Endogenous Strength in Competition Between and Within Groups*

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November 2, 2026

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Abstract

In this paper, I study competition between and within groups. I develop a model and design an experiment in which subjects play a two-stage contest: a group contest followed by a contest between members of the winning group. The experiment consists of different treatments in which a subject's strength in the second stage may be linked positively or negatively to how much they helped their group in the first stage. I also consider benchmark cases in which strength is exogenous and either equivalent for everyone or randomly assigned for each subject. I find that subjects compete more aggressively with each other in the second stage when helping the group makes an individual weaker in within-group competition. My results provide insights for managers designing incentive schemes when their employees must collaborate in teams but also compete for internal rewards.

Keywords: group behavior, contests, experiment, personnel economics

JEL: C72, C91, C92, M54

* I thank Anthony Kwasnica, Luke Boosey, Mark Isaac, Pellumb Reshidi, Tim Salmon, Phil Brookins, participants of the 2025 and 2026 South Carolina Game Theory Conference, participants of the 2026 Economic Science Association World Meetings, and attendees of the XS/FS readings group at FSU for helpful comments. This study received IRB approval from Florida State University (Study ID: 00006796) and was preregistered on the Open Science Framework (OSF DOI: 3jumk).
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1 Introduction

Group work is ubiquitous in firms, sports, politics, and research. According to Cross et al. (2016), employees in some companies spend as much as 80% of their time on collaborative activities. Group mates work together to achieve a common goal or to compete against other groups for prizes. But prizes may be indivisible or difficult to divide ex ante through formal contracts or informal agreements. In these cases, collaborating group members often end up competing against each other over the reward allocation. For example, employees in a firm work together to compete with rival firms for contracts and market share, and then compete internally for promotions and bonuses. Cyclists in breakaway groups coordinate to outpace the peloton and then sprint against each other for the finish line. After defeating the Axis powers in World War II, Allied nations clashed over spheres of influence in Europe. These examples all follow the same framework: an intergroup competition followed by an intragroup competition. Within this setting, group members choosing how much to help their group must anticipate the fact that they'll be competing with their fellow group members in the future. In many cases, an individual's strength or position in the intragroup competition depends explicitly or implicitly on how much they contributed to the intergroup competition. Helping to strengthen the group may make the individual either stronger or weaker when it comes time to compete with fellow group members.[1]

In this paper, I study competition between and within groups where an individual's strength in intragroup competition is linked to their contribution in the intergroup competition. I develop a model and conduct an experiment in which subjects play a two-stage contest,[2] and I systematically vary how contribution in the first stage affects strength in the second stage.

In my model, groups compete in two stages for an indivisible prize. The first stage (the group stage) is a standard group Tullock contest[3] (Katz et al., 1990; Münster, 2009). Each agent receives a fixed endowment and chooses how much to contribute to the group. Individual contributions are aggregated and the winning group is determined. Winning group members advance to the second stage (the individual stage) where they compete in a standard Tullock contest[4] (Tullock, 1967, 1980; Rogerson, 1982) to determine who ultimately wins the prize. In this stage, each agent's contributions are multiplied by their strength value, and the likelihood of winning is proportional to multiplied contributions. Strength is determined endogenously as a function of group stage contribution. I consider two different strength functions: one in which strength increases in group stage contribution and one in which it decreases. As benchmarks, I also consider two cases in which strength is exogenous to the group stage — one in which strengths are fixed and ex ante symmetric across all agents and another in which strength is randomly drawn and assigned for each agent from a known distribution. The model essentially

[1] For example, in a firm, the effort an employee devotes to attaining clients might affect her in the internal competition for promotions and bonuses. Depending on the firm's corporate culture or organizational structure, working hard to pursue a client might affect an employee's prospects of earning a promotion positively or negatively. In one case, doing background research on clients and delivering pitches might make an employee a stronger candidate for internal promotion. In another case, the strongest employee may be the one who privately lobbies the firm's superiors, not necessarily the one who performs the productive tasks.

[2] Contests and tournaments are frequently used to model competitive situations in firms, sports, lobbying, and R&D where output or likelihood of success is noisy and investments are unobservable or non-contractible (Tullock, 1967, 1980; Rogerson, 1982; Lazear & Rosen, 1981).

[3] See Sheremeta (2018) for a review of group contests.

[4] See Dechenaux et al. (2015) for a review of contests.

combines two standard models, with one key novel innovation: the endogeneity of individual strength, which imposes a link between the two stages that can be systematically manipulated. I characterize equilibrium contributions in each case and develop hypotheses based on theoretical predictions.

I then conduct a controlled laboratory experiment in which two groups of two subjects each play the two-stage contest described above. In a between-subjects design across four treatments, I vary the relationship between group stage contribution and individual strength. In the **Increasing** treatment, higher group stage contributions increase strength. In the **Decreasing** treatment, higher group stage contributions decrease strength. I also run two benchmark treatments where strength is exogenous: **Symmetric** where each agent receives an equal strength ex ante, and **Random** where strength is drawn stochastically for each agent. Subjects participate in 20 repeated rounds with random rematching of groups between rounds. I collect data on contributions in each stage to compare against theoretical predictions and across treatments. I devote special attention to analyzing treatment differences in the individual stage. In my experimental design, I set up a unique environment in which the individual stage results are robust to risk attitudes, social preferences, bounded rationality, joy of winning, confusion, norms, and many other explanations. Due to the nature of the individual stage across all treatments, differences in contributions cannot be rationalized by these common explanations. With this in mind, I study how varying the link between the stages affects individual stage behavior.

A laboratory experiment allows us to empirically study this environment in ways that would be otherwise intractable using naturally occurring data. Real-world contest contributions are often undisclosed or otherwise difficult to observe. Natural settings also preclude control over parameters that drive interesting comparative static predictions. In this particular case, field settings that differ in the link between group contribution and individual strength also presumably differ in other significant ways. A lab setting allows us to manipulate the link between the two stages while holding all else constant and study the causal impacts on behavior.

I find two main sets of results. First, between treatments, aggregate contributions across both stages are the same, but contributions within each stage differ significantly. Within the group stage, contributions follow the pattern predicted by theory. Subjects contribute the most when contributions increase next-stage strength and the least when contributions decrease strength. Within the individual stage, contributions are significantly higher when strength is decreasing versus when it is increasing in group stage contributions. Based on aggregate effort in the two-stage contest, the cases I study appear to be equally efficient or profitable. However, due to the stark differences within each stage, a particular case may be considered optimal for a principal or social planner if either the collective or individual effort is considered productive. For example, a firm may want to incentivize collective effort but discourage unproductive infighting. On the other hand, patent races involve significant duplication of effort between research teams, with the most valuable innovation often emerging from internal competition. These results extend research on optimal contest and tournament design to a two-stage setting with endogenous strength (Tsoulouhas et al., 2007; Fu & Lu, 2012).

The second main set of results focuses on behavior in the individual stage. According to the theory, equilibrium contributions in the individual stage contest are fully determined by the ratio of realized strengths between contestants. Consequently, for a given strength ratio, the theory predicts equivalent contributions across all treatments. I find that differences in contributions are robust to controlling for strength ratio. Specifically, group members compete less aggressively with each other when strength stems from high contributions to the group and

more aggressively when it stems from low contributions. Contrary to the theory, subjects care not only about the degree of strength asymmetry but also about the origins of that asymmetry.

This second set of results expands our understanding of discouragement effects in asymmetric contests.[5] The discouragement effect describes a common tendency for contributions in a contest to fall when contestants are asymmetric. I find that the discouragement effect survives in my experiment when higher strength comes from high contributions but disappears when higher strength comes from low contributions. In the latter case, both weak and strong players maintain relatively high levels of contributions indistinguishable from levels in the symmetric contests. The data suggest that when asymmetry arises endogenously, discouragement effects are sensitive to exactly how it arises. The behavioral pattern I observe in the individual stage also resembles previous findings on entitlement effects in dictator games (Hoffman et al., 1994; Cherry et al., 2002; Cappelen et al., 2007; Oxoby & Spraggon, 2008). An entitlement effect describes how individuals behave less prosocially when they earn an advantaged position. I extend this notion to a competitive setting and show how both the strong and weak players in a contest compete more aggressively when the strong position is earned through low contributions versus high contributions to the group.

This paper relates most directly to a small branch of the theoretical contest literature which studies competition between and within groups (Wärneryd, 1998; Katz & Tokatlidu, 1996). These models analyze the effects of varying group sizes and numbers of groups or the timing of competition (Münster, 2007). Extensions of the basic two-stage models study various types of asymmetry within or between groups (Choi et al., 2016; Stein & Rapoport, 2004). In my paper, I provide one of the few experimental tests of this setting, and I am the first to study an endogenous link between intergroup and intragroup competition.

Most closely related to my paper is one recent experiment that studies an intragroup contest followed by an intergroup contest (Bhattacharya & Rampal, 2024). In their experiment, group members first conflict over internal prize allocation before competing with other groups. This ordering of stages captures situations such as political elections where party members first compete in primaries for nominations, and then one candidate represents the party in the general election. In contrast to Bhattacharya & Rampal (2024), I study situations in which the intergroup competition precedes the intragroup competition. My setup focuses on situations in firms, sports, and research teams in which group members must first coordinate to defeat other groups before competing internally over rents. Also distinct from Bhattacharya & Rampal (2024), I focus on establishing an endogenous link between group and individual competition and explore how varying this link affects behavior.

The broader literature on multistage contests studies elimination tournaments (Gradstein & Konrad, 1999; Altmann et al., 2012; Sheremeta, 2010b) or situations in which investments in a contest carry over to future competition (Schmitt et al., 2004; Sheremeta, 2010a,b; Ryvkin, 2011). In a similar spirit, group stage contributions in my model affect an individual's position in the subsequent individual stage. My individual stage also borrows from previous contest models in which contestants possess asymmetric strength (or ability or effectiveness) (Stein, 2002; Baik, 1994; Schotter & Weigelt, 1992; Kirkegaard, 2012; Franke et al., 2013). While these models exogenously impose strengths, I study a unique setting in which strength is determined endogenously in different ways. I compare my findings to previous experimental work on asymmetric contests (Fonseca, 2009) and highlight how behavior differs when strengths are

[5] See Dechenaux et al. (2015), Mealem & Nitzan (2016), and Chowdhury et al. (2023) for recent surveys.

determined endogenously.

