,8	**$0** if 9,10,11,12,13,14,15,16,17,18,19,20	
10	**$1**	**$3** if 1,2,3,4,5,6,7,8,9	**$0** if 10,11,12,13,14,15,16,17,18,19,20	
11	**$1**	**$3** if 1,2, 3,4,5,6,7,8,9,10	**$0** if 11,12,13,14,15,16,17,18,19,20	
12	**$1**	**$3** if 1,2, 3,4,5,6,7,8,9,10,11	**$0** if 12,13,14,15,16,17,18,19,20	
13	**$1**	**$3** if 1,2, 3,4,5,6,7,8,9,10,11,12	**$0** if 13,14,15,16,17,18,19,20	
14	**$1**	**$3** if 1,2, 3,4,5,6,7,8,9,10,11,12,13	**$0** if 14,15,16,17,18,19,20	
15	**$1**	**$3** if 1,2, 3,4,5,6,7,8,9,10,11,12,13,14	**$0** if 15,16,17,18,19,20	

INSTRUCTIONS FOR PART 2
YOUR DECISION

The second part of the experiment consists of **30** decision-making periods. At the beginning of the first period, you will be randomly and anonymously placed into a group of **3 people**: group A or group B. You will remain in the same group for all 30 periods of the experiment. At the beginning of the first period, your group will be paired with another group. This pairing remains the same for all 30 periods of the experiment. Either group A or group B will receive a reward. The reward is **60 francs** to each group member.

Each period you will be given an endowment of **60** francs and asked to decide how much to allocate to the **group account** or the **individual account**. You may allocate any integer number of francs between **0** and **60**. An example of your decision screen is shown below.



COMMUNICATION

Each period before you are asked to make the allocation decision you will have an opportunity to communicate with other participants in the room. There are two messenger windows on the upper left corner of the screen, overlapping each other. Please shift the top one down so that you are able to see both of the windows. One messenger window is named “3-person chat x”, and the other is named “6-person chat”, where x is your Group ID (i.e., A1, B1 or A2, B2). Any messages sent in the “3-person chat x” window will only be viewed by you and the other two members in your group. Any messages sent in the “6-person chat” window will be viewed by all three members of your group, and also by the three people in your paired group.

The messenger windows will be active for 120 seconds at the beginning of the first 10 decision-making periods. From the 11th through 20th periods the chat time is set at 90 seconds, and for the last 10 periods the communication will last for 60 seconds.

Although we will record the messages you send to each other, your chat id remains anonymous. The first person to send a message in a period will always be referred to as “member1”, the second as “member2” and so on. In sending messages, you should follow two basic rules: (1) be civil to one another and do not use profanities, and (2) do not identify yourself in any manner. The communication channel is intended to discuss your investment choices and should be used that way. Please do not close any window at any time because that will cause delays and problems with the software.

After the chat period is over, all group members then make their actual decisions simultaneously; you do not learn the actual allocation decisions of your group members until after you make your decision.

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.

YOUR EARNINGS

After all participants have made their decisions, your earnings for the period are calculated. These earnings will be converted to cash and paid at the end of the experiment if the current period is one of the five periods that is randomly chosen for payment.

1) Your period earnings are the **sum of the earnings** from your **individual account** and the earnings from your **group account**.
2) For each franc in your individual account, you will earn **1** franc in return. So, if you keep all 60 francs that you are endowed with to your individual account you will earn 60 francs. But you can also earn some francs from your group account.
3) By contributing to the group account you may increase the **chance** of receiving the reward for your group. In determining which group receives the reward, the computer will consider only **the lowest contribution in group A's account** and **the lowest contribution in group B's account**. If the lowest contribution in group A's account exceeds the lowest contribution in group B's account, group A has higher chance of receiving the reward and vice versa. If your group receives the reward then in addition to the earnings from your individual account you receive the reward of **60 francs** from your group account. A group can never guarantee itself the reward. However, by increasing your contribution, you can increase your group's chance of receiving the reward.
4) The computer will assign the reward either to your group or to the other group, **via a random draw**. So, in each period, only one of the two groups can obtain the reward.

<u>**Example 1. Random Draw and Earnings**</u>

This is a hypothetical example used to illustrate how the computer is making a random draw. Let's say the members of groups A and B allocate their francs in the following way.

Table 1 – Allocation of francs by all members in group A and B

Group A	If Group A receives reward	Allocation to **individual account**	Allocation to **group account**
Member 1	60	40	20
Member 2	60	45	15
Member 3	60	50	**10**

Group B	If Group B receives reward	Allocation to **individual account**	Allocation to **group account**
Member 1	60	59	**1**
Member 2	60	50	10
Member 3	60	55	5

In group A, member 1 contributes 20 francs, member 2 contributes 15 francs, and member 3 contributes 10 francs to group A's account. In group B, member 1 contributes 1 franc, member 2 contributes 10 francs, and member 3 contributes 5 francs to group B's account.

