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Keywords
groups contests; inequality; optimal incentives; experiment

JEL Codes
C72, C91, D72

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An Experiment on Inequality within Groups in Contest*

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December 1, 2023

Abstract

We study Tullock contests allowing heterogeneity of both rewards and abilities within the competing groups. Our main concern is whether higher degrees of inequality in a group can improve its performance, namely group effort and probability of winning. First, we show that the answer to this question is positive under plausible conditions on players' cost function. Second, we test these predictions in the lab. Unlike theory predicts, inequality in abilities does not help a team win. Inequality in rewards does help but moderately. The efficient combination of both inequalities, which assigns high rewards to high ability players, substantially increases a team's performance. Finally, through the analysis of subjects' beliefs, we provide empirical evidence that overbidding is more severe than we expected.

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Introduction

Many competitions in life occur between groups rather than individuals. Examples include, wars, electoral campaigns, R&D races, workplace competitions, and sports. A common attribute among these situations is that group members spend costly resources (time, effort, or a budget) in order to win a prize (money, promotion, or resources). Although respective members win or lose the prize collectively, they often have different skills, rewards, and impact over the outcome of the competition. As a result, contests rarely occur between identical groups.

Examples abound. Politicians have different abilities in attracting votes for their parties during the political campaign and, in case of winning, they are assigned to different roles or ministries. In sports, it is well-known that there is a trade-off between building a team with a "superstar" versus a team with more homogeneous players.[1] Finally, in both competitions within and between firms, team managers can shape a group's performance by strategically manipulating the allocation of the rewards and the selection of the members. For example, in contests for bonuses between sales or production departments, managers decide not only on which tasks to assign employees, but also how much to reward them based on the related responsibilities. In general, it seems evident that a group's performance, namely the group effort and probability of winning, varies with the abilities and rewards' distribution within the group.

The main purpose of this article is to investigate whether higher degrees of inequality in a group can improve its performances. In order to do this, we study Tullock contest allowing for intra-group heterogeneity in both prize shares and abilities. That is, groups are competing for a private prize that can be split in any way among winning members with (possibly) different abilities. The model has the following features: groups' probability of winning is given by the Tullock success function, each group contribution is the linear sum of its members' effort, and players' cost is

[1] An interesting article is by Rory Smith in The New York Times "By His Absence, Zlatan Ibrahimovic Makes Sweden Stronger at the World Cup" available at `https://www.nytimes.com/2018/07/03/sports/world-cup/sweden-zlatan-ibrahimovic-.html`.

a strictly increasing and convex function of their effort.

A natural way to compare the effects on performance of different distributions of ability and prize shares is through inequality measures. Assuming players are symmetric in their abilities, Nitzan and Ueda (2014) and Cubel and Sanchez-Pages (2020) show that the more unequal the distribution of prize shares within a group, the greater its performance as long as the cost function is not too convex. That is, the group effort is maximised when a player receives the entire prize. In their model of contest, however, the level of inequality in a group is exogenously given. We contribute to the theoretical literature allowing groups to strategically choose the level of within group inequality in order to maximise their performance. We find that if the cost function is not too convex, all groups maximise their level of inequality, whether it is in ability, prize shares, or the efficient combination of both. Hereafter, by efficient combination of both inequalities we mean matching high prize shares with high ability players.

Despite many policymakers aim to reduce inequality,[2] the theoretical literature reveals that institutions are often incentivised to endogenously create it so as to increase a group's performance. Outside these models, however, inequality might affect group members' behaviour in various ways. For example, it may generate conflicting views about what is considered fair, which in turn could reduce group members' investment. To understand how inequality affects the contest's outcome in practice, we conduct a laboratory experiment. The advantage of a laboratory experiment is that it allows us to disentangle the effects on players' choices for each type of inequality by simply manipulating the team composition. In a field setting this is hard to achieve because what we can observe, players' performance, is a function of what we may not observe, abilities, prize valuations, and noise.

In the lab, we test the effects on group performance of three types of within group inequality: ability, prize shares, and the efficient combination of both. Importantly, we experimentally study (i) the effects of exogenously determined levels of inequality

[2]For instance, tackling both between and within countries income inequality is a political imperative for the European Commission, see `https://ec.europa.eu/info/research-and-innovation/research-area/social-sciences-and-humanities/reversing-inequalities_en`.

(ii) on Tullock contests in which it is predicted to improve group performance. The reason for focusing on exogenous variation of inequality is straightforward. Before studying whether a team manager, or a contest organiser, would design an unequal team, one needs to understand whether such design would improve group performance when put in practice. The reasons we restrict our attention only on contests in which unequal groups are expected to perform better, i.e. when the cost function is not too convex, are twofold: observations on such contests are more comparable with a large body of literature that uses linear costs;[3] theoretical predictions of such cases are invariant regardless of the exact parameters of the cost function.[4]

In the lab, we implemented contests involving two groups of two players each. While groups compete for the same prize and consist of on average equally capable players, they differ in their internal inequality. Specifically, we design three between-subjects treatments: i) Treatment Ability, ii) Treatment Prize, and iii) Treatment Combination. Treatment Ability runs a contest between a fully equal group, and a group unequal in ability. Treatment Prize runs a contest between a fully equal group, and a group that shares the prize unequally among its members. Finally, Treatment Combination runs a contest between a fully equal group and a group unequal in both ability distribution and prize division. In the latter treatment, we match high prize shares with high ability players as it predicts to elicit greater group performance.

In contrast to the theoretical predictions, we do not find empirical evidence that inequality in ability improves performance. That is, in Treatment Ability there is no significant difference between the effort of the group unequal in ability and equal one. Regarding the inequality in the prize allocations, we find evidence that it moderately increases a team's performance, especially in the second part of the experimental sessions. Indeed, in Treatment Prize the group that splits the prize unequally exerts higher effort than the equal one. Finally, we find strong evidence that a combination of both types of inequality significantly improves a group's performance. In Treat-

[3]A model with linear costs function predicts that unequal groups perform better than equal ones.

[4]To have a clear-cut result on the effects of each type of inequality when the cost function is very convex we would need to impose additional assumptions on the cost function.

ment Combination, the group unequal in both ability and prize share' distributions not only exerts higher effort than the fully equal one, but its contribution is also the highest among all groups and across all treatments.

Another feature of the experiment is the investigation of subjects' behaviour and deviations from theoretical predictions. Broadly speaking, observed deviations could be the result of two grounds: strategic uncertainty, e.g. subjects fail to correctly predict other people's actions, and personal characteristics, e.g. risk-preferences. We separate the former effect from the latter using the data collected on subjects' beliefs about others' decisions. We call the difference between a subject's contribution and the best response according to her beliefs about others *belief adjusted deviation* (BAD). The BAD in our experiment is significantly higher than the standard measure of overbidding, i.e. the difference between subjects' contributions and their best response. As a result, we find evidence that subjects overbid more than we expected once we control for the strategic uncertainty. In addition, the BAD is positively correlated with risk-seeking, and it declines with experience, suggesting that the overbidding is a result of both risk preference and errors. Finally, compared to the beliefs about teammates, those about opponents' strategies are a more significant predictor of a player's contributions.

Overall, to the best of our knowledge, this is the first paper that provides empirical evidence of i) the positive effect on group performance of different types of inequality and ii) of the underestimation of overbidding in contest experiments.

Literature review

Much progress has been made in the study of contests since the seminal work of Tullock (1980). Regarding team contests, the theoretical literature has considered contests with different sharing rules (Nitzan, 1991a,b), group sizes (Esteban and Ray, 2001; Nitzan and Ueda, 2011), heterogeneous players (Baik, 2008; Nitzan and Ueda, 2018; Choi et al., 2016), and timings of the choices (Balart et al., 2018). These papers employ one of the following prize allocations among winning group members: the egalitarian rule, the relative effort rule, or any linear combination of the two; of which the relative effort rule better incentivises groups[5] as it eliminates free-riding by putting teammates in competition for the appropriation of the prize. However, it is contingent on ex-post individual efforts, which are not always observable.

Nitzan and Ueda (2014) and Cubel and Sanchez-Pages (2020) are the few models studying how different prize distributions, which are not contingent on ex-post efforts, affect the group performance. They find that an unequal distribution of the prize within a group maximises a team's performance as long as players' effort cost function is not too convex. We extend their model permitting heterogeneity in both abilities and prize share, and allowing groups to strategically choose the level of within group inequalities. For cost functions that are not too convex, our analysis shows that maximising each type of inequality is the group optimal strategy.

The literature on contests has also dedicated much attention to empirically test the theoretical predictions, especially those regarding sharing rules (Gunnthorsdottir and Rapoport, 2006; Amaldoss et al., 2000; Kugler et al., 2010), team sizes (Abbink et al., 2010; Ahn et al., 2011), endowments (Heap et al., 2015, 2021), alliance formations (Herbst et al., 2015), and power differentials (Bhattacharya, 2016). Most of the experiments design groups with symmetric members. Exceptions are in Sheremeta (2011), where groups have a stronger member, and in Brookins et al. (2015a), where all players differ in their cost of contributing. Both in theory and in the lab, non-incentivised types of heterogeneity are studied in Konrad and Morath (2019). The authors model a dynamic contest in which contestants possibly differ only in behavioural motives that go beyond the payoff maximisation. Learning about others' motives and self-selection have possible implications on players' effort escalation. The corresponding experimental set-up provides evidence for such heterogeneous motives, for self-selection and for effort escalations. Consistent with their study, we also find a persistent and positive correlation between subjects' effort and their beliefs about opponents' efforts.

The experimental paper most similar to ours is Fallucchi et al. (2020), which carries contests involving two groups of three players each. Groups can be of two

[5] See Flamand et al. (2015) for a survey.

types: fully equal, or unequal in ability. Depending on the treatment, they compete either against another group of their same type, or against a different one. The authors' main finding is that the highest total effort is obtained in a competition between two unequal groups. The authors also have a treatment involving a fully equal group and a group unequal in ability, which is comparable to our Treatment Ability. Here, they don't find substantial differences between the two groups' chances of winning, a result in accordance to ours. Despite this similarity, the two papers' experimental designs differ substantially. We randomly rematch players every round whilst they employ a partner-matching protocol.[6] We use a convex cost function instead of a linear one and analyse the effects on team effectiveness of three types of internal inequality, rather than studying groups' behaviour under different group matching.

1 The basic model

There are N groups competing in a contest. The i-th group is composed of n_i risk-neutral members who are indexed by $ik = (i1, ..., in_i)$. The winning group receives a prize normalised to 1, which is shared among its members according to the allocation $\phi_i = (\phi_{i1}, ..., \phi_{in_i})$ s.t. $\sum_{k=1}^{n_i} \phi_{ik} = 1$ and $\phi_{ik} \geq 0 \ \forall k$. The prize allocation is not contingent on ex-post efforts. That is, if group i wins the contest, then member ik receives a reward of ϕ_{ik}. The losing group receives nothing.

In order to win the prize, player ik exerts an effort $x_{ik} \geq 0$ at a cost $v_{ik}^{-1} g(x_{ik})$, where $v_{ik} \in (0, \infty)$ is the (possible) heterogeneous ability parameter.[7] Group i's total effort is $X_i = \sum_{k=1}^{n_i} x_{ik}$, and group i's probability of winning is given by the Tullock success function $\sigma_i = X_i/X$, where $X = \sum_{i=1}^{N} X_i$.[8] Overall, for an arbitrary prize allocation $\phi_i = (\phi_{i1}, ..., \phi_{in_i}) \ \forall i$, the expected payoff of player ik is given by

[6]In other words, we try to avoid any cooperative behaviour that may occur in a partner-matching protocol given the repeated interaction between players.