2 Model

Consider m groups $g \in \{1, ..., m\}$ of n risk-neutral agents $i \in \{1, ..., n\}$ who compete in a two-stage contest for a known and common-value prize $V > 0$. Each agent ig receives an endowment $w > 0$ from which she may make contributions over both stages. In the first stage, the group stage, groups compete in a group contest. One group wins and advances to the second stage, the individual stage, in which members of the winning group compete for the prize. In the individual stage, each agent possesses strength θ_{ig} which may depend endogenously on group stage contributions.

2.1 Group Stage

In the group stage, m groups compete for the right to advance to the individual stage and compete for a prize. Each agent chooses how much of her endowment to contribute to the group contest. Individuals simultaneously select group stage contribution x_{ig}, and a group's contribution is the sum of its members' group stage contributions $X_g = \sum_{i=1}^{n} x_{ig}$. Any portion of an agent's endowment that she doesn't contribute in the group stage, $w - x_{ig}$, remains with her if she advances to the individual stage. Once all groups submit their contributions, one winning group is determined stochastically. According to a group Tullock lottery contest success function (Münster, 2009; Skaperdas, 1996), group g wins with the following probability:

$$p_g = \begin{cases} \frac{X_g}{\sum_{h=1}^{m} X_h} & \text{if} \quad \sum_{h=1}^{m} X_h > 0 \\ \frac{1}{m} & \text{otherwise} \end{cases} \tag{1}$$

Agents earn no reward in the group stage. Members of the winning group advance to the individual stage where they have the opportunity to compete against one another for the prize V.

2.2 Individual Stage

In the individual stage, each member of the winning group chooses how much of her remaining endowment to contribute. Individuals simultaneously select individual stage contributions y_{ig}. Individual stage contributions are then multiplied by strength θ_{ig}, and multiplied contributions are used to determine the winner in the individual stage. Given multiplied contributions of both agents, agent ig wins with the probability captured by the following contest success function (Baik, 1994; Stein, 2002; Skaperdas, 1996):

$$p_{ig} = \begin{cases} \frac{\theta_{ig} y_{ig}}{\sum_{j=1}^{n} \theta_{jg} y_{jg}} & \text{if} \quad \sum_{j=1}^{n} \theta_{jg} y_{jg} > 0 \\ \frac{\theta_{ig}}{\sum_{j=1}^{n} \theta_{jg}} & \text{otherwise} \end{cases} \tag{2}$$

2.3 Payoffs

Each agent earns her endowment minus her group stage contribution. Members of the winning group also subtract their individual stage contributions. Ultimately only one agent earns the prize V. This agent belongs to the winning group and wins the individual stage. Given the above probabilities of winning in each stage, the expected payoff for the two-stage contest for agent ig is:

$$\pi_{ig} = w - x_{ig} + p_g(p_{ig}V - y_{ig}) \tag{3}$$

2.4 Strength

The main innovation of the model is the agent-specific strength which makes it possible to establish a link between the two stages. In the individual stage, an agent's strength is a function of her group stage contribution. In general, $\theta_{ig} = f(x_{ig})$ where f represents the *strength function*. I consider two cases in which strength is endogenous to group stage contribution. In one case f is monotonically increasing and concave in x_{ig}. Higher group stage contributions translate into higher strength. In another case, f is monotonically decreasing and convex in x_{ig}. In this case, the more an agent contributes to her group, the lower her strength becomes in the individual stage.

As a baseline, I also consider when strength is exogenous and symmetric across all subjects such that $\theta_{ig} = \theta \quad \forall \quad ig$. In this case, regardless of group stage decisions, strength is known, constant, and equivalent across all agents. Finally, I consider an additional benchmark case in which strength is exogenous and asymmetric. For each agent, strength is drawn randomly from a uniform distribution on the interval [1,5]. In the analysis that follows, I discuss equilibria and comparative statics for these different cases.

2.5 Analysis

I now characterize subgame perfect equilibria of the two-stage contest with potentially endogenous strength. In order to make the analysis more tractable and derive closed-form predictions for an experiment, I focus on the version of the model with $m = 2$ groups and $n = 2$ agents. The model is solved via backward induction. Without loss of generality, fix the winning group in the individual stage to be group a and define

$$\theta_{ia} = f(x_{ia}), \qquad r_{ia} = w - x_{ia}$$

where r_{ia} denotes the remaining endowment. Each agent $ia \in \{1a, 2a\}$ chooses $y_{ia} \in [0, r_{ia}]$ to maximize

$$u_{ia}(y_{ia}, y_{ja}) = \frac{\theta_{ia}y_{ia}}{\theta_{1a}y_{1a} + \theta_{2a}y_{2a}}V - y_{ia} + r_{ia}.$$

Lemma 1 (Individual stage Nash equilibrium)**.** *Assuming non-binding budget constraints,*[6] *given any vector of strengths* $(\theta_{1a}, \theta_{2a})$*, the individual stage has a unique Nash equilibrium in which*

[6]For a discussion of the individual stage Nash equilibrium when budget constraints bind, see Appendix A.1.

$$y_{1a}^* = y_{2a}^* = \frac{V\theta_{1a}\theta_{2a}}{(\theta_{1a}+\theta_{2a})^2}.$$

Winning probabilities are

$$p_{1a}^* = \frac{\theta_{1a}}{\theta_{1a}+\theta_{2a}}, \qquad p_{2a}^* = \frac{\theta_{2a}}{\theta_{1a}+\theta_{2a}},$$

and continuation payoffs net of remaining endowment are

$$U_{1a} = \frac{V\theta_{1a}^2}{(\theta_{1a}+\theta_{2a})^2}, \qquad U_{2a} = \frac{V\theta_{2a}^2}{(\theta_{1a}+\theta_{2a})^2}.$$

Proof. See Appendix A.2. □

Notice that the individual stage Nash equilibrium is symmetric even if agents are asymmetric, but equilibrium effective contributions (contributions multiplied by strength), probabilities of winning, and expected payoffs differ between the strong and weak agent.

Figure 1 illustrates how the individual stage Nash equilibrium changes with strengths using example parameters that match the experiment. The horizontal axis is the strength ratio, which equals the lower strength in the group divided by the higher strength in the group. A strength ratio of 1 means perfect symmetry between agents. Notice that the stage Nash equilibrium is the highest whenever agents are symmetric and decreases as agents become more asymmetric. The intuition is that higher inequality between agents discourages competition and puts downward pressure on contributions. The strong agent can achieve the same probability of winning with a lower contribution, so he finds it optimal to decrease contributions. The weak agent finds it optimal to decrease contributions as well. The greater the wedge between the strong and weak agent, the lower the equilibrium contribution level.

Importantly, strengths should be taken as given by both agents in the individual stage, and the equilibrium remains identical regardless of how strengths are determined. Therefore, whether strengths are randomly assigned or endogenously earned in a particular way should not affect the individual stage equilibrium as long as the budget constraint doesn't bind.

Remark 1 (Strength assignment)**.** *The individual stage Nash equilibrium depends only on the vector of strengths and not on how strengths are assigned.*

Moving backwards to the group stage and substituting individual stage continuation values conditional on winning, the expected payoff of agent ig in the group stage is

$$\pi_{ig}(x_{ig}, x_{jg}, X_{-g}) = w - x_{ig} + p_g(X_g, X_{-g})\, U_{ig}\big(f(x_{ig}), f(x_{jg})\big) \tag{4}$$

Agent ig chooses $x_{ig} \in [0, w]$ to maximize expected two-stage payoff. I first consider symmetric equilibrium group stage actions.

Lemma 2 (Symmetric interior equilibrium)**.** *Any symmetric interior equilibrium with $x^* > 0$ in the group stage satisfies*

$$1 = \frac{V}{32x^*} + \frac{V}{8}\frac{f'(x^*)}{f(x^*)}.$$

Proof. See Appendix A.2. □

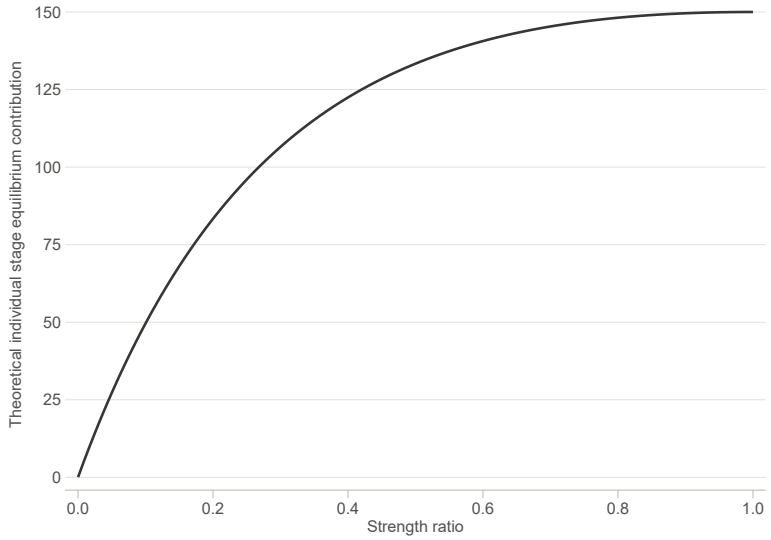


Figure 1: Theoretical Individual Stage Equilibria by Strength Ratio, Experimental Parameters

Notes: Theoretical individual stage Nash equilibria for given strength ratios using experimental parameters ($w = 300$, $V = 600$). Strength ratio equals the lower strength in the group divided by the higher strength in the group.

This condition highlights the two forces governing group stage investment. The first term reflects the effect of contributions on the probability of advancing to the individual stage, while the second term captures the effect of contributions on strength and the continuation value in the individual stage.

2.5.1 Exogenous Symmetric Strength

As a benchmark, suppose strength is exogenous and symmetric across all agents:

$$\theta_{ig} = \theta > 0 \qquad \forall\, i, g.$$

Then the individual stage (conditional on reaching it) is a standard symmetric two-player Tullock contest. By Lemma 1, the unique (interior) Nash equilibrium of the individual stage satisfies

$$y^*_{1g} = y^*_{2g} = \frac{V}{4}, \qquad p^*_{1g} = p^*_{2g} = \frac{1}{2}, \qquad U_{1g} = U_{2g} = \frac{V}{4},$$

where $U_{ig} = p^*_{ig}V - y^*_{ig}$ denotes the continuation payoff conditional on the group winning the group stage net of $r_{ig} = w - x_{ig}$.