Then the computer chooses **the lowest contribution in group A's account** and **the lowest contribution in group B's account**. The two highest contributions in group A and the two highest contributions in group B will **not** be considered by the computer. In this example, member 3 has the lowest contribution of **10 francs** in group A and member 1 has the lowest contribution of **1 franc** in group B. For each franc of member 3 in group A the computer puts **1 red token** into a bingo cage and for each franc of member 1 in group B the computer puts **1 blue token**. Thus, the computer places **10 red tokens** and **1 blue token** into the bingo cage (**11 tokens total**). Then the computer randomly draws one token out of the bingo cage. If the drawn token is red group A receives the reward, if the token is blue group B receives the reward. You can see that since group A has more tokens it has a higher chance of receiving the reward (**10 out of 11 times** group A will receive the reward). Group B has a lower chance of receiving the reward (**1 out of 11 times** group B will receive the reward).

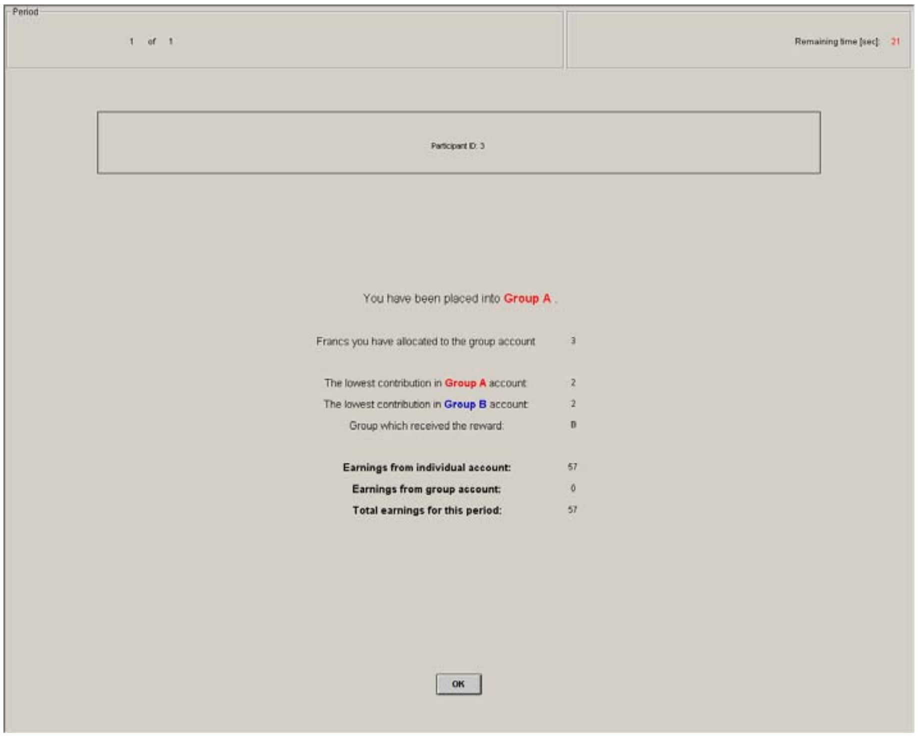
Let's say the computer made a random draw and **group A receives the reward**. Thus, all the members of group A receive the reward of 60 francs from the **group account** plus they also receive earnings from the **individual account**. All members of group B receive earnings **only from the individual account**, since group B does not receive the reward. The calculation of the total earnings is shown in Table 2 below.

Table 2 – Calculation of earning for all members in group A and B

Group A	Earnings from **group account**	Earnings from **individual account**	Total earnings
Member 1	**60**	**40**	60+40 = 100
Member 2	**60**	**45**	60+45 = 105
Member 3	**60**	**50**	60+50 = 110

Group B	Earnings from **group account**	Earnings from **individual account**	Total earnings
Member 1	**0**	**59**	59
Member 2	**0**	**50**	50
Member 3	**0**	**55**	55

At the end of each period, the total number of francs in the two groups' accounts, group which receives the reward, earnings from individual and group accounts, and total earnings for the period are reported on the outcome screen as shown below. Please record your results for the period on your **record sheet** under the appropriate heading.



Outcome Screen

IMPORTANT NOTES

You will not be told which of the participants in this room are assigned to which group. At the beginning of the first period, you will be randomly and anonymously placed into a group of 3 people: group A or group B. You will remain in the same group for all 30 periods of the experiment. At the beginning of the first period, your group will be paired with another group. This pairing remains the same for all 30 periods of the experiment. Either group A or group B will receive a reward. The reward is **60 francs** to each group member. A group can never guarantee itself the reward. However, by increasing your contribution, you can increase your group's chance of receiving the reward.

At the end of the experiment we will randomly choose **5 of the 30** periods for actual payment in **Part 2** using a bingo cage. You will sum the total earnings for these 5 periods and convert them to a U.S. dollar payment.

Are there any questions?