[7]This approach to define heterogeneity is commonly used in the literature of contests, see for example Ryvkin (2011, 2013), Brookins et al. (2015b), Nitzan and Ueda (2018) and Trevisan (2020).

[8]If the total effort is 0, each group's probability of winning is $1/N$.

$$\pi_{ik} = \frac{X_i}{X}\phi_{ik} - \frac{g(x_{ik})}{v_{ik}}. \tag{1}$$

We assume that the cost function $g(x)$ is strictly increasing, convex, and that the marginal cost of exerting zero effort is equal to zero. Under these conditions, formally stated in Assumption 1, all players receiving a positive prize share exert a positive effort in equilibrium.

Assumption 1 i) $g(0) = 0$; ii) $g'(0) = 0$; iii) $g'(x) > 0$ for all $x > 0$; iv) $g''(x) > 0$ for all $x > 0$; v) $g'''(x)$ exists for all $x > 0$.

Since g is monotonic and continuous, it has a well-defined inverse function, $f = (g')^{-1}$. Under Assumption 1, the first-order condition of π_{ik} is necessary and sufficient for player ik's best response:

$$\frac{X - X_i}{X^2}\phi_{ik}v_{ik} = g'(x_{ik}). \tag{2}$$

The contest stage has a unique pure strategy Nash equilibrium in which all groups always exert a strictly positive effort.

Lemma 1. *Given Assumption 1, the contest between groups has a unique equilibrium effort x^*_{ik} $\forall ik$ in pure strategies. The equilibrium levels of effort satisfies the system of equations (2) with equality and defines the group i's effort as*

$$X_i^* = \sum_{k=1}^{n_i} x_{ik}^* = \sum_{k=1}^{n_i} f\left(\frac{X^* - X_i^*}{(X^*)^2}\phi_{ik}v_{ik}\right). \tag{3}$$

1.1 Within group inequality

In the model discussed above, players can be heterogeneous among two dimensions: the prize share and the ability parameters. As a result, we can identify three types of inequality within a group: the inequality in ability, in prize, and the combination of both.

How does the level of inequality within a group affect its probability of winning? The answer to this question can be found in Nitzan and Ueda (2014) and Cubel and Sanchez-Pages (2020). The authors show that for exogenous levels of inequality, unequal groups perform better than equal ones, i.e. they exert higher effort and have greater probability of winning as long as the cost function is not too convex, precisely when $g'''(x) < 0$. Formally,

Lemma 2. *Let $v_{i1} = v_{ik}$ $\forall k$ be players' ability in group i. Given Assumption 1 and $g'''(x) < 0$, the winning probability of group i can be raised by an exogenous increase of the inequality in the prize allocation.*[9]

Lemma 2 states the when group members are symmetric, the group effort and probability of winning can be increased by raising the inequality in prize distribution. The same result extends to the case in which group members equally share the prize, $\phi_{i1} = \phi_{ik}$, and there is an exogenous increase in the inequality of ability.[10] Finally, it is possible to elicit even higher efforts by efficiently combining the two inequalities. If an increase in inequality in ability is accompanied by an increase in inequality in prize shares that matches high stakes with high ability players, then it further enhances the group effort and probability of winning.

Note that the results above rely on the assumption that changes in the level of inequality are exogenous. In Appendix B, we provide a model in which groups can strategically choose their level of within group inequality in order to maximise their probability of winning. We show that when the cost function is not too convex, i.e. $g'''(x) < 0$, in the equilibrium of the game each group maximises its level of inequality. That is, the results of the strategic game are in line with results discussed above.[11]

[9] Proofs can be found in Nitzan and Ueda (2014).

[10] Note that the ability parameter and prize share have the same effect on players and groups' effort, see equation (3). However, it can be show that they have different effects on equilibrium's payoffs.

[11] In Appendix B, we dot not provide the results of the strategic game when the cost function is very convex, i.e. $g'''(x) > 0$. The reason for that is twofold: we do not have the empirical analysis on it, and there are no clear-cut results on the optimal level of each type of inequality unless we impose additional assumptions on the cost function.

In Section 2, we describe the design of our experiment which aims to empirically test the theoretical predictions on team performance of three types of within group inequality: in ability, in prize, and the combination of both. Further, we undertake a in depth analysis on individual behaviors.

2 The experiment

Our experiment is based on the model presented above. Using a between-subjects design and a random-matching protocol, we created contests between two groups of two players each. Importantly, all groups are, on average, symmetric— they have the same average ability and prize— and differ only on their within group inequality.

As summarised in Table 1, we designed a total of three treatments: Treatment Ability, Treatment Prize, and Treatment Combination. In Treatment Ability, we run contests between the fully equal Group E and the unequal in ability Group UA. In Treatment Prize, we run contests between the fully equal Group E and the unequal in prize shares Group UP. In Treatment Combination, we run contests between the fully equal Group E and Group UC, which combines the two types of inequality. That is, each treatment allow us to disentangle the effect on performance of each specif type of inequality.[12]

	Group E	**Group UA**	**Group UP**	**Group UC**	**Subjects**	**Sessions**
Treatment Ability	✓	✓			52	4
Treatment Prize	✓		✓		60	4
Treatment Combination	✓			✓	56	4

Table 1: Treatments description

In order to implement within group inequality and design our groups, we choose three ability parameters, $v_L = 1, v_M = 2, v_H = 3$, and two prize allocations, 50-50 split and 75-25 split. Although there is no compelling reason why one specific inequal-

[12]We did not design a treatment between two symmetric groups as the expected probability of winning would be 0.5.

ity configuration of values should be selected, we chose these values to sufficiently incentivise all subjects.[13]

As shown in Table 2,Group E is formed by two symmetric players with the same ability and prize share. The unequal in ability Group UA is formed by two players that differ only in their ability parameter. The unequal in prize Group UP is formed by two players that differ only in their prize shares. Finally, Group UC combines the two types of inequality and is formed by two players that differ both in ability and prize share. For explanatory convenience we call the symmetric players M type, and the asymmetric players H and L type.[14] At the beginning of each experimental session, subjects were randomly assigned a type that did not change during the entire experiment.

	Group E	**Group UA**	**Group UP**	**Group UC**
Player's type	M, M	H, L	H, L	H, L
Player's ability v_{ik}	2, 2	3, 1	2, 2	3, 1
Player's prize share ϕ_{ik}	0.5, 0.5	0.5, 0.5	0.75, 0.25	0.75, 0.25

Table 2: Groups description

The experiment was conducted at the BLUE lab at the University of Edinburgh and programmed in z-Tree (Fischbacher, 2007). We ran 4 sessions per treatment with 12 or 16 subjects each. In total, we recruited 168 subjects from the university's subject pool. Subjects were allowed to participate in only one session. They earned an average of £12.9, including a show-up fee of £3, for a session lasting approximately 75 minutes.

All treatments included the following parts: (i) 30 rounds of contests,[15] 5 of

[13]Theory predicts that the higher the inequality the greater the group probability of winning. However, we avoided a design with extreme levels of inequality. We implemented a sharing rule of 75-25 instead of 100-0, and abilities parameters of 1-3 instead of 0-4 because we find it unnatural and practically difficult to form a group where a subject participate in the experiment without receiving a reward from winning the contest.

[14]To avoid framing, we used X, Y, Z in the experiment.

[15]At the end of each round, we provide subjects with feedback about their own payoff, their team and the competing one's contributions, their team and the competing one's probability of winning, and the winning group of the contest.

which were randomly selected for payments at the very end of the experiment, (ii) the IQ test, (iii) the elicitation of the subjects' risk preferences with real incentives using the Holt and Laury (2002) multiple price list method, and (iv) a survey about personality questions and basic information such as gender and age. The printed instructions were distributed and read aloud by an experimenter and can be found in Appendix E.

2.1 Numerical Predictions and Hypotheses

In order to win the prize, subjects ik makes a contribution $x_{ik} \in [0, 50]$ at a cost of $g(x_{ik})/v_{ik} = 10x^{1.2}/v_{ik}$, where v_{ik} is the ability parameter.[16] All subjects start with an endowment of 300 points,[17] which they could either use to pay for their contribution or keep as a reward. The expected payoff and best-response of player ik are

$$\pi_{ik} = \frac{X_i}{X}\phi_{ik}1000 - 10x_{ik}^{1.2}/v_{ik} + 300, \tag{4}$$

$$x_{ik} = \left(\frac{X - X_i}{X^2}\frac{1000\phi_{ik}v_{ik}}{1.2}\right)^5. \tag{5}$$

As we also investigate the role of beliefs in players' behaviour, we incentivised subjects to submit their predictions about their own and opponent group's contribution. They receive a reward of 50 points for every correct prediction and zero otherwise. The predictions about others' and their own contribution's choice were submitted at the same time.[18]

The equilibrium values for each treatment are derived replacing the respective player's ability and prize parameters into Equation 4 and 5, and then by solving the model. The theoretical predictions for each treatment are shown in Table 3 and 4.

[16] Subjects were asked to buy lottery tickets as in Chowdhury et al. (2020).

[17] The endowment is not binding as subject could pay a cost for their effort which is higher than 300 points.

[18] We elicited the point estimation of the distribution of beliefs, which is incentive compatible (Hurley and Shogren, 2005).

As seen from Table 3, unequal groups are expected to perform better. Indeed, they are expected to exert a higher effort and have a higher probability of winning. Further, Group UC, which combines ability and prize shares inequality, is predicted to exert the highest effort and have the highest the probability of winning among all treatments. The following hypothesis is formulated based on the predictions in Table 3.

Hypothesis 1. All types of within group inequality— ability, prize shares, and the combination of both— have a positive effect on a team's performance.

	Treatment Ability		**Treatment Prize**		**Treatment Combination**	
	Group E	Group UA	Group E	Group UP	Group E	Group UC
Group Payoff	940	1056	940	1006	860	1092
Group Effort	14	17.1	14	17.1	13.2	23.1
Prob. of Winning	44.4	55.6	44.4	55.6	36.4	63.6

Table 3: Groups' Predictions (Group payoff include the 300 endowment points for each subject.)

As seen from Table 4, we expect that H types exert higher effort than M types, which are expected to exert higher effort than L types. Further, the H type in Group UC, who has both high ability and high prize, is predicted to exert the highest effort among all types in all treatments. The following hypothesis is formulated based on the predictions in Table 3.

Hypothesis 2. Individuals' efforts are expected to be ranked based on their types as follow: H>M>L.

	Treatment Ability			**Treatment Prize**			**Treatment Combination**		
	Group E	Group UA		Group E	Group UP		Group E	Group UC	
Player's Types	M	L	H	M	L	H	M	L	H
Individual Payoff	470	578	478	470	439	567	430	459	633
Individual Costs	52	0	100	52	0	150	50	0	144
Individual Effort	7	0.1	17	7	0.1	17	6.6	0	23.1

Table 4: Individuals' Predictions

Since we are aware that experimental evidence on group contests typically shows the presence of over-dissipation,[19] our formal hypothesis are based on qualitative predictions only. Nevertheless, we will undertake a in depth analysis on individual behaviours so as to better understand the reasons behind subjects' deviations from the Nash predictions.

3 Main Results

3.1 Group-level results

In this section, we describe the group level findings related to Hypothesis 1. Table 5 reports the summary statistics of the efforts and winning probabilities in comparison to the theoretically predicted values. It shows that, on average, unequal groups contribute less than the equal ones in Treatment Ability, but contributed more in Treatment Prize and Treatment Combination. However, not all differences in group efforts are significant. The Wilcoxon rank-sum p values for the difference between the fully equal group and the unequal one in Treatment Ability, Prize and Combination are $0.38 < 0.01 < 0.01$, respectively.