Substituting $U_{ig} = V/4$ into the group stage payoff, agent ig's expected two-stage payoff in the group stage becomes

$$\pi_{ig}(x_{ig}, x_{jg}, X_{-g}) = p_g(X_g, X_{-g})\frac{V}{4} - x_{ig} + w, \tag{5}$$

where X_{-g} is the other group's total contributions.

Proposition 1 (Multiple subgame perfect equilibria with exogenous strength)**.** *Assume $\theta_{ig} = \theta > 0$ for all ig and that individual stage budget constraints do not bind. Then there is a continuum of subgame perfect equilibria such that*

$$X_a^* = X_b^* = \frac{V}{16},$$

and within each group, any split of the total group contribution is consistent with equilibrium:

$$x_{1g}^* \in \left[0, \frac{V}{16}\right], \qquad x_{2g}^* = \frac{V}{16} - x_{1g}^*.$$

In the individual stage, the unique equilibrium is $y_{1g}^* = y_{2g}^* = V/4$.

Proof. See Appendix A.2. □

2.5.2 Endogenous Strength

In the general model, the strength function f is unrestricted. However, without additional structure, the reduced group stage game may admit multiple equilibria, including asymmetric equilibria, which complicates both theoretical characterization and empirical predictions. To obtain sharp and tractable predictions, I restrict attention to the following class of strength functions:

$$f(x) = (x + \alpha)^\gamma, \qquad \alpha > 0,\ \gamma \in (-1, 1) \setminus \{0\}.$$

This class of functions is strictly positive and continuously differentiable on $[0, w]$, ensuring well-defined contest success functions and facilitating backward induction. When $\gamma \in (0, 1)$, strength is increasing in group stage contributions, while when $\gamma \in (-1, 0)$, strength is decreasing.

These strength functions permit tractable equilibrium characterization, allowing for closed-form solutions and transparent comparative statics. The experimental treatments correspond to two particular cases within this class: $f(x) = (x + 3)^{1/3}$, which features positive monotonically increasing concave strength, and $f(x) = (x + 3)^{-1/3}$, which features positive monotonically decreasing convex strength. These cases generate distinct incentives linking the group stage to the individual stage while remaining analytically tractable, and the equilibrium in each case is symmetric and unique.

Proposition 2 (Unique symmetric subgame perfect equilibrium with endogenous strength)**.** *Assume individual stage budget constraints do not bind and let*

$$f(x) = (x + \alpha)^\gamma, \qquad \alpha > 0,\ \gamma \in (-1, 1) \setminus \{0\}.$$

Then, as long as $\alpha > 2$, the two-stage game admits a unique symmetric subgame perfect equilibrium. In this equilibrium, group stage contributions are symmetric and equal across all agents,

$$x_{1a}^* = x_{2a}^* = x_{1b}^* = x_{2b}^* = x^* > 0.$$

The symmetric group stage contribution x^* is the unique solution in $(0, w]$ to

$$1 = \frac{V}{32x} + \frac{V}{8}\frac{f'(x)}{f(x)} = \frac{V}{32x} + \frac{V\gamma}{8(x + \alpha)}, \tag{6}$$

and is given in closed form by

$$x^* = \frac{V(1+4\gamma) - 32\alpha + \sqrt{(32\alpha - V(1+4\gamma))^2 + 128V\alpha}}{64}. \tag{7}$$

Individual stage contributions are given by the unique Nash equilibrium characterized in Lemma 1 for any vector of strengths.

Proof. See Appendix A.2. □

Next, I verify that no equilibrium exists involving asymmetric group stage contributions. Again, for tractability, I focus on the cases I study in the experiment. From this analysis, I can derive predictions and hypotheses for behavior in the experiment.

Corollary 1 (No asymmetric group stage equilibrium in special cases)**.** *Assume individual stage budget constraints do not bind and focus on specific cases in which $w = 300$, $V = 600$, and*

$$f(x) = (x+3)^\gamma, \qquad \gamma \in \left\{\tfrac{1}{3}, -\tfrac{1}{3}\right\}.$$

Then an interior subgame perfect equilibrium does not admit asymmetric group stage contributions. In equilibrium,

$$x^*_{1a} = x^*_{2a} = x^*_{1b} = x^*_{2b} = x^* > 0.$$

Proof. See Appendix A.2. □

Finally, I state the theoretical predictions that follow from the above results. These predictions offer testable hypotheses for comparing data against theory and across treatments. The following comparative statics guide the empirical analysis that follows in later sections.

Corollary 2 (Comparative statics across experimental treatments)**.** *Assume budget constraints do not bind. Consider the following treatments:*

1. ***Increasing strength (INC):*** $f(x) = (x+3)^{1/3}$.
2. ***Decreasing strength (DEC):*** $f(x) = (x+3)^{-1/3}$.
3. ***Symmetric strength (SYM):*** $f(x) = \theta > 0$.

Let x^*_T denote the symmetric equilibrium group stage contribution of each agent under treatment $T \in \{INC, SYM, DEC\}$, and let y^*_T denote the symmetric equilibrium individual stage contribution of each agent. Then:

1. ***Group stage contributions.***

$$x^*_{INC} > x^*_{SYM} > x^*_{DEC}.$$

2. ***Individual stage contributions.***

$$y^*_{INC} = y^*_{SYM} = y^*_{DEC}.$$

3. ***Total contributions.*** *Fix a as the winning group and let total expenditure be defined as*

$$TOT^*_T = X_a + y_{1a} + y_{2a}.$$

Then

$$TOT^*_{INC} > TOT^*_{SYM} > TOT^*_{DEC}.$$

Proof. Follows directly from Proposition 1 and Proposition 2. □

2.5.3 Exogenous Asymmetric Strength

Finally, I consider the case in which strength is exogenous but asymmetric. Suppose each agent's strength θ_{ig} is independently drawn from a continuous uniform distribution on $[1, 5]$. In the group stage, each agent observes only her own strength and knows the distribution from which all strengths are drawn. An agent does not observe the strength of her group mate. Once a group advances to the individual stage, both members observe realized strengths. Lemma 1 characterizes the unique equilibrium in the individual stage and the corresponding continuation payoffs. Conditional on group g winning the group stage, agent ig's continuation payoff is

$$U_{ig} = \frac{V\theta_{ig}^2}{(\theta_{ig} + \theta_{jg})^2}. \tag{8}$$

Differentiating with respect to own strength yields

$$\frac{\partial U_{ig}}{\partial \theta_{ig}} = \frac{2V\theta_{ig}\theta_{jg}}{(\theta_{ig} + \theta_{jg})^3} > 0, \tag{9}$$

which indicates that continuation payoffs in the individual stage increase in own strength.

Moving backwards to the group stage, an agent observes her own strength but not the strength of any other player. Let $x(\theta_{ig})$ denote a Bayesian equilibrium contribution strategy, where $x(\theta_{ig})$ specifies the group stage contribution of an agent with strength θ_{ig}. Consider agent $1a$ who observes θ_{1a} and chooses $x(\theta_{1a}) \in [0, w]$ to maximize

$$\pi_{1a} = w - x(\theta_{1a}) + \mathbb{E}\left[V\frac{x(\theta_{1a}) + x(\theta_{2a})}{x(\theta_{1a}) + x(\theta_{2a}) + x(\theta_{1b}) + x(\theta_{2b})}\frac{\theta_{1a}^2}{(\theta_{1a} + \theta_{2a})^2}\right], \tag{10}$$

where the expectation is taken over all possible draws of the unobserved strengths. Differentiating expected payoff with respect to $x(\theta_{1a})$ yields

$$1 = \mathbb{E}\left[V\frac{x(\theta_{1b}) + x(\theta_{2b})}{(x(\theta_{1a}) + x(\theta_{2a}) + x(\theta_{1b}) + x(\theta_{2b}))^2}\frac{\theta_{1a}^2}{(\theta_{1a} + \theta_{2a})^2}\right] \tag{11}$$

where the right hand side represents the marginal benefit of increasing group stage contribution.

I do not offer a closed-form characterization of the equilibrium contribution function $x(\theta_{ig})$ which specifies the optimal group stage contribution for every strength. Instead, I make one remark about the relationship between observed own strength and equilibrium group stage contribution to guide predictions about behavior in the experiment. Since continuation value increases in own strength, agents who draw a higher strength face a higher expected reward from winning the group stage and advancing to the individual stage. Consequently, equilibrium group stage contribution increases in observed own strength.

Remark 2 (Group stage contributions and randomly assigned strengths)**.** *When strength is randomly drawn for each agent from a uniform distribution, group stage contributions are strictly increasing in strength. That is, for $\theta', \theta \sim U[1, 5]$ with $\theta' > \theta$,*

$$x(\theta') > x(\theta). \tag{12}$$

Proof. See Appendix A.2. □

Essentially, higher strength translates to higher individual stage continuation value and higher marginal benefit of increasing group stage contribution. Therefore, group stage contribution increases in strength.

3 Experimental Design

I conducted a laboratory experiment in which subjects played the two-stage contest outlined above. The first stage was called the group stage and the second stage was called the individual stage. I employed a between-subjects design across four treatments where I varied the relationship between group stage contribution and individual strength. In the **Increasing** treatment, strength increased in group stage contribution. In the **Decreasing** treatment, strength decreased in group stage contribution. In the baseline **Symmetric** treatment, strength was exogenously given and symmetric. Finally, I ran an additional **Random** treatment in which strength was exogenously given and randomly drawn for each subject from a uniform distribution on the interval [1,5].[7] Table 1 summarizes the experimental sessions, treatments, and total participants. I ran a total of 12 sessions consisting of 16 subjects each for a total of 192 subjects (55% female). Each session took place in the XS/FS Lab at Florida State University and lasted at most 90 minutes. Each subject participated in exactly one session and had no prior experience with related experiments. I implemented the experiment using z-Tree (Fischbacher, 2007) and recruited subjects in ORSEE (Greiner, 2015). Subjects earned $19.86 on average, including a $7 show-up fee.

Table 1: Summary of Experimental Treatments

Treatment	**Sessions**	**Participants**
Increasing	3	48
Decreasing	3	48
Symmetric	3	48
Random	3	48
	12	192

In each session, subjects first watched a video recording of the experimenter reading over the instructions.[8] Before proceeding to the decision rounds, subjects completed a comprehension check quiz and participated in an unpaid 3-minute practice module to get familiar with the experiment interface. Next, subjects completed the main incentivized part of the experiment involving a sequence of decision rounds. Finally, subjects answered a survey consisting of unincentivized questions on gender and risk preferences as well as open-ended questions about how they made their decisions.