	Treatment Ability		**Treatment Prize**		**Treatment Combination**	
	Group E	**Group UA**	**Group E**	**Group UP**	**Group E**	**Group UC**
Group Payoff	764 (940)	749 (1056)	794 (940)	770 (1006)	736 (860)	817 (1092)
Group Effort	37.3 (14)	35.3 (17.1)	32.3 (14)	35.8 (17.1)	31.0 (13.2)	42.2 (23.1)
P. of Winning	51.6 (44.4)	48.4 (55.6)	48.5 (44.4)	51.5 (55.6)	42.2 (36.4)	57.8 (63.6)

Table 5: Comparison statistics with experimental results and predicted values

Note: Theoretical predictions are in parentheses. Individual payoff include the 300 endowment points for each subject.

Figure 1 shows the dynamics of the aggregated contribution. One notable difference between the equal and unequal groups is their level of contribution over time.

[19]see Sheremeta (2018a) for an overview.

Both groups share a similar declining trend in Treatment Ability, while the declining trend only applies to the equal groups in Treatment Prize and Combination.

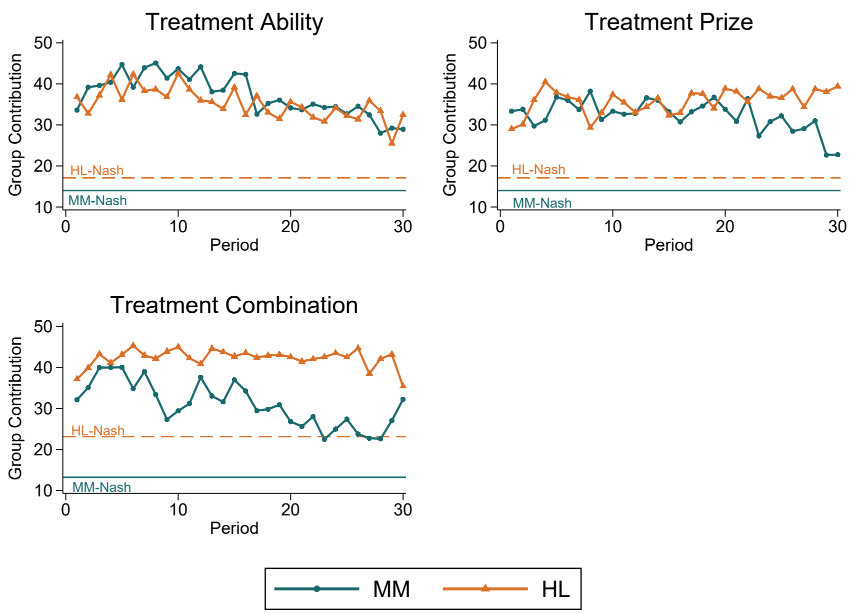

Figure 1: Group contribution over time

In Table 6, we show the results of the multilevel linear mixed-effects regressions. In Appendix D, we provide alternative non-hierarchical models as robustness checks. The regressions investigate how the total contribution of the unequal groups differ from the equal groups across treatments, taking into account the inter-dependency of observations in the same experimental sessions. The results confirm that, in all treatments, the total contribution decreases over time. However, it also shows that the diminishing trend is mainly driven by the homogeneous groups, especially for Treatment Prize and Treatment Combination.

Result 1. *Inequality in ability alone does not improve a group's performance. Inequality in prize shares, and its efficient combination with inequality in ability have a positive and significant effect on a group's performance.*

Overall, the unequal in ability Group UA did not contributed more than the fully

Dependent variable: Group contribution			
	Treatment Ability	**Treatment Prize**	**Treatment Combination**
Unequal group	-4.109	-2.485	4.524*
	(2.294)	(1.940)	(2.152)
Period	-0.418***	-0.228**	-0.461***
	(0.091)	(0.077)	(0.086)
Period×Unequal group	0.136	0.387***	0.436***
	(0.129)	(0.109)	(0.121)
Constant	48.42***	38.05***	33.54***
	(4.811)	(3.525)	(3.478)
Observations	780	900	840

Table 6: Group contribution difference between equal and unequal groups

Note: Multilevel linear mixed-effects models using random intercepts for experimental sessions. Unequal group is a dummy variable with the equal group being 0 and the unequal group being 1. Numbers in parentheses indicate standard errors. Significance levels * $p < 0.1$, ** $p < 0.05$, *** $p. < 0.01$.

equal Group E, a result in accordance to Fallucchi et al. (2020). The unequal in prize shares Group UP contributed more than Group E, especially in the later part of the experiment. Finally, the combination of both types of inequality made Group UC to provide a substantially higher contribution than Group E. We also conducted a series of Kruskal-Wallis test on the unequal groups' contributions by including all three treatments. The results are all statistically significant ($p < 0.01$) confirming that the Group UC's contribution is the highest among all treatments.

3.2 Individual-level results

In this section, we describe the individual level findings related to Hypothesis 2. In Figure 2, we present the distribution of players' efforts, which are dispersed or overspread (Chowdhury et al., 2014), for all types in all treatments. We compared the distributions of effort between types using the Kolmogorov–Smirnov test, and found that they differ significantly ($p < 0.01$ for all comparisons in all treatments). It also appears in Figure 2 that the H type's distribution of efforts first-order stochastically dominates M type's distribution, which stochastically dominates L type's one for all treatments.

The figure also shows that zero contributions for L type subjects, though predicted by the model, are not commonly observed.[20] Overall, our data confirm the hypothesis that subjects were responsive to the type assigned. This result is also confirmed by the regression results in the following paragraphs (see Table 8).

Result 2. *Subjects are responsive to their types and their contribution can be ranked as $H > M > L$.*

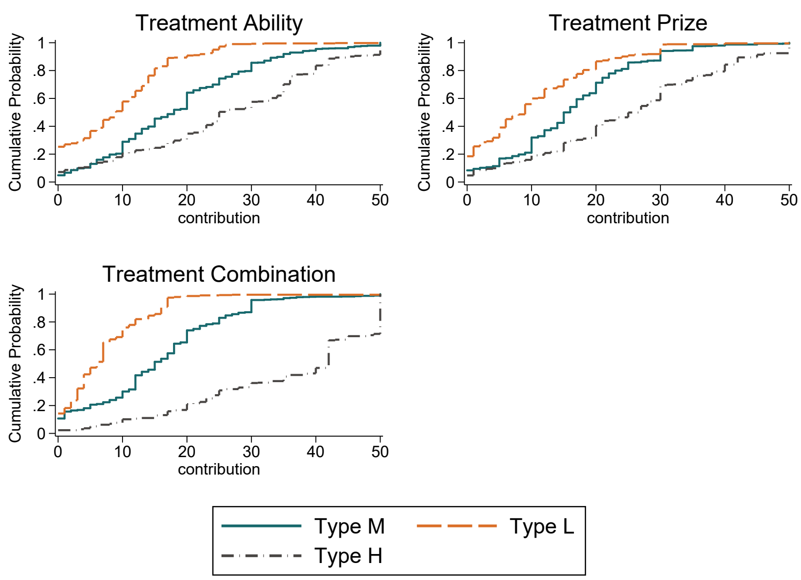

Figure 2: Effort dispersion by treatment

4 Additional Results

In this section, we undertake a in depth analysis on individuals' behaviour so as to provide additional results on what drives their choices and better understand the reasons behind deviations from the Nash predictions.

[20]The proportion of zero contributions is similar across treatments, while the proportion of maximum contribution choices are more frequent in Treatment Combination.

4.1 Overbidding

The average contribution across treatment for each type is shown in Figure 3. It is possible to note that average contributions of type M and L are similar across treatments, and they decrease over time. On the other hand, H type's contribution gradually increase, especially in Treatment Prize and Combination.

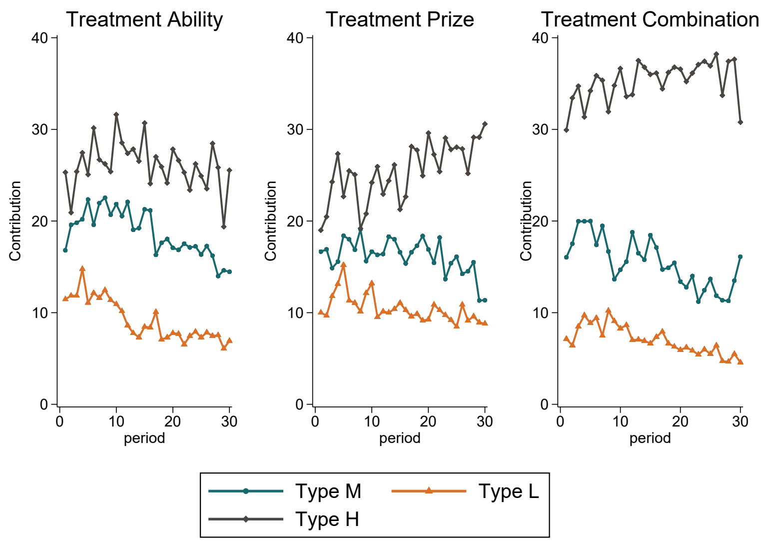

Figure 3: Contribution by type over time

Furthermore, as presented in Table 7, it is evident that, on average, there is substantial overbidding compared to the Nash prediction. The overbidding is ubiquitous and similar in absolute terms across treatments and types. The average overbidding for Treatment Ability, Treatment Prize and Treatment Combination is 10, 9.1 and 9.4 respectively. The average overbidding for type L, type M and type H is 8.8, 9.9 and 9.7 respectively.[21]

Result 3. *In all treatments there is a substantial overbidding by all types compared to the Nash Equilibrium predictions.*

[21] Overbidding in contest experiments has been found and addressed by many existing studies (Brookins et al., 2015a; Abbink et al., 2010; Ahn et al., 2011; Fallucchi et al., 2020)

	Treatment Ability			Treatment Prize			Treatment Combination		
	Group E	Group UA		Group E	Group UP		Group E	Group UC	
Type	M	L	H	M	L	H	M	L	H
Individual Costs	176 (52)	160 (0)	175 (100)	148 (52)	91 (0)	249 (150)	143 (50)	115 (0)	244 (144)
Individual Payoff	382 (470)	382 (578)	367 (478)	397 (470)	336 (439)	434 (567)	368 (430)	329 (459)	488 (633)
Individual Effort	18.6 (7)	9.3 (0.1)	26.2 (17)	16.2 (7)	10.3 (0.1)	25 (17)	15.6 (6.6)	7.1 (0)	35.1 (23.1)

Table 7: Experimental results with predicted values in parentheses

4.2 Distribution of belief

To better understand subjects' decision process, in each contest's round we elicited subjects' beliefs about others' decisions. Figure 4 and 5 present the distribution of the belief gap, defined as players' belief minus the actual contributions of the peer member and competing group. We conclude that subjects' beliefs are similar across types, treatments, and on average accurate (slightly positive but close to zero: the mean of peer belief gap is 0.70 and the mean of opponent belief gap is 1.13.). The symmetric plot and time trend are presented in the Appendix C, showing that the belief gaps are symmetric without significant directional or time trend.[22]

Result 4. *Subjects on average hold unbiased and accurate beliefs about other's contribution decisions.*

4.3 Individual contributions analysis

To investigate how subjects' beliefs and other characteristics influence their contributions, we conduct multi-level mixed effect Tobit regressions presented in Table 8. In Appendix D, we provide alternative non-hierarchical models as robustness checks. In all models, we include the variables *L type* and *H type* to capture the effects of different costs and prize share, the variable *period* to capture the potential trend over time and the variable *L. contribution* to control for path dependency.

[22]It should be noted that, as presented in the instruction, we elicited subjects' belief about their own group (not their peer directly), thus we calculated beliefs about the peer by deducting their own contribution. We dropped less than 1 percent observations if the calculated belief about their peer is either below 0 or above 50 as these observations are caused by errors or misunderstandings.

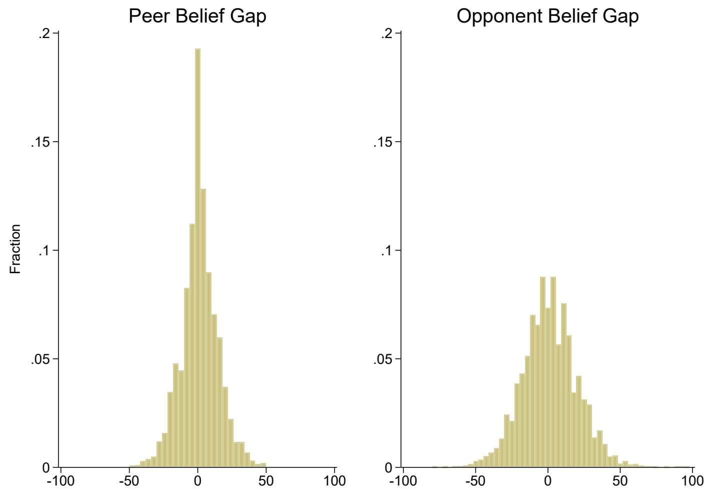

Figure 4: The gap between prediction and actual outcome

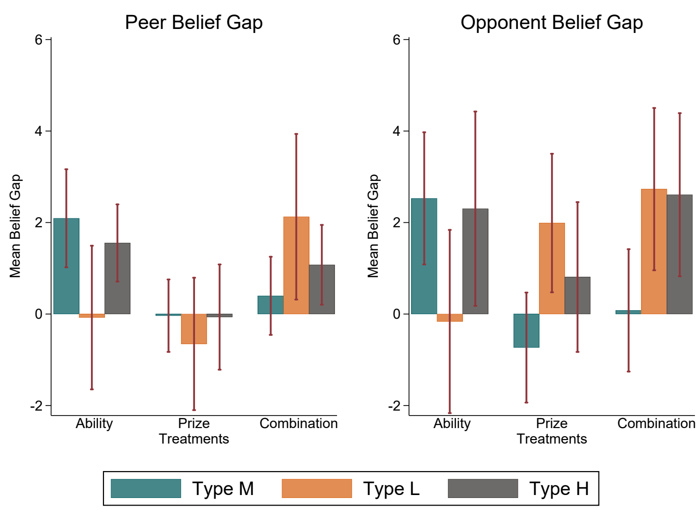

Figure 5: The belief gap by types with 95% confidence interval

In our experiment, it is evident that players respond to their type since *L type*'s parameter is negative, *H type*'s parameter is positive, and both are significant in all models. The *period* parameter is negative and significant in all models across all treatments. Despite this suggests that subjects potentially learn to reduce overbidding over time,[23] the interaction effect between *period* and *type* shows that H type's behaviour differs from M and L types. Indeed, H types increase their contributions over time, a trend which is more significant in Treatment Prize and Treatment Combination. Further, we don't find any gender difference in terms of contribution decisions.[24]

In Model 2, we include players' beliefs to investigate how they affect contribution decisions. The results indicate that subjects are positively responsive to the beliefs about their opponent contribution, as they choose to contribute more if they believe their opponents provides a higher contribution. A significant correlation between subjects' contribution and the beliefs about their peer's contribution is present in Treatment Combination only. In other words, there is weak evidence of rewarding cooperative behaviours within a group, but strong evidence of a competitive attitude between copeting groups.[25] One possible explanation is the often observed in-group favoritism and out-group derogation. The in-group/out-group discrimination literature indicates that people are less likely to punish a member of in-group but more likely towards the out-group ones (see (Chen and Li, 2009)).

Result 5. *Subjects' contributions are positively correlated with the expectation of their opponent group's contribution.*

Finally, model 3 controls for personal characteristics including *IQ score* and *Risk-seeking*. The IQ test does not have a significant predicting power, while the risk-seeking parameter, which is measured by the Holt and Laury (2002)'s lottery method, is positively correlated with subjects' contribution, a result confirmed in other studies (Sheremeta, 2011; Mago et al., 2016). Intuitively, contributing zero is a safe choice as it guarantees a secure payoff of 300 (endowment) points. On the other hand, a strictly positive contribution is a risky choice since it involves uncertainty on the outcome of the competition.

[23]Declining contributions are consistent with many prior experiments (Brookins et al., 2015a; Cason et al., 2012, 2017; Fallucchi et al., 2020).

[24]Previous studies provide mixed evidence (Heap et al., 2015; Baik et al., 2019).

[25]This result seems to contradict and complement Abbink et al. (2010)'s finding, with the belief data, that subjects focus more on the interaction with team members than on that with the rival team.

Dependent Variable: individual contribution									
	Treatment Ability			Treatment Prize			Treatment Combination		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
L.contribution	0.416***	0.352***	0.353***	0.282***	0.272***	0.272***	0.386***	0.372***	0.371***
	(0.0277)	(0.0275)	(0.0275)	(0.0267)	(0.0262)	(0.0262)	(0.0309)	(0.0304)	(0.0304)
L-Type	-7.308***	-7.883***	-8.173***	-4.509*	-4.980**	-5.184**	-5.869**	-6.793**	-7.837***
	(2.495)	(2.514)	(2.371)	(2.400)	(2.432)	(2.499)	(2.759)	(2.799)	(2.763)
H-Type	3.046	3.558	4.946**	2.961	3.219	2.957	11.43***	12.49***	12.24***
	(2.470)	(2.491)	(2.438)	(2.385)	(2.421)	(2.387)	(2.745)	(2.780)	(2.666)
Period	-0.156***	-0.105***	-0.104***	-0.110***	-0.126***	-0.126***	-0.172***	-0.170***	-0.170***
	(0.0353)	(0.0346)	(0.0346)	(0.0319)	(0.0314)	(0.0314)	(0.0374)	(0.0371)	(0.0371)
Female	0.959	1.196	1.456	0.260	0.374	0.0924	0.165	0.1000	0.477
	(1.904)	(1.927)	(1.851)	(1.833)	(1.866)	(1.867)	(2.118)	(2.136)	(2.035)
L-Type × Period	-0.0648	-0.0808	-0.0808	-0.0214	-0.000351	-0.000686	0.0469	0.0383	0.0381
	(0.0638)	(0.0627)	(0.0627)	(0.0564)	(0.0565)	(0.0565)	(0.0631)	(0.0647)	(0.0647)
H-Type × Period	0.117*	0.0889	0.0886	0.304***	0.314***	0.314***	0.240***	0.283***	0.283***
	(0.0613)	(0.0596)	(0.0596)	(0.0559)	(0.0548)	(0.0548)	(0.0663)	(0.0652)	(0.0651)
Guess-peer		0.0104	0.0107		0.0208	0.0218		0.0806***	0.0806***
		(0.0280)	(0.0279)		(0.0279)	(0.0279)		(0.0305)	(0.0305)
Guess-other		0.169***	0.168***		0.101***	0.101***		0.0896***	0.0903***
		(0.0184)	(0.0184)		(0.0193)	(0.0193)		(0.0204)	(0.0204)
Risk-seeking			1.249***			1.041			1.226**
			(0.482)			(0.654)			(0.589)
IQ score			0.756			0.0432			-0.111
			(0.566)			(0.664)			(0.636)
Constant	12.57***	6.459***	-6.713	12.54***	8.975***	4.010	11.06***	6.185***	1.035
	(1.844)	(2.002)	(6.043)	(1.690)	(1.850)	(7.476)	(1.992)	(2.182)	(7.384)
Observations	1560	1543	1543	1800	1792	1792	1320	1313	1313

Table 8: Individual contribution multi-level Tobit regression

Note: Multilevel Tobit models using random intercepts for experimental sessions and individual subjects. The upper limit of the Tobit model is 50, the lower limit is 0. *L.contribution* is the individual contribution of the previous round. *L-Type* and *H-type* are categorical variables standing for the low ability/prize subjects and high ability/prize subjects respectively. The omitted category is the *M type*. *Guess-other* stands for the expectation about the opponent group's total contribution. *Guess-peer* stands for the expectation about the other group members' individual contribution. *Female* is a dummy variable with female subjects being 1. *Risk-seeking* ranges from 1 to 10 with higher values indicating more risk-seeking attitudes. *IQ score* is the total No. of correct answers from 12 Raven questions. Numbers in parentheses indicate standard errors. Significance levels: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Observations with belief data error are excluded.

4.4 Belief adjusted deviation

As it often occurs in the experimental literature on contests, we find that subjects' behaviour deviates from the Nash predictions. Broadly speaking, behavioural deviations could be the result of two grounds: strategic uncertainty, e.g. subjects fail to correctly predict other people's actions, and personal characteristics, e.g. social preference and cognitive limitation.[26] The research challenge is to identify the significance of the latter in the presence of the former. In order to achieve this purpose, we introduce the *Belief Adjusted Deviation (BAD)* constructed as follows. We collect players' beliefs about others' contributions to derive the best response holding that beliefs.[27] Then, we define the difference between the observed contribution and the best response controlling for beliefs as follows:

$$\text{BAD} = \text{actual contribution - best response controlling for elicited beliefs},$$

The BAD represents the behavioural deviations apart from strategic concerns.[28] We focus on four potential determinants of the BAD: competitiveness, risk attitude, cognitive ability and gender. Competitiveness is measured by a score based on four personality questions from Duffy and Kornienko (2010).[29] Risk preferences are collected and approximated through Holt and Laury (2002) multiple price list method. Cognitive abilities are measured by incentivised Raven matrices.

Figure 6 shows that BAD is asymmetrically distributed. In all treatments, the distributions of BAD are similar and negatively skewed with a positive mean. It should also be noted that there are peaks around zero across all treatments, suggesting that a large portion of the decisions maximise the expected payoffs after controlling for players' beliefs. The significant positive value of the BAD indicates that the systematic overbidding in our experiment is mainly driven by factors besides the strategic uncertainty.

To further specify the determinants of BAD, we conduct multilevel mixed effects regressions, which are presented in Table 12. In Appendix D, we provide alternative non-hierarchical models as robustness checks. In all treatments, the variable period

[26]See Sheremeta (2018b) for a list of potential explanations on overbidding.

[27]The best response controlling for beliefs can be derived by replacing the player's beliefs about others in Equation (2).

[28]We treat BAD as a directional difference instead of an absolute difference because it might be a result of both errors (undirectional) and preferences (directional).

[29]The competition score ranges from -10 to 10, with higher values suggesting competition seeking. We provide two for-competition questions and two against-competition questions, and subjects could choose on a scale of 1 to 6 from strongly disagree to strongly agree. For for-competition questions, we generate a score from 0 to 5, and -5 to 0 for against-competition questions. The competitive score is the summed score of all four questions.