In the main part of the experiment, subjects played 20 repeated rounds of the two-stage contest. Each round consisted of the group stage followed by the individual stage. I created match groups of 8 subjects each and explained that subjects would only interact with members

[7] This treatment was not in the original preregistration. It was introduced after observing initial data from the first three treatments.

[8] A copy of the instructions for **Increasing** can be found in Appendix C. Instructions for the other three treatments are available upon request.

of their match groups. I randomly re-paired group mates and rematched groups within match groups between rounds. At the beginning of each decision round, each participant received an endowment of $w = 300$ points which they could allocate over both stages.

In the group stage, two groups of two subjects each participated in the group contest outlined in section 2. Groups competed only for the right to earn a prize in the next stage. Each individual chose a group stage contribution from their endowment by typing a number in a box and pressing submit. A group's contribution was the sum of the group stage contributions of both members. Whatever a subject decided not to contribute in this stage remained with her for the next stage.

Subjects in each treatment understood if and how group stage contributions affected their strengths. In **Increasing** and **Decreasing**, subjects were given a calculator to check the strengths that would result from various group stage contributions. They were free to use this calculator as much as they wanted, and there was no time limit on submitting a final decision. Once a subject submitted her group stage contribution, she immediately saw her own strength appear on screen. In **Random**, subjects understood that everyone's strength was drawn from a uniform distribution on the interval [1,5]. Each subject saw her own strength on screen at the beginning of the group stage but did not observe her group mate's strength until the individual stage.[9]

Once all group stage contributions had been submitted, subjects immediately progressed to the individual stage. Importantly, all subjects advanced without learning the outcome of the group stage. In other words, both winning groups and losing groups completed the individual stage. Subjects were instructed to participate in the individual stage as if their group had won. They understood that their decisions in the individual stage would only affect their payoffs if their group actually won.

At the beginning of the individual stage, all subjects saw their group stage contributions and their group mate's contributions as well as the corresponding remaining endowments. They also observed the other group's total contributions and the probability that each group won. At this time, in **Increasing**, **Decreasing**, and **Random**, each subject also learned her group mate's strength.

In the individual stage, subjects participated in the contest described in the model. The two group mates from the previous stage competed for a prize of $V = 600$ points. Each subject selected an individual stage contribution from her remaining endowment by typing a number. Individual stage contributions were then multiplied by strength, and multiplied contributions determined each subject's probability of winning the individual stage. Subjects were provided an on-screen calculator to help them calculate their multiplied contributions before submitting a final decision.

After all subjects submitted individual stage contributions, all decisions and corresponding multiplied contributions were revealed. Everyone then learned the outcome of the round including the results of each stage and the round payoffs. Subjects who lost in the group stage earned their endowment minus only their group stage contribution. Subjects who won in the group stage but lost in the individual stage earned their endowment minus their group stage contribution minus their individual stage contribution. Subjects who won in both stages earned an additional 600 points. Before each session, I used a random number generator to randomly select 4 out of 20 rounds for payment and placed the selected rounds in a sealed envelope at the

[9]Revealing only own strength in the group stage most closely aligns with the information structure of the endogenous strength treatments in which subjects effectively choose their own strengths at the time of making a group stage contribution decision.

Table 2: Summary Statistics, Last 10 Rounds

	Group Stage		Individual Stage	
Treatment	Mean	Prediction	Mean	Prediction
Increasing	60.35	42.09	121.03	150.00
	[39.24, 86.16]		[101.98, 138.27]	
Decreasing	17.48	4.19	160.73	150.00
	[3.75, 37.92]		[123.16, 194.17]	
Symmetric	32.82	18.75	174.10	150.00
	[22.80, 41.90]		[152.13, 188.44]	
Random	52.04	27.55	125.86	143.25
	[35.67, 67.13]		[109.03, 152.95]	

Notes: Mean contributions by stage and treatment with theoretical predictions. Data from last 10 rounds. 95% wild cluster bootstrap confidence intervals in brackets.

front of the lab. At the end of the session, I revealed the chosen rounds. Points were converted to USD for payment at a rate of 1 point to \$0.01.

Below, I list testable hypotheses that follow directly from the theoretical analysis in section 2. Since multiple equilibria exist in **Symmetric**, I focus on the symmetric equilibrium for predictions and comparisons.[10]

Hypothesis 1 (Group Stage)**.** *Group stage contributions are highest in* ***Increasing****, next highest in* ***Symmetric*** *and lowest in* ***Decreasing****.* $x^*_{INC} > x^*_{SYM} > x^*_{DEC}$*. In* ***Random****, group stage contributions are increasing in own strength.*

Hypothesis 2 (Individual Stage)**.** *Individual stage contributions are equivalent across* ***Increasing****,* ***Symmetric****, and* ***Decreasing****.* $y^*_{INC} = y^*_{SYM} = y^*_{DEC}$.

Hypothesis 3 (Total Contributions)**.** *Total contributions are highest in* ***Increasing****, next highest in* ***Symmetric*** *and lowest in* ***Decreasing****.* $TOT^*_{INC} > TOT^*_{SYM} > TOT^*_{DEC}$.

In theory, strengths should be taken as given once the individual stage is reached. Subjects should only care about the strengths themselves and not how those strengths came about. Whether strengths were exogenously assigned or endogenously determined in a particular way should not affect decisions. Therefore, I propose an additional null hypothesis that individual stage behavior should be the same across treatments when strengths are the same.

Hypothesis 4 (Strength Assignment)**.** *For a given vector of strengths, individual stage contributions should not vary across treatments.*[11]

4 Results

I analyze aggregate results on group stage contributions and individual stage contributions from 192 subjects over 12 sessions and four treatments. Since I randomly rematch within match

[10] The prediction for group stage contributions in this treatment can also be interpreted as the average equilibrium contributions.

[11] This hypothesis was not included in the original preregistration.

groups each round, I conduct non-parametric tests on match group averages as independent observations. I also employ linear regression analysis. Due to the small number of independent clusters, I report 95% wild cluster bootstrap confidence intervals on regression coefficients, and I conduct all statistical inference using p-values computed with the wild cluster bootstrap method (Cameron et al., 2008). I focus my main analysis on the last 10 rounds of the data.[12]

Table 2 reports summary statistics and theoretical predictions for contributions in each stage and each treatment over the last 10 rounds. Predictions in **Increasing**, **Decreasing**, and **Symmetric** are derived from subgame perfect equilibria. For **Symmetric**, multiple equilibria exist, but I focus on the symmetric equilibrium. The prediction for **Random** is a benchmark derived from the mean strength draws given the distribution of strength used in the experiment. Data from **Random** will primarily be used to study individual stage contributions in a later section.

4.1 Group Stage Contributions

Figure 2 depicts mean contributions by round in the group stage. It also includes the theoretical predictions for each treatment. Substantial adjustments take place over the first 10 rounds after which behavior stabilizes considerably. In figure 7 in Appendix B, I also plot the empirical CDF of contributions in the group stage for each treatment for the last 10 rounds.

In the group stage, contributions exceed the equilibrium predictions on average for each treatment.[13] However, overinvestment diminishes over the course of 20 repeated rounds (see figure 2).

Variations in group stage contributions across treatments follow the pattern predicted by the theory and in Hypothesis 1. According to pairwise Wilcoxon rank-sum tests on match group averages, contributions are significantly higher in **Increasing** compared to each of the other treatments except **Random**. Contributions in **Symmetric** exceed contributions in **Decreasing**.[14] It appears subjects in each treatment anticipate the effect of group stage contributions on individual strength. As predicted by theory, group stage contributions in **Random** increase in own strength ($p = 0.03$; see table 6 in Appendix B).

Result 1 (Group stage contributions)**.** *Subjects in all treatments overinvest in the group stage relative to subgame perfect equilibrium predictions. Consistent with the theory and Hypothesis 1, group stage contributions are highest when the strength function is increasing and lowest when it is decreasing. As predicted, group stage contributions in* ***Random*** *increase in strength.*

4.2 Individual Stage Contributions

Figure 3 depicts mean contributions by round in the individual stage along with theoretical predictions by treatment. As in the group stage, behavior in this stage levels off after the first 10 rounds. In figure 8 in Appendix B, I also plot the empirical CDF of contributions in the individual stage for each treatment over the last 10 rounds.

[12] Table 5 in Appendix B shows summary statistics using data from all rounds. Other results using data from all rounds are available upon request.

[13] Wald tests comparing coefficients in linear regression to predictions: INC, $p = 0.11$; DEC, $p = 0.06$; SYM, $p = 0.01$; $RAND$, $p = 0.01$

[14] Wilcoxon rank-sum tests: INC vs. DEC, $p = 0.009$; INC vs. SYM, $p = 0.04$; INC vs. $RAND$, $p = 0.59$; DEC vs. SYM, $p = 0.09$; DEC vs. $RAND$, $p = 0.009$; SYM vs. $RAND$, $p = 0.04$

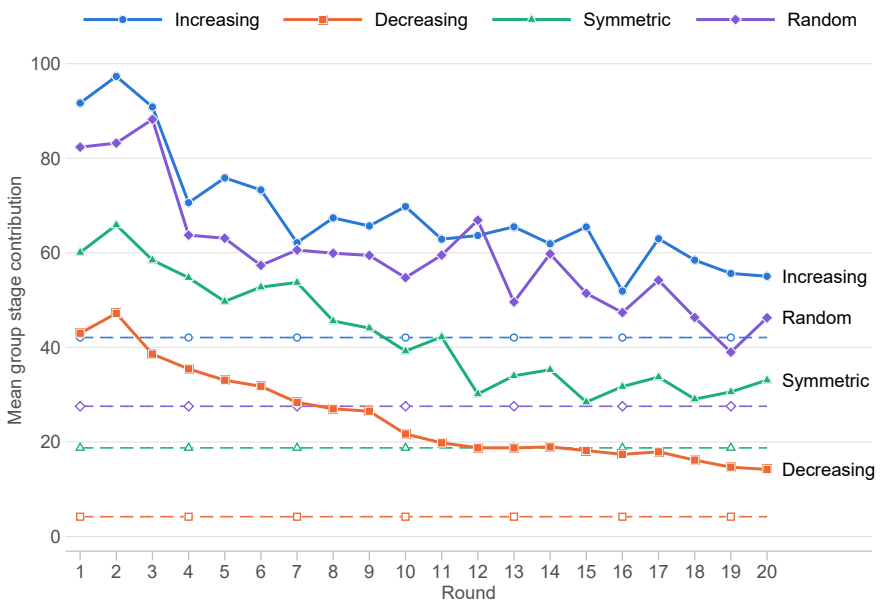


Figure 2: Group Stage Contributions by Round

Notes: Mean group stage contributions in each round by treatment. Dashed lines with markers show theoretical predictions for each corresponding treatment.

In the individual stage, the subgame perfect equilibrium in each treatment predicts a contribution of 150 points. Contrary to the typical result found in individual Tullock contest experiments, I observe little overinvestment in this stage relative to the equilibrium benchmark. Focusing on the last 10 rounds, participants only significantly overinvest on average in **Symmetric**. Contributions in **Increasing** actually fall significantly below the equilibrium prediction on average.[15]

Of course, a better benchmark for testing overinvestment in the individual stage is the realized Nash equilibrium for each group. Along the equilibrium path, group stage contributions are symmetric. Off-equilibrium-path group stage contributions may induce asymmetry in the individual stage which dampens competition and puts downward pressure on the unique symmetric individual stage Nash equilibrium (see figure 1).

I determine the realized individual stage Nash equilibrium for each group of two subjects given their group stage contributions and corresponding strengths.[16] I then calculate percent deviations from the stage Nash equilibrium. In figure 9 in Appendix B, I plot mean percent deviations from stage Nash equilibrium by round for each treatment.[17] I find that the mean

[15]Wald tests comparing coefficients in linear regression to predictions: INC, $p = 0.01$; DEC, $p = 0.44$; SYM, $p = 0.04$; $RAND$, $p = 0.11$

[16]Figure 10 in Appendix B plots the raw data on the realized strength ratio and corresponding stage Nash equilibrium for each group.

[17]I exclude contests in which at least one subject contributes the entire 300 point endowment in the group stage. In this case, the contestant who contributed everything must choose zero in the individual stage. The optimal best response for the other contestant is to contribute exactly one point. If this contestant submits something substantially larger than one, then the percent deviation is extreme and greatly affects the mean percent deviation

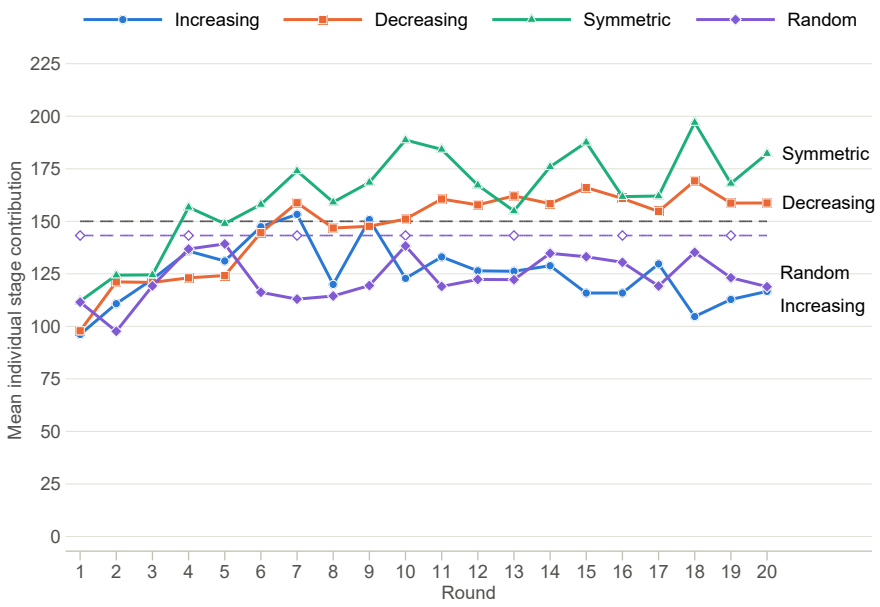


Figure 3: Individual Stage Contributions by Round

Notes: Mean individual stage contributions in each round by treatment. Flat black dashed line shows subgame perfect equilibrium prediction for Increasing, Decreasing, and Symmetric. Dashed purple line with diamonds shows theoretical prediction for Random.

percent deviation in **Symmetric** is 16.27% above the stage Nash equilibrium and significantly greater than 0. In **Increasing** and **Random**, mean percent deviation is negative. Mean individual stage contribution in **Increasing** is 11.99% below the stage Nash equilibrium, but the difference from 0 is not significant.[18] Many laboratory experiments involve subjects playing one-shot or repeated contests in isolation. Perhaps framing contests in dynamic environments that are more complex and realistic deters overinvestment. I also find that percent deviations are at least marginally significantly lower in **Increasing** compared to **Decreasing** and **Symmetric** but no different compared to **Random**.[19]

I next compare mean individual stage contributions across treatments. According to the theory, despite differences in group stage contribution levels, individual stage contributions should be the same across treatments. Contrary to the theoretical predictions and Hypothesis 2, I find significant differences on average across treatments. Mean contributions in **Increasing** and **Random** are significantly below those in **Decreasing** and **Symmetric**. I find no significant difference between **Decreasing** and **Symmetric** or between **Increasing** and **Random**.[20]

calculations. Therefore, for this analysis, I drop cases in which subjects contribute everything in the group stage which only occurs twice in the last 10 rounds.

[18] Wald tests comparing coefficients in linear regressions to predictions: INC, $p = 0.14$; DEC, $p = 0.25$; SYM, $p = 0.04$; $RAND$, $p = 0.24$

[19] Wilcoxon rank-sum tests: INC vs. DEC, $p = 0.09$; INC vs. SYM, $p = 0.02$; INC vs. $RAND$, $p = 0.59$; DEC vs. SYM, $p = 0.94$; DEC vs. $RAND$, $p = 0.06$; SYM vs. $RAND$, $p = 0.009$

[20] Wilcoxon rank-sum tests: INC vs. DEC, $p = 0.06$; INC vs. SYM, $p = 0.02$; INC vs. $RAND$, $p = 0.70$; DEC vs. SYM, $p = 0.70$; DEC vs. $RAND$, $p = 0.06$; SYM vs. $RAND$, $p = 0.009$

Result 2 (Individual stage contributions)**.** *In the individual stage, relative to the subgame perfect equilibrium or the realized Nash equilibrium, subjects do not overinvest on average in the endogenous strength treatments. Contrary to the theory and Hypothesis 2, individual stage contributions are lower when the strength function is increasing versus when it is decreasing.*

Recall that in my experimental design, the individual stage is set up in such a way that the results are robust to a variety of models of preferences and behavior including risk attitudes, social preferences, bounded rationality, joy of winning, confusion, norms, and many others. Due to the nature of the individual stage across all treatments, differences in contributions cannot be rationalized by these common explanations. With this in mind, later sections explore these differences in more detail.

The first two results analyze contributions in each stage in isolation. I now consider aggregate contributions over both stages before returning to the individual stage for additional analysis.

4.3 Total Contributions over Both Stages

So far, I observe significant differences between contributions in each stage in the endogenous strength treatments. Next, I consider aggregate contributions over both stages within a two-subject group. I calculate this statistic by summing all contributions made over both stages for each group in a given round. This statistic serves as a measure of market efficiency or rent dissipation.[21] Figure 4 plots mean within-group total contributions for each treatment. The figure also includes equilibrium predictions and 95% wild cluster bootstrap confidence intervals around estimates.[22] Theoretically, any differences across treatments in within-group total contributions should be solely driven by differences in group stage contributions. Pairwise Wilcoxon rank-sum tests show no significant differences between treatments except for a marginally significant difference when comparing **Symmetric** and **Random**.[23] In particular, contrary to the theory and Hypothesis 3, no significant difference emerges in contributions between **Increasing** and **Decreasing**. Compared to the equilibrium predictions, within-group total contributions are higher than expected in **Symmetric** and **Decreasing** (significantly so in **Symmetric**) but lower than expected in **Increasing** on average.[24] Ultimately, the results show that the differences in contributions within each stage go in opposite directions and cancel each other out so that no significant differences exist in aggregate contributions over both stages.

Result 3 (Total contributions over both stages)**.** *Contrary to the theory and Hypothesis 3, total contributions over both stages do not differ significantly between treatments with endogenous strength. Varying the relationship between group stage contribution and individual strength only affects how contributions are allocated over the two stages.*

In conjunction with Result 1 and Result 2, Result 3 summarizes the first key contribution of the paper which offers potential implications for organizational and industrial policy. In the end, whether group stage contributions positively or negatively affect an individual's position

[21] In figure 11 and table 8 in Appendix B, I consider expected payoffs as an alternative measure.

[22] Mean estimates and confidence intervals are located in table 7 in Appendix B.

[23] Wilcoxon rank-sum tests: INC vs. DEC, $p = 0.94$; INC vs. SYM, $p = 0.24$; INC vs. $RAND$, $p = 1.00$; DEC vs. SYM, $p = 0.13$; DEC vs. $RAND$, $p = 0.82$; SYM vs. $RAND$, $p = 0.09$

[24] Wald tests comparing coefficients in linear regression to predictions: INC, $p = 0.46$; DEC, $p = 0.14$; SYM, $p = 0.008$; $RAND$, $p = 0.68$

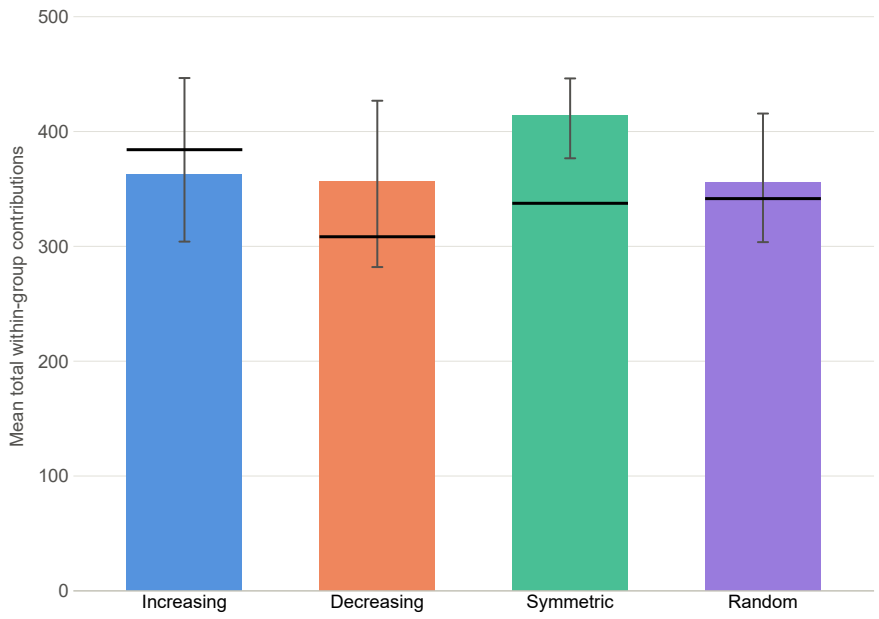


Figure 4: Within-Group Total Contributions, Last 10 Rounds

Notes: Mean total within-group contributions over both stages by treatment. Black lines show theoretical predictions. Data from last 10 rounds. Error bars represent 95% wild cluster bootstrap confidence intervals.

in future internal conflict, total effort expenditure remains the same on average. However, the relationship between group effort and individual strength does substantially affect the timing and nature of effort expenditure. Specifically, when strength is increasing compared to when it is decreasing, group effort is higher and individual effort is lower.