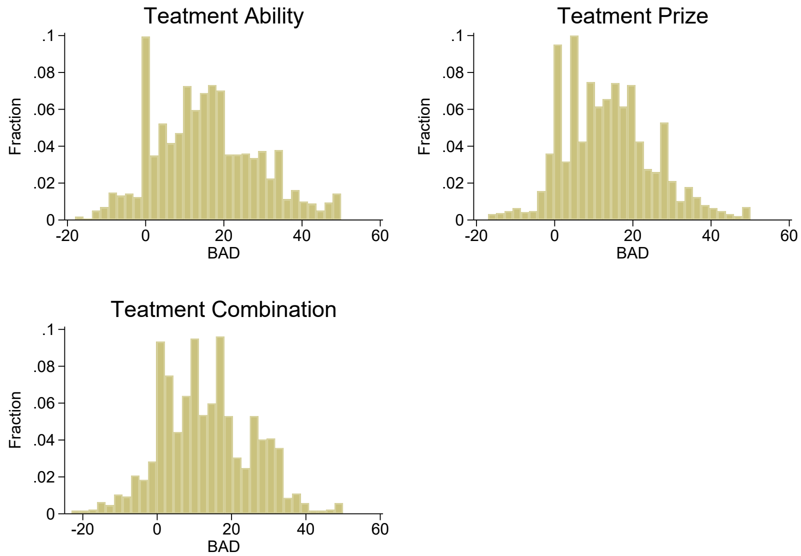

Figure 6: The distribution of BAD by treatments

Note: For a more detailed distribution of BAD across treatments and types see Appendix E

has a significant and negative impact on BAD, which indicates that subjects learn to reduce their contributions over time. Further, risk preference has a significant and positive impact on BAD for Treatment Ability and Treatment Combination. Finally, we do not find a correlation between gender, competitive personality or cognitive score and BAD.[30]

To conclude, in Figure 7 we compare BAD with the conventional overbidding measure, the observed contribution minus Nash prediction. In all treatments, the average BAD is higher than Nash overbidding for both type M and type H subjects. This result suggests that the conventional measure of overbidding (players' contribution minus Nash predictions) might represents a conservative estimate of overbidding. As a matter of fact, overbidding seems to be higher when strategic uncertainty is controlled for. Finally, BAD is type specific while the Nash overbidding

[30]BAD is type specific. Compared to the M type, L type subjects show significantly less BAD. Thus subjects with a disadvantageous role are less likely to overbid.

	Dependent Variable: BAD					
	Treatment Ability		Treatment Prize		Treatment Combination	
	(1)	(2)	(3)	(4)	(5)	(6)
L-Type	-7.907**	-7.759**	-4.646*	-4.697*	-8.933***	-10.89***
	(3.310)	(3.167)	(2.721)	(2.828)	(2.815)	(3.123)
H-Type	1.151	3.201	-3.420	-3.366	-0.114	-1.556
	(3.308)	(3.302)	(2.721)	(2.719)	(2.816)	(2.956)
Period	-0.202***	-0.202***	-0.141***	-0.141***	-0.278***	-0.306***
	(0.0360)	(0.0360)	(0.0306)	(0.0306)	(0.0326)	(0.0357)
L-Type × Period	-0.0215	-0.0218	0.0417	0.0417	0.140**	0.155**
	(0.0622)	(0.0622)	(0.0530)	(0.0530)	(0.0564)	(0.0617)
H-Type × Period	-0.00638	-0.00676	0.345***	0.345***	0.281***	0.319***
	(0.0620)	(0.0620)	(0.0531)	(0.0531)	(0.0565)	(0.0618)
Female		-0.377		-0.215		-0.612
		(2.744)		(2.219)		(2.386)
Risk-seeking		1.768**		0.662		1.654**
		(0.698)		(0.759)		(0.686)
IQ score		0.343		-0.330		0.0199
		(0.804)		(0.777)		(0.750)
Competitive score		0.103		0.257		0.00822
		(0.315)		(0.309)		(0.281)
Constant	20.40***	8.945	16.40***	16.02*	18.06***	10.41
	(1.910)	(8.873)	(1.571)	(8.533)	(1.625)	(8.793)
Observations	1543	1543	1792	1792	1670	1313

Table 9: BAD multi-level mixed effects regression

Note: Multilevel mixed effects models using random intercepts for experimental sessions and individual subjects. *L-Type* and *H-Type* are categorical variables standing for the low ability/prize subjects and high ability/prize subjects respectively. The omitted category is the M type. *Female* is a dummy variable with female subjects being 1. *Risk-seeking* ranges from 1 to 10 with higher values indicating more risk-seeking attitudes. *IQ score* is the total No. of correct answers from 12 questions. *Competitive score* ranges from -10 to 10 with higher values indicating more competitive personality. Numbers in parentheses indicate standard errors. Significance levels * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Observations with belief data error are excluded. The last column sees a smaller sample size due to a technical issue that in one session, we did not record the gender information of 12 subjects.

is much more homogeneous among all types. Type H and M have a higher BAD than type L subjects.

Result 6. *The BAD in our experiment is positive and higher than conventional measure of overbidding. It is type specific, positively correlated with risk-seeking, and diminishes over time.*

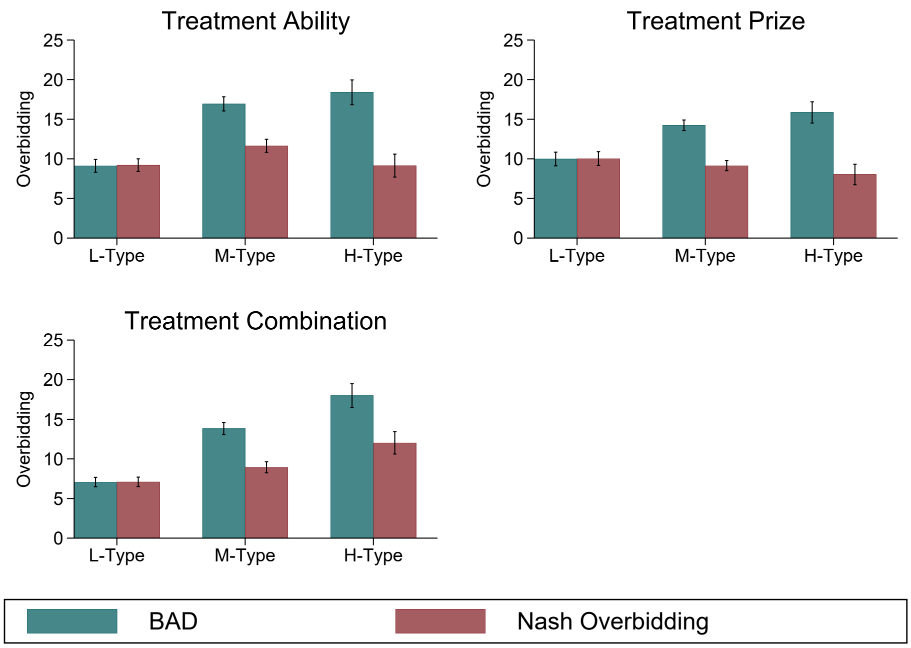

Figure 7: BAD vs. Nash overbidding

5 Conclusions

Competitions between groups are ubiquitous and share the common features that individuals spend costly resources to win a prize. On the other hand, group members often differ among each other. Some differences may be due to innate skills, e.g. the ability of performing task, other may be the result of other people's action, e.g. managers' decision on how to split a prize among winning members. In both scenarios, we expect that competitions between groups are not symmetric.

In this paper, we experimentally tested the effect on group performance of three types of within group inequality: in ability, prize shares, and the efficient combination of both. Throughout our treatments, we provide a direct comparison of the efforts exerted by equal and unequal groups.

First, our experimental results suggest that inequality in ability does not help a team win. On the other hand, inequality in prize, although theoretically equivalent, it moderately increases a group's performance. The difference between the two treatments is mainly driven by the behavior of H types. One possible explanation is that receiving a higher reward is a stronger incentive than having a lower cost of effort. Further, we have a clear and consistent evidence that the efficient combination of both types of inequality substantially increase a group' performance.

We believe these findings provide practical insights to contest designers and social planners. If from one side inequality has been tackled by policymakers, e.g a reduction of income inequality is a political imperative for the European Commission, then on the other we have evidence that it improves productivity. In Appendix B, we also show that managers aiming to maximise their group chances of winning, under plausible conditions on the cost function, find it strategically optimal to maximise intra-group inequality. Indeed, as inequality in prize distribution seems to improve performances despite players are equally skilled, a team manager or a contest organiser may endogenously create inequality even in an environment that lacked of it. Similarly, when inequality in ability is already present within a group, a manager may want to combine it with an unequal distribution of the prize. That is, one type of inequality leads also to the other.

Second, in our experiment we elicited subjects' beliefs about others. Here, we find that subjects positively respond to their belief about the opponents' contribution, but to a smaller extent to the teammate's decisions. Our data on beliefs is consistent with the in-group/out-group discrimination literature.

Finally, we provided empirical evidence that overbidding in our experiment is more severe than we expected. Specifically, we defined the difference between a player's contribution and her best response (controlling for her beliefs) as BAD. Our results show that the value of the BAD is significantly higher than the standard measure of overbidding (contribution minus Nash prediction). In addition, we find that the BAD is positively correlated with risk-seeking attitudes, and it diminishes over time. That is, the "strategic-uncertainty-free" overbidding measured by the BAD is can be explained by both error and risk attitudes.

We are aware that the experiment found a positive effect on group competitiveness by implementing a mild level of inequality. An interesting question is to construct an empirical calibration of the relationship between the level of inequality and the effectiveness. Although the model predicts a monotonic positive relationship between the level of inequality and group contribution, behavioural factors such as social comparison concerns may make extreme levels of within group inequality harmful for competitiveness. We leave it for future research.

Appendix A

Proof of Lemma 1

Recalling that $\sigma_i = X_i/X$, we can rewrite Equation (3) as

$$\sigma_i = \sum_{k=1}^{n_i} f\left(\frac{1-\sigma_i}{X}\phi_{ik}v_{ik}\right)/X. \tag{6}$$

Equation (6) implicitly defines a group i's probability of winning as a function of the aggregate effort X, $\sigma_i = s_i(X)$. The equilibrium value of X is determined by the condition $\sum_{i=1}^{N} s_i(X) = 1$. Note that the left-hand side of (6) exceeds the right at $\sigma_i = 1$. Furthermore, the right-hand side is decreasing on σ_i, which implies that there is a unique σ_i that solves (6) for any $X > 0$. Finally, because $\sigma_i = s_i(X)$ is strictly decreasing and continuous in X for all i, $lim_{X\to\infty}s_i(X) = 0$ and $lim_{X\to 0}s_i(X) = 1$,[31] then it should be clear by the intermediate value theorem that there is only one equilibrium aggregate effort $0 < X^* < \infty$ such that $\sum_{i=1}^{N} s_i(X^*) = 1$. Finally, the equilibrium aggregate X^* and probability of winning σ_i^* define the groups' efforts as $X_i^* = \sigma_i^* X^*\ \forall i$.

Appendix B

The Strategic Game

Let assume that the game is dynamic with two stages: a prize allocation stage, and a contest stage. In the prize allocation stage, all groups (or their group manager) simultaneously choose a prize allocation to maximise their chances of winning. For now, we assume that the distribution of abilities is given. The allocation cannot be contingent on ex-post individual's efforts as they are not observable. In the contest stage, all players simultaneously exert an effort knowing the prize allocations implemented by all groups. The solution concept is the Subgame Perfect Nash equilibrium in pure strategies. We focus only on stage one as stage two has been

[31]Function $s_i(X)$ is known as the "share function" and its properties follow directly from Cornes and Hartley (2005).

solved in Section 1.