If a manager or social planner cares only about aggregate effort expenditure, the implicit corporate culture or explicit incentive structure that links group competition and individual conflict does not matter. However, if it is optimal to promote either group effort or individual effort and mitigate the other, the results from this experiment provide useful insight. For example, if group efforts are considered productive and individual efforts are considered wasteful, an increasing strength function would be preferred. By incentivizing higher group contributions through the promise of higher strength in internal competition, the principal actually discourages infighting without sacrificing collective effort. However, if only individual efforts are productive, then a decreasing strength function would be preferred to disincentivize group effort and heighten individual competition. Ultimately, the results of this paper suggest that an optimal organizational or industrial policy may depend on whether collective or individual effort is considered productive versus wasteful. If the relationship between contribution to group effort and strength is purely an artifact of a particular environment and not up to the discretion of the principal, then the results still provide descriptive information about how efforts are expended in different real-world settings.

For the next main set of results, I focus on the individual stage and explore how behavior varies across treatments with different relationships between the group stage and individual

Table 3: Individual Stage Contributions and Controls, Last 10 Rounds

	(1)	(2)	(3)	(4)	(5)	(6)
Increasing	-4.829	-6.350	-4.450	-8.634	-3.576	-51.697
	[-31.387 19.975]	[-31.929 17.660]	[-31.411 20.491]	[-33.991 15.587]	[-31.186 26.280]	[-135.954 37.501]
Decreasing	34.871*	41.201**	33.294*	34.380*	35.895*	75.878
	[-2.723 71.077]	[3.483 79.353]	[-3.365 70.433]	[-2.045 72.866]	[-1.789 75.906]	[-52.531 198.980]
Symmetric	48.246***	51.766***	47.369***			
	[19.544 73.202]	[21.250 78.808]	[17.781 74.139]			
Group Stage Contribution		0.183*	-0.046	0.188*	0.185*	0.147
		[-0.013 0.451]	[-0.259 0.223]	[-0.022 0.485]	[-0.012 0.472]	[-0.033 0.403]
Group Probability of Winning			96.509***			
			[62.828 129.553]			
Strength Ratio				69.821**	331.966**	57.123
				[13.737 123.237]	[19.044 687.425]	[-56.552 142.830]
Strength Ratio Squared					-199.366	
					[-463.392 34.228]	
Increasing × Strength Ratio						64.599
						[-51.260 188.068]
Decreasing × Strength Ratio						-55.820
						[-204.688 101.347]
Constant	125.856***	116.325***	79.976***	70.944***	-7.192	81.314**
	[108.984 153.217]	[92.585 144.865]	[53.055 108.075]	[21.433 118.105]	[-127.387 100.459]	[10.741 152.505]
Observations	1920	1920	1920	1440	1440	1440
Clusters	24	24	24	18	18	18

Notes: Individual stage contributions regressed on treatment dummies and controls. Random treatment omitted. Symmetric treatment not included in specifications (4)-(6). Strength ratio equals the lower strength in the group divided by the higher strength in the group. Data from last 10 rounds. 95% wild cluster bootstrap confidence intervals in brackets. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

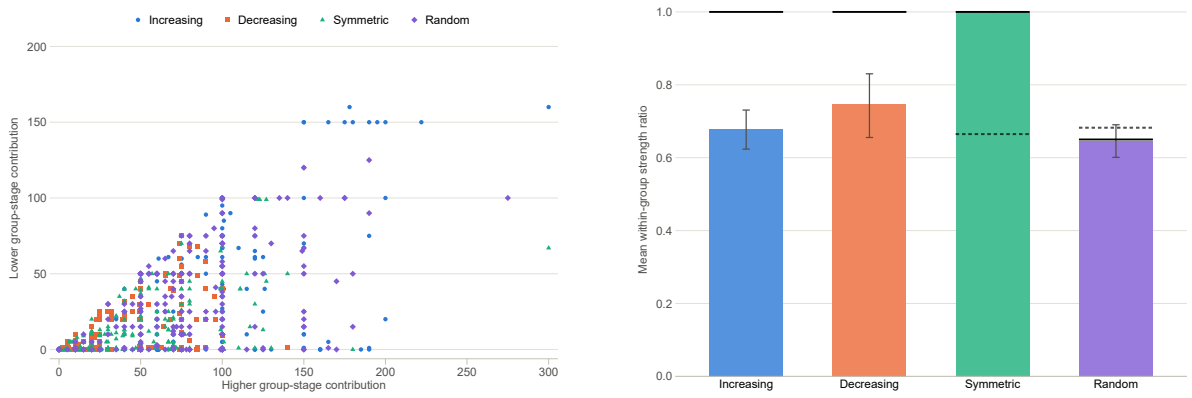
stage.[25]

4.4 Behavior in the Individual Stage

In this section, I more closely investigate differences in contributions across treatments in the individual stage. Recall Hypothesis 4, which predicts that the strength ratio between contestants fully determines equilibrium contributions, and that how strengths are assigned should not affect behavior. In the analyses that follow, I test whether individuals respond differently to asymmetry depending on how asymmetry arises.[26]

[25] In tables 9 and 10 in Appendix B, I analyze the effects of previous round history on group stage and individual stage contributions. I include lags for previous round contributions and outcomes. I find that group stage contributions increase significantly in previous-round own group stage contributions for all treatments and in winning the prize only for **Increasing**. Individual stage contributions also increase significantly in previous-round contributions. Individual stage contributions decrease if the group won in the last round but the individual didn't win the prize.

[26] Recall that in my design, I use a "strategy method" approach. I withhold the outcome of the group stage until the end of each round, so all groups participate in the individual stage. However, the individual stage only affects payoffs for the group that wins. After submitting group stage contributions, subjects do see the probability that their group wins. There is a possibility that this could influence behavior in the individual stage. In figure 12 in Appendix B, I plot a positive relationship between the sum of individual stage contributions and the group probability of winning for each treatment. Individuals internalize the likelihood that the individual stage will affect their round payoffs and behave more competitively. This is consistent and similar across all treatments. I rerun the results of the following section on only the groups that actually win, only the groups that have a probability of winning greater than 0.5, and only the groups that have a probability of winning greater than 0.33. These results are available upon request. While precision and hypothesis test results change occasionally compared to studying the full sample, most of the qualitative results remain the same albeit with a higher level of individual stage contributions across the board. Therefore, I utilize the full sample for the following analyses.



(a) Group Coordination

(b) Strength Ratio

Figure 5: Group Coordination and Asymmetric Strengths, Last 10 Rounds

Notes: Panel (a): Lower group stage contribution over higher group stage contribution for each group by treatment. Each point represents one group. Data from last 10 rounds. Panel (b): Mean strength ratio by treatment. Black lines show theoretical predictions. Dashed lines show mean strength ratio in exogenous strength treatments if strength were endogenized. Data from last 10 rounds. Error bars represent 95% wild cluster bootstrap confidence intervals.

4.4.1 Within-Group Coordination and Asymmetry

Asymmetry in the individual stage arises when group mates select different group stage contributions or are randomly assigned different strengths. I now analyze the extent to which group members coordinate contributions in the group stage. Figure 5a shows a scatter plot in which each dot represents one group of two subjects. Each point captures the relationship between the lower group stage contribution to the higher group stage contribution within the group. Points along the diagonal represent perfect coordination in which both group members choose the same contribution level. Points along the horizontal axis represent perfect free-riding in which one group member contributes something positive while the other contributes nothing. Points in between represent partial free-riding in which both group members contribute something positive but one out-contributes the other. In the treatments with endogenous strength, the theory predicts perfect coordination. In **Symmetric**, many equilibria exist involving asymmetric contributions. The scatter plot reveals that, while some perfect coordination and perfect free-riding exists, most groups involve group members choosing different positive group stage contributions. The same pattern arises regardless of treatment.

Figure 5b shows how differences in group stage contributions can translate to individual stage asymmetry. I plot the mean within-group strength ratio for the individual stage in the last 10 rounds. Recall that strength ratio is the ratio of the group's minimum strength to the group's maximum strength. Mechanically, in **Symmetric**, since both group members are assigned a strength of 1 in the individual stage, strength ratio equals 1.

Theory predicts equal strengths in the endogenous strength treatments. I instead observe that in both endogenous strength treatments, the weaker group member is about 2/3 as strong as the stronger group member upon entering the individual stage. This corresponds with the average draw of strengths in **Random** so that all treatments involving asymmetry register about the same strength ratio on average. The strength ratio is slightly higher in **Decreasing**

compared to **Increasing** and **Random**, but the difference is only significant when compared to **Random**.[27] In figures 13, 14, and 15 in Appendix B, I plot histograms of strength ratios by treatment which reveal slightly more mass at lower strength ratios in **Increasing** even though there is no difference on average.

In figure 5b, I also plot a dashed line for each exogenous strength treatment representing the strength ratio that would've resulted if strength were endogenous. This reinforces the idea that we find similar degrees of miscoordination in the group stage across all treatments.