In the allocation stage, all groups simultaneously choose a prize allocation $\phi_i = (\phi_{i1}, ..., \phi_{in_i})$ in order to maximise their probability of winning $\sigma_i = X_i/X$.[32] Thus, the group i's objective function is given by

$$\begin{aligned} &\phi_i \in argmax\ \sigma_i \\ s.t. &\sum_k^{n_i} \phi_{ik} = 1,\ \phi_{ik} \geq 0\ \forall k. \end{aligned} \tag{7}$$

If we find a profile of prize allocations $(\phi_i^*, ..., \phi_N^*)$ that solves (7) for all i and all players maximise their expected payoff, then we can state that it is a Subgame Perfect Nash Equilibrium in pure strategies.[33] The same analysis holds if the choice variable is the distribution of abilities within a group, i.e. when $v_i = (v_{i1}, ..., v_{in_i})$, s.t. $\sum_k^{n_i} v_{ik} = V_i,\ v_{ik} \geq 0\ \forall k$.

Proposition 5.1. *Suppose that $g'''(x) < 0$, then the strategic game has $\prod_{i=1}^N n_i^h$ Subgame Perfect Equilibria, where n_i^h is the number of group members with the highest ability in group i. The equilibrium allocation ϕ_i^* rewards the entire prize to one of the n_i^h members.*

Note that, when $g(x)''' < 0$, the optimal allocation assigns the entire prize to the most able player of the group. It follows that, when it is possible to combine both types of inequalities, the equilibrium distributions of abilities and prize shares is $v_{ik} = V_i$ and $v_{il} = 0$, $\phi_{ik} = 1$ and $\phi_{il} = 0\ \forall l \neq k$. This can be easily shown as in the proof of Proposition 5.1, while choosing the optimal $v_i = (v_{i1}, ..., v_{in_i})$ under the

[32]This is a common situation assuming that the prize division is imposed by a third subject, whose compensation is aligned with the results of the group. Examples include organisations that use contests to boost workers productivity and retail firms that set-up monetary reward contests for sales departments during periods with a peak in the demand for goods. Furthermore, in sports competitions managers face the task of dividing the prize among the winning members.

[33]In Lemma 2, we show that an allocation that maximises a group's probability of winning also maximises the group effort. In other words, under the equilibrium profile of prize allocations $(\phi_i^*, ..., \phi_N^*)$ no group has an incentive to deviate by implementing a different allocation rule neither to increase its probability of winning nor to increase its effort.

constraint $\phi_{ik} = 1$.

Proof of Proposition 5.1

A Subgame Perfect Nash Equilibrium in pure strategies is a profile of prize allocations $(\phi_i^*, ..., \phi_N^*)$ and aggregate effort X^* that simultaneously solve the following equations:

$$\begin{gathered}\phi_i \in argmax\ \sigma_i\ \forall i \\ s.t. \sum_{k}^{n_i} \phi_{ik} = 1,\ \ \phi_{ik} \geq 0\ \forall k;\end{gathered} \tag{8}$$

$$\sum_{i}^{N} s_i(X, \phi_i) = 1; \tag{9}$$

where $\sigma_i = s_i(X, \phi_i)$, as defined in the proof of Lemma (1), and implicitly by

$$\sigma_i = \sum_{k=1}^{n_i} f\left(\frac{1-\sigma_i}{X}\phi_{ik}v_{ik}\right)/X. \tag{10}$$

In Lemma 1 we proved that for any profile of prize allocations $(\phi_1, ..., \phi_N)$ there exists a unique equilibrium aggregate $0 < X^* < \infty$ such that $\sum_i^N \sigma_i^* = 1$ and $0 < \sigma_i^* < 1\ \forall i$, where $\sigma_i^* = s_i(X^*, \phi_i)$. Hence, it must hold that at an equilibrium profile of prize allocations $(\phi_1^*, ..., \phi_N^*)$ the aggregate X^* is unique. Here, we have to prove that there is only one $0 < X^* < \infty$ that simultaneously solves for Equation (8-9).

Now, note that for any $0 < X < \infty$, the left-hand side of (10) exceeds the right at $\sigma_i = 1$, while the right-hand side exceeds the left at $\sigma_i = 1$ and it is decreasing in σ_i. It implies that there is a unique $0 < \sigma_i < 1$ that solves (10) for any $0 < X < \infty$ and prize allocation $\phi_i = (\phi_{i1}, ..., \phi_{in_i})$. Thus, for a fixed aggregate $0 < X < \infty$, the group i can achieve any probability of winning $\sigma_i \in [\sigma_i^L, \sigma_i^H]$ by choosing the appropriate $\phi_i = (\phi_{i1}, ..., \phi_{in_i})$. Clearly, there may be more than one ϕ_i that achieves the same $\sigma_i \in [\sigma_i^L, \sigma_i^H]$. In order to find σ_i^H, which is the highest probability of winning that group i can reach at a given aggregate $0 < X < \infty$, we could either take the implicit derivative of function (10) or solving the following equivalent system of equations:

$$
\phi_i \in argmax \ \sum_{k=1}^{n_i} f\left(\frac{1-\sigma_i}{X}\phi_{ik}v_{ik}\right)/X \ \forall i
$$
$$
s.t. \sum_{k}^{n_i} \phi_{ik} = 1, \ \phi_{ik} \geq 0 \ \forall k, \tag{11}
$$

$$
\sigma_i = \sum_{k=1}^{n_i} f\left(\frac{1-\sigma_i}{X}\phi^o_{ik}v_{ik}\right)/X, \tag{12}
$$

where ϕ^o_{ik} is the solution of (11). In other words, we maximise the right-hand side of (10) under the condition that $\sigma^H_i = s_i(X, \phi^o_i)$.

If $g''' < 0$, the right-hand side of Equation (10) is a sum of strictly convex functions, i.e. it is strictly convex. Thus, for any $0 < \sigma^H_i < 1$, the solution of (11) is a corner solution. It implies that there are n^h_i equilibrium allocation that maximises the group i's probability of winning, where n^h_i is the number of players with the highest ability in group i. Thus, we are left with proving that there is a unique $0 < X^* < \infty$ that solves for $\sum_i^N \sigma^H_i = 1$, i.e. $\sum_i^N s_i(X^*, \phi^o_i) = 1$. However, this follows immediately from Lemma 1.

Lemma 3. *Let $\phi^o_i(\phi^o_{ik}, ..., \phi^o_{in_i})$ be the prize allocation that maximises group i's probability of winning at the aggregate effort X. If ϕ^o_i is the solution of $\phi_i \in argmax \ s_i(X, \phi_i)$, then it is also the solution of $\phi_i \in argmax \ X_i$. Formally,*

$$
\phi_i \in argmax \ \sigma_i \Leftrightarrow \phi_i \in argmax \ X_i
$$

Proof. Note that $\sigma_i = X_i/X$. Hence, at a fixed X, it clearly holds that $\phi_i \in argmax \ \sigma_i \Leftrightarrow \phi_i \in argmax \ X_i$.

□

Appendix C

In this section of the Appendix, we present several additional figures describing our experimental results.

C.1

The detailed illustration of the beliefs is presented in the following figure.

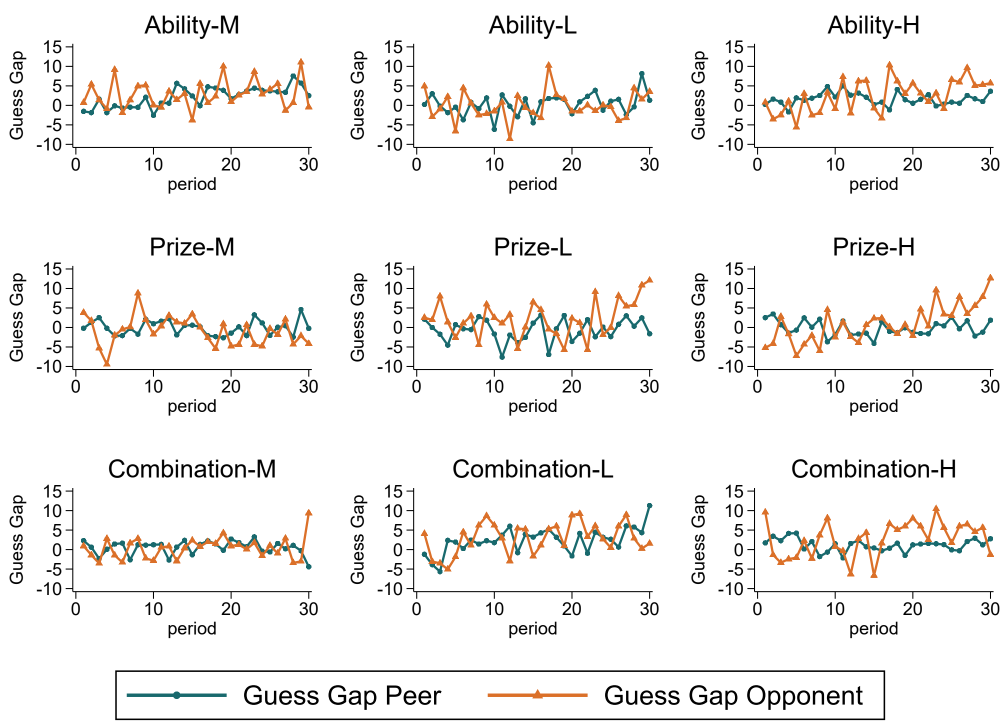

Figure 8: The guess gap across treatments and types

Note: Guess Gap Peer is calculated by the prediction elicited minus the actual contributions about the subject's peer group member. Guess Gap Opponent is calculated by the prediction elicited minus the actual contributions about the subject's opponent group total contributions.

C.2

The detailed distribution of BAD across types and treatments is presented in the following figure.

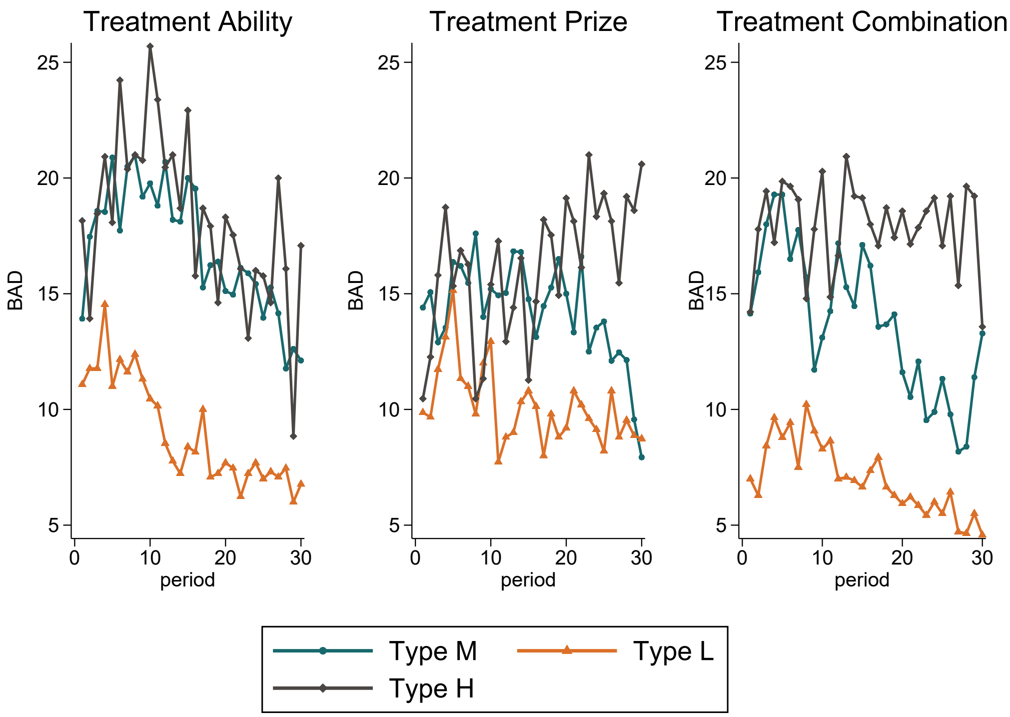

Figure 9: BAD by types and treatments

C.3

The symmetric plots by D'agostino et al. (1990) of the guesses show that subjects' guesses are very symmetrically distributed as they are located very close to the reference line, especially for the guesses about the contribution of their peer.