4.4.2 Asymmetric Contests

Once subjects arrive in the individual stage and face an asymmetric contest, it should not matter how they got there. In theory, a subject who is twice as strong as her group mate shouldn't behave differently whether she is stronger due to high group stage effort, low group stage effort, or a random draw. Any differences in contributions should be explained only by differences in the degree of asymmetry between subjects within a group. Unexplained variation must be due to some behavioral biases regarding how asymmetry arises.[28]

To better understand differences in individual stage behavior and especially in asymmetric individual stage contests, I now test the robustness of the treatment differences in contributions to various regression specifications. Table 3 shows the results for six different specifications regressing individual stage contributions on treatment dummies and various control variables. In all specifications, **Random** is the excluded category.

The first specification is the naive model without any controls. Comparing mean individual stage contributions via regression analysis yields the same conclusions as the nonparametric tests above.[29] The second specification controls for group stage contribution. Since endowment is linked over both stages, it is important to consider whether lower individual stage contributions in **Increasing** are simply the result of higher group stage contributions and lower remaining endowments. Table 3 shows how results are robust to controlling for group stage contributions. Group stage contributions appear to have a significant positive effect, but the sign flips and the effect becomes insignificant when also controlling for group probability of winning (specification (3)). All in all, treatment differences remain robust, suggesting that a pure wealth effect isn't driving differences.[30]

[27] Wilcoxon rank-sum test: INC vs. DEC, $p = 0.18$; INC vs. $RAND$, $p = 0.31$; DEC vs. $RAND$, $p = 0.03$

[28] Strictly speaking, in the endogenous strength treatments, there is, intentionally and mechanically, no random variation in strengths or measures of asymmetry. Subjects in these treatments certainly select into their strengths. However, once the individual stage arises, group stage behavior is sunk, and the realized strengths should in theory be treated no differently than if they were randomly assigned. Any differences that arise suggest some selection effects or other behavioral effects of endogenously assigning strengths. These biases are exactly what the following analyses seek to explore.

[29] Wald tests comparing coefficients in linear regression: INC vs DEC, $p = 0.03$; INC vs SYM, $p = 0.002$; INC vs. $RAND$, $p = 0.68$; DEC vs. SYM, $p = 0.43$; DEC vs. $RAND$, $p = 0.07$; SYM vs. $RAND$, $p = 0.005$

[30] To investigate this further, in table 11 in Appendix B, I regress individual stage contributions on group stage contributions interacted with treatment dummies. Individual stage contributions actually increase slightly in group stage contributions for every treatment except **Decreasing**, but the effects are marginally significantly different from null only for **Increasing** (Wald tests comparing coefficients in linear regression to predictions: INC, $p = 0.09$; DEC, $p = 0.51$; SYM, $p = 0.99$; $RAND$, $p = 0.30$). For a sharper test, a pure wealth effect might predict a one unit decrease in individual stage contributions for every one unit increase in group stage contributions. I find that the coefficient on group stage contriution is significantly different from -1 for all treatments (Wald tests comparing coefficients in linear regression to predictions: INC, $p = 0.01$; DEC, $p = 0.06$; SYM, $p = 0.01$; $RAND$, $p = 0.002$). There are also no significant differences in the effects between treatments

Specifications (4)–(6) control for strength ratio as a measure of asymmetry between contestants. These specifications drop data from **Symmetric** and focus solely on treatments where asymmetric strengths can arise. Strength ratio as defined above is calculated for each group as the minimum strength divided by the maximum strength. Importantly, the strength ratio isolates the degree of asymmetry in the contest and ignores which player is stronger.[31] Specification (6) includes interaction terms between treatment dummies and strength ratio to study potential slope differences across treatments.

The results are robust to controlling for strength ratio. Contrary to theory, given a particular degree of asymmetry, there are still differences in individual stage contributions across treatments. In particular, contributions remain significantly higher in **Decreasing** compared to **Increasing**. In both endogenous strength treatments, a gap in strengths arises due to differences in contributions to group effort. What matters is exactly what implies higher strength. When helping the group leads to high strength, competition is discouraged. Following the pattern predicted by theory and evidence from previous research, asymmetry dampens competition. It seems competitors in this case accept that the higher group contributor is entitled in some way to the higher likelihood of winning the prize. I see similar results when strengths are assigned randomly. On the other hand, when the shirker in the group attains higher strength, players behave more competitively. The level of contributions doesn't decrease significantly from the level of contributions in the case of symmetric players. For some reason, contrary to theoretical predictions, asymmetry does not discourage effort in this case. Players appear to reject that the stronger subject has earned the right to the prize. In summary, subjects respond differently to a particular degree of asymmetry depending on how that asymmetry arises. This warrants further investigation into what drives the unexpected differences we observe.

Result 4a (Strength assignment)**.** *Contrary to the theory and Hypothesis 4, individual stage contributions vary across treatments for a given strength ratio.*

4.4.3 Strength Ratio

Recall that theory predicts that greater asymmetry in this form of contest discourages competition and reduces equilibrium contributions. To study this and compare across treatments, I regress individual stage contributions on treatment dummies interacted with strength ratio in specification (6) of table 3.

I compare coefficients on strength ratio to 0,[32] and I compare across treatments.[33] For both **Increasing** and **Random**, a higher strength ratio (greater symmetry) is positively corre-

(Wald tests comparing coefficients in linear regression: INC vs. DEC, $p = 0.18$; INC vs. SYM, $p = 0.28$; INC vs. $RAND$, $p = 0.37$; DEC vs. SYM, $p = 0.51$; DEC vs. $RAND$, $p = 0.29$; SYM vs. $RAND$, $p = 0.68$). Combining these results with the results from table 3 suggests that mere differences in wealth don't drive the differences in individual stage contributions. Figure 6 provides even more evidence.

[31] Here, I intentionally separate the effects of whether a player is strong or weak from the effects of the degree of asymmetry. In the following subsections, I consider each one in turn. In tables 16 and 17 in Appendix B, I offer an alternative approach to try to isolate the effects of asymmetry and relative position in one regression. I regress individual stage contributions on strength ratio and a dummy for whether the player is stronger or weaker and report the slope coefficients on strength ratio for each treatment-type combination. In doing so, I allow the effects of asymmetry to differ between stronger and weaker players and across treatments.

[32] Wald tests comparing coefficients in linear regression to predictions: INC, $p = 0.03$; DEC, $p = 0.99$; $RAND$, $p = 0.22$

[33] Wald tests comparing coefficients in linear regression: INC vs. DEC, $p = 0.11$; INC vs. $RAND$, $p = 0.28$; DEC vs. $RAND$, $p = 0.45$

Table 4: Individual Stage Contributions by Treatment and Type, Last 10 Rounds

Type	Increasing	Decreasing	Symmetric	Random
Equal	146.74	133.60	174.10	126.14
	[71.29,178.82]	[96.15,182.28]	[151.58,188.34]	[84.37,159.25]
Strong	133.20	181.69	.	139.19
	[105.95,168.52]	[118.02,236.77]		[115.63,165.16]
Weak	99.78	154.78	.	112.46
	[73.93,131.66]	[111.80,206.29]		[87.90,140.90]

Notes: Mean individual stage contributions by treatment and type. Estimates from regressing individual stage contribution on treatment dummy and type dummy. Data from last 10 rounds. 95% wild cluster bootstrap confidence intervals in brackets.

lated with individual stage contributions. The effect is significant in **Increasing**. This pattern matches the theoretical prediction that greater parity between players induces more fierce competition. The effect of strength ratio goes in the opposite direction in **Decreasing** relative to the baseline **Random**, but the overall effect isn't significantly different from 0.

Result 4b (Discouragement effect)**.** *In **Increasing**, as the strength ratio increases and subjects become more evenly matched, contributions increase.*

4.4.4 Strong vs. Weak Types

Next, I set aside the degree of strength asymmetry and focus on the effect of being stronger or weaker relative to group mate.[34] I calculate mean individual stage contributions and mean percent deviations from stage Nash equilibrium broken down by treatment and type (equal, strong, or weak). Table 4 shows mean contributions for each category and table 14 in Appendix B shows mean percent deviation. In these tables, equality is defined broadly as being within a range based on the absolute strength values in each treatment (within 0.2 in **Increasing** and **Random** and within 0.02 in **Decreasing**). In tables 13 and 15 in Appendix B, I consider only exact equality, and the qualitative results do not change substantially.

I start by comparing contributions between strong and weak types within each treatment. Theory predicts the same contribution level regardless of type, and previous experimental evidence supports this claim. In **Random**, I find that the strong player contributes significantly more on average than the weak player. This pattern also emerges in **Increasing** and **Decreasing**, but the differences are not significant.[35]

To compare within-type differences across treatments, I consider the share of individual stage contributions made by the strong type. In figure 6, I plot the stronger player's share of

[34] I can compare this analysis to previous research on asymmetric contests (particularly Fonseca (2009)) and explore whether results differ when asymmetry arises endogenously. Fonseca (2009) compares symmetric and asymmetric contests where strength is randomly assigned for each player. Each treatment involves either a symmetric or an asymmetric format, and subjects within treatments are categorized as being equal, weak, or strong. The author draws three main conclusions from the experimental data. Firstly, subjects in symmetric contests and both types in asymmetric contests all overinvest on average. Secondly, both types in asymmetric contests invest less on average than subjects in symmetric contests. Thirdly, both types in asymmetric contests invest about the same level on average.

[35] Wald tests comparing coefficients in linear regression: INC_{strong} vs. INC_{weak}, $p = 0.13$; DEC_{strong} vs. DEC_{weak}, $p = 0.31$; $RAND_{strong}$ vs. $RAND_{weak}$, $p = 0.02$

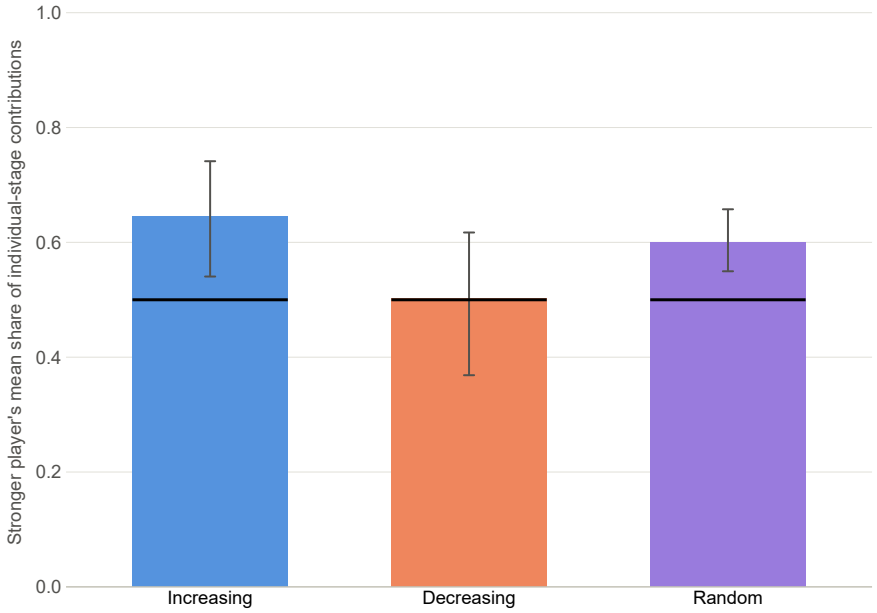


Figure 6: Share of Individual Stage Contributions, Last 10 Rounds

Notes: The stronger player's share of the total individual stage contributions within a group for each treatment in which asymmetric strengths can exist. Black lines show theoretical predictions. Data from last 10 rounds. Error bars represent 95% wild cluster bootstrap confidence intervals.

the total individual stage contributions in only asymmetric contests. Theory predicts a 50-50 split in each treatment.