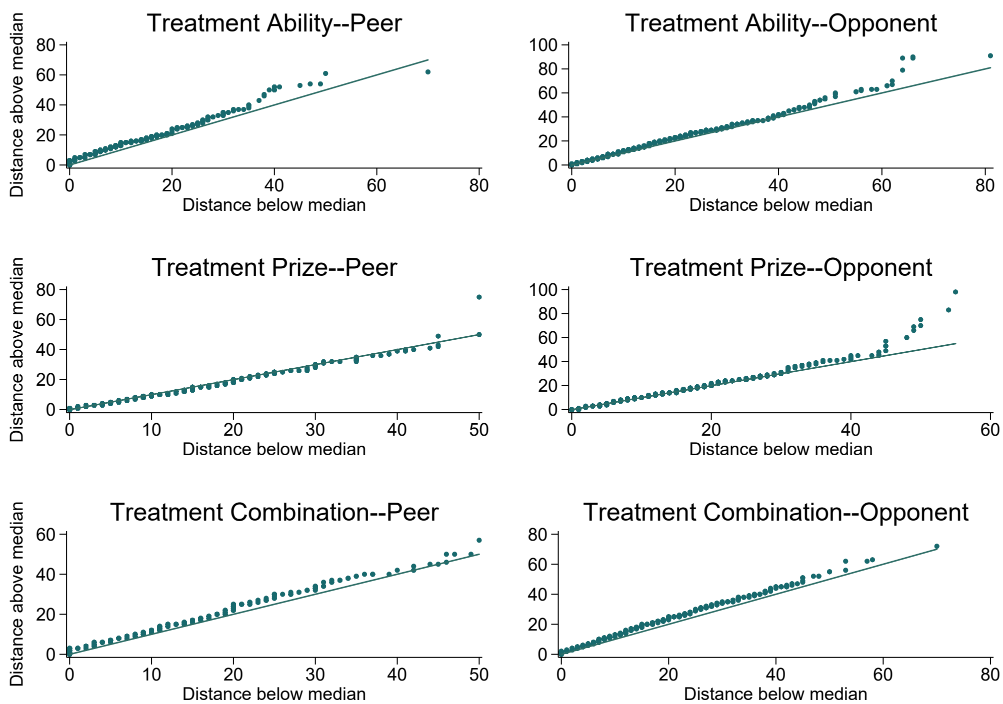

Figure 10: The symmetric plot of the guesses

Note: The symmetric plot of the guesses for peer and opponent across treatments.

Appendix D

In this section of the Appendix, we present results from simple alternative regression models as robustness checks for all regression tables we present in the main part of the paper.

D.1

The following table shows the OLS regression results, in lieu of the hierarchical model in Table 6.

	Dependent variable: Group contribution		
	Treatment Ability	**Treatment Prize**	**Treatment Combination**
Unequal group	-4.109*	-2.485	4.524**
	(2.492)	(1.989)	(2.253)
Period	-0.418***	-0.228***	-0.461***
	(0.102)	(0.0734)	(0.0854)
Period × Unequal group	0.136	0.387***	0.436***
	(0.141)	(0.115)	(0.127)
Constant	47.88***	38.33***	33.57***
	(4.002)	(2.897)	(3.416)
Observations	780	900	840

Table 10: Group contribution difference between equal and unequal groups (OLS)

Note: OLS regression with robust standard errors. Unequal group is a dummy variable with the equal group being 0 and the unequal group being 1. Numbers in parentheses indicate standard errors. Significance levels * $p < 0.1$, ** $p < 0.05$, *** $p. < 0.01$.

D.2

The following table shows the random-effects GLS regression results, in lieu of the hierarchical model in Table 8.

Dependent Variable: individual contribution									
	Treatment Ability			Treatment Prize			Treatment Combination		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
L.contribution	0.685***	0.637***	0.615***	0.634***	0.629***	0.623***	0.674***	0.664***	0.642***
	(0.0312)	(0.0495)	(0.0580)	(0.0658)	(0.0585)	(0.0647)	(0.0624)	(0.0704)	(0.0679)
L-Type	-3.520**	-4.029***	-4.403***	-2.103**	-2.329**	-2.498**	-3.056***	-3.763***	-4.453***
	(1.630)	(1.506)	(1.291)	(0.833)	(0.922)	(1.233)	(0.930)	(1.255)	(1.435)
H-Type	1.279	1.667	2.382	1.792	1.762	1.718	5.400**	6.170**	6.372**
	(1.166)	(1.336)	(1.490)	(1.427)	(1.707)	(1.547)	(2.269)	(3.122)	(3.008)
Period	-0.0884	-0.0542	-0.0547	-0.0614***	-0.0774***	-0.0775***	-0.0695*	-0.0723*	-0.0784*
	(0.0544)	(0.0390)	(0.0393)	(0.0204)	(0.0104)	(0.0102)	(0.0364)	(0.0394)	(0.0406)
Female	-0.112	0.0756	0.109	-0.152	-0.0310	-0.161	-0.277	-0.314	-0.176**
	(0.979)	(0.942)	(0.752)	(0.464)	(0.404)	(0.360)	(0.279)	(0.363)	(0.0722)
L-Type × Period	0.0304	0.0319	0.0282	0.00793	0.0380	0.0361	0.0108	0.0119	0.0160
	(0.0562)	(0.0682)	(0.0693)	(0.0410)	(0.0319)	(0.0336)	(0.0581)	(0.0698)	(0.0698)
H-Type × Period	0.0709**	0.0532	0.0537	0.132***	0.136***	0.139***	0.0749*	0.106*	0.118**
	(0.0339)	(0.0401)	(0.0404)	(0.0257)	(0.0234)	(0.0266)	(0.0425)	(0.0576)	(0.0599)
Guess-peer		0.00507	0.0102		-0.0272	-0.0208		0.0549	0.0545
		(0.0383)	(0.0383)		(0.0419)	(0.0432)		(0.0375)	(0.0356)
Guess-other		0.129***	0.131***		0.0778**	0.0804**		0.0692***	0.0747***
		(0.0349)	(0.0310)		(0.0322)	(0.0332)		(0.0104)	(0.0126)
Risk-seeking			0.529***			0.404			0.537***
			(0.190)			(0.387)			(0.122)
IQ score			0.391			0.0447			0.00665
			(0.240)			(0.137)			(0.0613)
Constant	7.222***	2.592***	-3.366	6.826***	4.777***	2.504	6.192***	2.620***	0.0665
	(0.910)	(0.825)	(2.168)	(1.127)	(0.937)	(2.724)	(0.570)	(0.441)	(0.144)
Observations	1560	1543	1543	1800	1792	1792	1320	1313	1313

Table 11: Individual contribution random-effects GLS

Note: GLS random-effects model with cluster robust standard error over experimental sessions. *L.contribution* is the individual contribution of the previous round. *L-Type* and *H-type* are categorical variables standing for the low ability/prize subjects and high ability/prize subjects respectively. The omitted category is the *M type*. *Guess-other* stands for the expectation about the opponent group's total contribution. *Guess-peer* stands for the expectation about the other group members' individual contribution. *Female* is a dummy variable with female subjects being 1. *Risk-seeking* ranges from 1 to 10 with higher values indicating more risk-seeking attitudes. *IQ score* is the total No. of correct answers from 12 Raven questions. Numbers in parentheses indicate standard errors. Significance levels: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Observations with belief data error are excluded.

D.3

The following table shows the random-effects GLS regression results, in lieu of the hierarchical model in Table 12.

	Dependent Variable: BAD					
	Treatment Ability		Treatment Prize		Treatment Combination	
	(1)	(2)	(3)	(4)	(5)	(6)
L-Type	-7.906**	-7.758**	-4.646**	-4.697**	-8.933***	-10.89***
	(3.667)	(3.824)	(2.070)	(2.166)	(1.985)	(2.160)
H-Type	1.151	3.201	-3.420	-3.366	-0.113	-1.555
	(4.179)	(3.872)	(3.071)	(2.773)	(2.691)	(3.095)
Period	-0.202	-0.202	-0.141**	-0.141**	-0.278***	-0.306***
	(0.191)	(0.192)	(0.0569)	(0.0569)	(0.0648)	(0.0768)
L-Type × Period	-0.0215	-0.0219	0.0417	0.0417	0.140*	0.155
	(0.140)	(0.141)	(0.106)	(0.106)	(0.0763)	(0.100)
H-Type × Period	-0.00643	-0.00683	0.345***	0.345***	0.281**	0.319**
	(0.117)	(0.118)	(0.130)	(0.130)	(0.125)	(0.157)
Female		-0.377		-0.215		-0.612*
		(2.168)		(0.621)		(0.350)
Risk-seeking		1.769***		0.662		1.654***
		(0.571)		(1.100)		(0.270)
IQ score		0.343		-0.330		0.0198
		(1.019)		(0.345)		(0.493)
Competitive score		0.103		0.257*		0.00821
		(0.104)		(0.143)		(0.285)
Constant	20.40***	8.941	16.40***	16.02*	18.06***	10.41***
	(1.764)	(12.08)	(0.541)	(8.349)	(1.086)	(3.772)
Observations	1543	1543	1792	1792	1670	1313

Table 12: BAD random-effects GLS

Note: GLS random-effects models using cluster robust standard errors over experimental sessions. *L-Type* and *H-Type* are categorical variables standing for the low ability/prize subjects and high ability/prize subjects respectively. The omitted category is the M type. *Female* is a dummy variable with female subjects being 1. *Risk-seeking* ranges from 1 to 10 with higher values indicating more risk-seeking attitudes. *IQ score* is the total No. of correct answers from 12 questions. *Competitive score* ranges from -10 to 10 with higher values indicating more competitive personality. Numbers in parentheses indicate standard errors. Significance levels * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Observations with belief data error are excluded. The last column sees a smaller sample size due to a technical issue that in one session, we did not record the gender information of 12 subjects.

Appendix E

The following instructions are for Treatment Ability and have been read out loud by the experimenter.

Experimental instructions

You are about to participate in an experiment in the economics of decision-making. These instructions are meant to clarify how the experiment actually works and how you earn money in the experiment. Your earnings will be paid to you **privately**

in cash at the end of the experiment. To ensure the best results for yourself, and accurate data for the experimenters, please **do not communicate** with the other participants at any point during the experiment. If you have any questions, or need assistance of any kind, raise your hand and an experimenter will come to you. Economics experiments have a strict policy against deception. If we do anything deceptive, or don't pay you in cash as described, then you can complain to the school of Economics at the University of Edinburgh and we will be in serious trouble. The currency in this experiment is expressed in points. Your points will be converted to cash and paid to you at the end of the experiment privately, based on the exchange rate.

The currency in this experiment are expressed in points. Your points will be converted to cash and paid to you at the end of the experiment privately, based on the exchange rate.

1500 points = £4.

In addition you will be paid £3 for participation and a bonus (£2 + a lottery) for completing all survey questions at the end of this experiment.

The experiment

This experiment involves a decision-making task in groups. The same task will be played a total of 30 times (rounds). You will not know who your group members are neither during nor after the experiment. You will be randomly rematched into a new group after each round. At the beginning of the experiment, you will be randomly assigned to one of the three types - X, Y or Z. Types will remain **fixed** until the end of the entire experiment.

Groups and matching

First, before each round, all participants will be randomly divided into groups of two assigned in the following way:

XX groups and YZ groups.

If your type is X, then you will always be in a group with another X type player.
If your type is Y, then you will always be in a group with a Z type player.
If your type is Z, then you will always be in a group with a Y type player.

Second, your group will randomly match with a group of the other type. Hence, if you are in a XX group, then you are always matched with a YZ group and vice versa. Finally, after each round all groups are dissolved, all participants will be randomly assigned (again) into groups according to their types, and then the groups will randomly re-match.

The task

For every round, your group is competing against your matched group for a reward worth 1000 points. If your group wins, the reward will be divided equally between the two of you.

All participants begin each round with an endowment of 300 points and choose a contribution to the group account. The minimum No. of contributions is 0 and the maximum is 50, and any integer between 0 and 50 is also allowed. The group account is the sum of the contributions of its members. Contributions have a cost based on the participants' type and details are listed on Table 1 (*a separate piece of paper on your desk*). You are allowed to contribute with costs higher than your endowment, by paying more points than your endowment. Doing so may result in a negative payoff for that specific round, however, at the end of the experiment, we will make sure you earn at least the show-up fee.

The chance that your group receives the reward in a round depends on the contributions on your group account and your matched group's account. At the start of each round, all 4 participants (you, your group member, and the two participants in the other group) will decide how much to contribute simultaneously. Once the contribution decisions are made, a computerized lottery will determine which group will receive the reward.

In this lottery draw there are 2 types of tickets: type XX and type YZ. Each type of ticket corresponds to the group who will receive the reward if a ticket of this type is drawn. Thus, if a type XX ticket is drawn, then group XX wins. If a type YZ ticket is drawn, then group YZ wins. The reward will be equally shared between the winning group members.

The number of tickets of each type corresponds exactly to the contributions on the group account.

No. of XX tickets = No. of contributions by member X + No. of contributions by member X.No. of YZ tickets = No. of contributions by member Y + No. of

contributions by member Z.

Every ticket is *equally likely* to be drawn by the computer.

In addition to the above task, while you are deciding your contribution, you will be asked to predict (1) the total contribution on your group's and (2) on the other group's account. For every correct prediction, you will receive 50 points (0 for incorrect predictions).

An example

Suppose the contributions on group XX's account are 32 (13 + 19), and the contribution on group YZ's account is 15 (5 for Y + 10 for Z). There will be a total of 47 (32+15) tickets and each ticket is equally likely to be the winning one. The feedback will be shown to you as following:

group	Contributions	Tickets	Chance of winning	Winner ticket	Winning group
XX	32	1-32	0.68	8	XX
ZY	15	33-47	0.32	8	XX

In this example, the winning group, XX players have a payoff calculated as:

Payoff = prize/2 + endowment – individual cost of contribution + prediction profit.

Then, in points is Payoff = 1000/2 + 300 – individual cost of contribution + 50*No. of correct prediction.

On the other hand, the other group, YZ players have a payoff calculated as:

Payoff = endowment – individual cost of contribution+ prediction profit.

Note that each player has her own contribution decision and the corresponding costs (listed in Table 1). Numbers in the example are for illustrative purpose and in no way they suggest what you should do in the actual experiment.

At the end of the experiment, 5 rounds will be randomly selected for actual payments and you will earn the sum profit of these *5 rounds*. Thus it is in your best interest to make serious decisions for every round.

Feedback

At the end of each round, you will receive feedback information on your group's contributions, the other group's contributions, the winning group and your profit in this round.

Practice questions

Before the start of today's session, please answer the practice questions shown on your screen. Feel free to go back and check the instructions while answering these questions.

Trial round

After the practice questions, you will experience a trial round which will not be selected for payment. After the trial round, you will be given additional opportunities to ask questions. After which, the 30 rounds eligible for payments begin.

The survey

After the end of round 30, you will be asked to participate in a survey. Instructions for completing the survey will be shown on your screen. At the end the survey, a bonus reward will be provided.

The end of the experiment

Please remain seated and follow the instructions by leaving the room one by one to receive your payment. Thank you very much.

The cost table (for Treatment Ability)

This table specifies the cost of contribution for different types. For example, if you are type X, by choosing to contribute 7 tickets, it costs you 52 points.

No. of contributions	X type	Y type	Z type
0	0	0	0
1	5	10	3
2	11	23	8
3	19	37	12
4	26	53	18
5	34	69	23
6	43	86	29
7	52	103	34
8	61	121	40
9	70	140	47
10	79	158	53
11	89	178	59
12	99	197	66
13	109	217	72
14	119	237	79
15	129	258	86
16	139	279	93
17	150	300	100
18	160	321	107
19	171	342	114
20	182	364	121
21	193	386	129
22	204	408	136
23	215	431	144
24	227	453	151
25	238	476	159
26	249	499	166
27	261	522	174
28	273	545	182
29	284	569	190
30	296	592	197
31	308	616	205
32	320	640	213
33	332	664	221
34	344	688	229
35	356	713	238
36	369	737	246
37	381	762	254
38	393	787	262
39	406	811	270
40	418	837	279
41	431	862	287
42	443	887	296
43	456	912	304
44	469	938	313
45	482	964	321
46	495	989	330
47	508	1015	338
48	521	1041	347
49	534	1067	356
50	547	1093	364

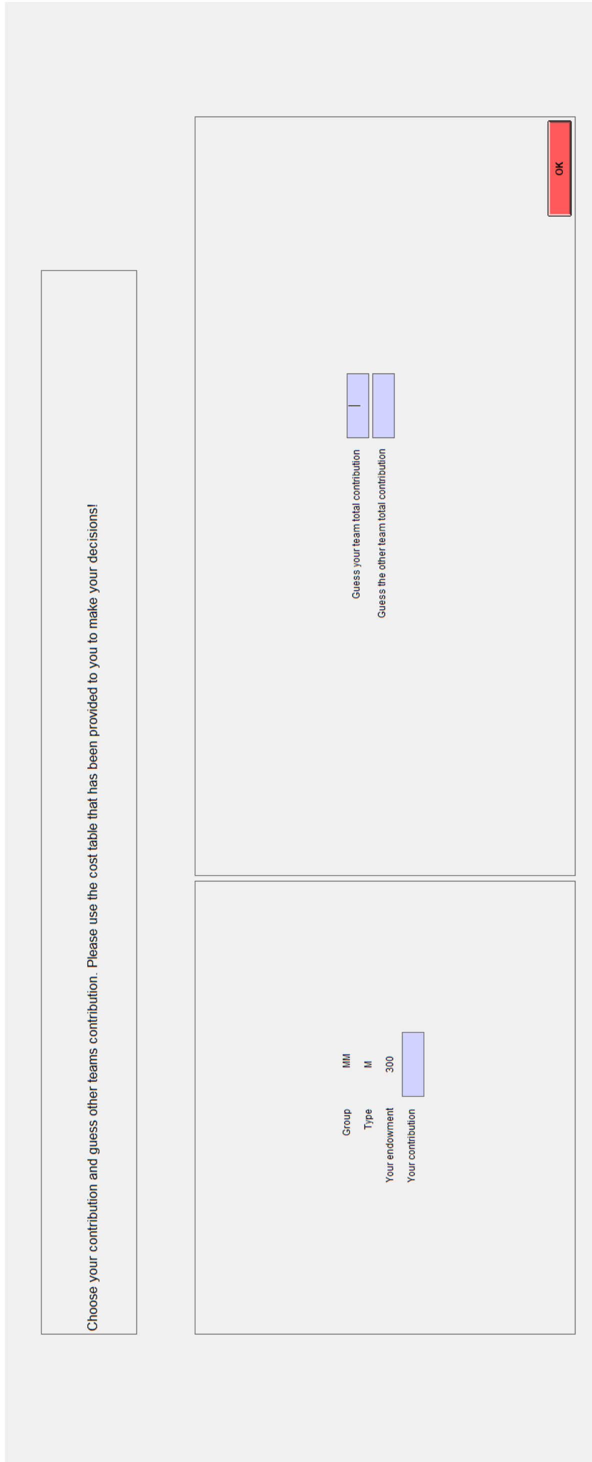

Figure 11: Contribution stage

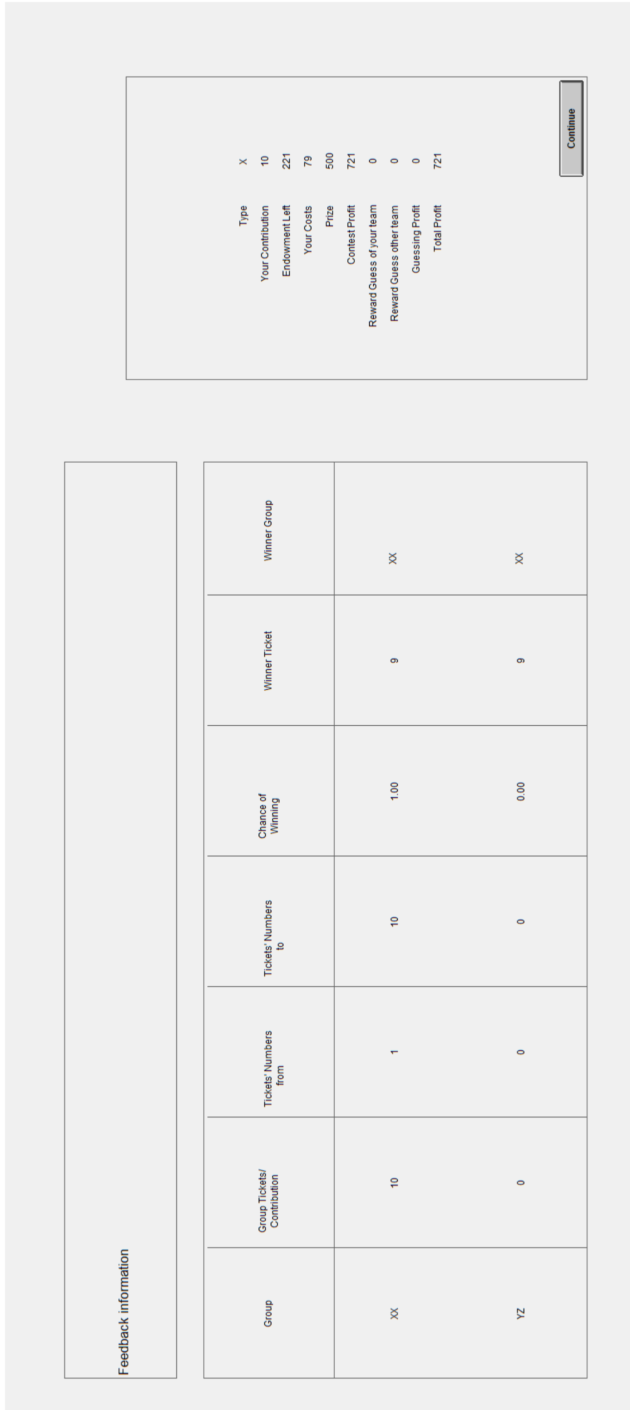

Figure 12: Feedback

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