In **Decreasing**, the stronger and weaker players both contribute about an equal share of the total individual stage contributions. However, in **Increasing** and **Random**, the stronger player behaves relatively more aggressively, contributing about 64% and 60%, respectively. In these two treatments, the stronger player contributes a share which is significantly greater than an even split.[36] Comparing across treatments, I find that the stronger player's share is significantly higher in **Increasing** compared to **Decreasing**.[37]

In table 18 in Appendix B, I also regress the stronger player's share of individual stage contributions on treatment interacted with strength ratio. I compare the slope coefficients on strength ratio to 0,[38] and I compare across treatments.[39] I find a significant difference in the effect of strength ratio on the stronger player's share of contributions between the two endogenous strength treatments and between **Increasing** and **Random**. When a subject earns a strong position in **Increasing**, greater asymmetry increases her share of the contributions. The stronger player's share in **Random** also increases with greater asymmetry, but not as

[36] Wald tests comparing coefficients in linear regression to predictions: INC, $p = 0.04$; DEC, $p = 0.96$; $RAND$, $p = 0.01$

[37] Wilcoxon rank-sum test: INC vs. DEC, $p = 0.04$; INC vs. $RAND$, $p = 0.24$; DEC vs. $RAND$, $p = 0.18$

[38] Wald tests comparing coefficients in linear regression to predictions: INC, $p = 0.009$; DEC, $p = 0.84$; $RAND$, $p = 0.09$

[39] Wald tests comparing coefficients in linear regression: INC vs. DEC, $p = 0.09$; INC vs. $RAND$, $p = 0.006$; DEC vs. $RAND$, $p = 0.63$

severely as in **Increasing**. On the contrary, stronger players in **Decreasing** who receive a strong position by withholding contributions in the group stage actually submit a lower share of contributions as the strength gap widens.

The results suggest that both strong and weak types in an asymmetric contest behave differently depending on how asymmetry arises. When a strong position is earned by helping the group, the stronger player outspends the weaker player in their within-group competition as well. The difference in their contributions grows as the strength gap widens. On the other hand, when a strong position is earned through shirking, strong and weak players contribute about the same share in within-group competition.[40]

Result 4c (Strong vs. weak types)**.** *The share of individual stage contributions expended by the stronger player is greater when strength is increasing in group stage contributions versus when it is decreasing. As the strength ratio drops and subjects become more unevenly matched, the stronger player's share rises when strength is increasing in group stage contributions.*

Next, I compare contributions within each type across treatments, beginning with the strong and weak types. Previous research on asymmetric contests has been unable to perform this analysis because it holds fixed the method for assigning types. I observe that within strong types, there are no significant differences across treatments despite mean contributions being lower in **Increasing** and **Random** than in **Decreasing**.[41] However, weak types contribute significantly more on average in **Decreasing** compared to both **Increasing** and **Random**.[42]

Differences in individual stage contributions across treatments seem to be especially driven by weak types. When higher strength is earned through shirking, weak types compete aggressively. On the other hand, when higher strength is the result of helping the group or a random assignment, competitiveness dampens for both strong and weak types, with weak types especially dialing back contributions.

Result 4d (Weak types across treatments)**.** *Weak types contribute significantly more on average when strength is decreasing in group stage contributions versus when it is increasing or randomly assigned.*

I also compare contributions in asymmetric contests to those in symmetric contests. In my experiment, I have symmetric contests that arise exogenously and endogenously. First, I consider the exogenous case as the benchmark and compare contributions by different types in asymmetric contests to contributions in **Symmetric**. Both strong and weak types in **Increasing** and **Random** contribute significantly less than subjects in **Symmetric**.[43] On the other hand, contributions in **Decreasing** do not differ significantly.[44] Asymmetry appears to discourage

[40] This result also provides more evidence that a pure wealth effect isn't driving differences across treatments in the individual stage. A wealth effect would predict that subjects with higher remaining endowments contribute more. In **Increasing**, the weaker player has a higher remaining endowment due to a lower group stage contribution, but the stronger player contributes a greater share of total contributions. In **Decreasing**, the stronger player has the higher endowment but doesn't contribute significantly more. In addition to table 3 and table 11 in Appendix B, this provides more evidence that differences in individual stage wealth aren't directly driving treatment differences.

[41] Wald tests comparing coefficients in linear regression: INC_{strong} vs. DEC_{strong}, $p = 0.12$; INC_{strong} vs. $RAND_{strong}$, $p = 0.71$; DEC_{strong} vs. $RAND_{strong}$, $p = 0.15$

[42] Wald tests comparing coefficients in linear regression: INC_{weak} vs. DEC_{weak}, $p = 0.02$; INC_{weak} vs. $RAND_{weak}$, $p = 0.44$; DEC_{weak} vs. $RAND_{weak}$, $p = 0.05$

[43] Wald tests comparing coefficients in linear regression to SYM: INC_{strong}, $p = 0.03$; INC_{weak}, $p = 0.002$; $RAND_{strong}$, $p = 0.03$; $RAND_{weak}$, $p = 0.001$

[44] Wald tests comparing coefficients in linear regression to SYM: DEC_{strong} , $p = 0.77$; DEC_{weak} , $p = 0.34$

competition for both types, but only in **Increasing** and **Random**.

The results flip when comparing asymmetric contests to symmetric contests that arise endogenously in **Increasing** and **Decreasing**. In fact, when subjects in **Decreasing** are equally matched as a result of coordinating contributions in the group stage, they compete marginally significantly less aggressively compared to subjects who are equally matched ex ante.[45] It appears coordination in the group stage dampens competition in the individual stage. If we instead use these endogenously equal subjects as our benchmark symmetric contests and compare to asymmetric counterparts by treatment, we find suggestive evidence of higher contributions by strong and weak types in **Decreasing** and no significant difference for either type in **Increasing**.[46] Regardless of which symmetric contest benchmark I use (exogenously symmetric or endogenously symmetric), contrary to theoretical predictions and previous experimental findings, I do not find that both strong and weak types in asymmetric contests unequivocally contribute less on average than those in symmetric contests.

Finally, to test for overinvestment in each category, I analyze whether percent deviation from Nash equilibrium differs from 0. Contrary to previous research, I find that not all types exhibit overinvestment. Subjects in **Symmetric**, who have equal strengths by default, significantly overinvest ($p = 0.04$), but weak types in **Increasing** and **Random** actually marginally significantly underinvest on average ($p = 0.07$ and $p = 0.08$, respectively). The equal types in both endogenous strength treatments also exhibit an average percent deviation less than 0, but the difference is not significant. The results provide some suggestive evidence that the lack of overinvestment we observe in **Increasing** and **Random** may be driven by the weak players.

4.4.5 Discussion

The results in this section shed light on discouragement effects in asymmetric contests. The discouragement effect describes how aggregate contributions in a contest tend to fall when contestants are asymmetric. The individual stage of my experiment in isolation is a standard static environment in which the discouragement effect could operate.[47] The above data find evidence of the discouragement effect when strength increases in group stage contributions. Weaker types especially decrease contributions in response to asymmetry. However, when strength decreases in group stage contributions, the effect vanishes, and aggregate contributions are not significantly different from the case of symmetric strengths. If asymmetry in a static contest arises endogenously, then the discouragement effect appears to be sensitive to exactly how it arises. Future research should further investigate how endogenizing asymmetry in different ways affects aggregate contest contributions.

An alternative interpretation of the results in this section is that individuals exhibit behavior resembling the entitlement effect first observed in bargaining games (Hoffman et al., 1994; Cappelen et al., 2007; Oxoby & Spraggon, 2008). These studies find that individuals behave less generously when a position of advantage is earned rather than given. I import this idea into a new competitive setting and expand it to not only consider whether a position of advantage is given or earned, but also *how* it is earned. In my data, when the strong position is earned

[45] Wald tests comparing coefficients in linear regression to SYM: INC_{equal} , $p = 0.14$; DEC_{equal} , $p = 0.06$

[46] Wald tests comparing coefficients in linear regression: INC_{strong} vs. INC_{equal} , $p = 0.54$; INC_{weak} vs. INC_{equal} , $p = 0.13$; DEC_{strong} vs. DEC_{equal}, $p = 0.11$; DEC_{weak} vs. DEC_{equal} , $p = 0.43$

[47] In a recent paper, Drugov & Ryvkin (2025) demonstrate how the discouragement effect in static settings is not as robust as is often believed.

through high group contributions, both players appear to accept the outcome and reduce competition. The weak players especially seem to acknowledge the stronger player's right to the prize and decrease contributions. However, when the strong position is earned through low group contributions, competition ramps up. In this case, it appears neither player accepts that the stronger group member possesses some salient right to the prize. The weak player stays aggressive and matches the stronger player.

5 Conclusion

In this paper, I study situations in which individuals coordinate and compete for prizes. Such situations commonly arise in the real world in organizations, sports, industries, and politics. I focus on the link between an individual's contribution to a group's collective effort and her position in competition within the group. To study this topic, I develop a two-stage model of intergroup and intragroup competition. In the group stage, two groups of two agents compete in a group Tullock contest for the right to advance to the next stage. Group members coordinate and pool their contributions to increase their likelihood of advancing. The winning group moves on to the individual stage in which group members compete against one another for an indivisible prize. Contributions in the individual stage are multiplied by strengths. Strength may be endogenously or exogenously determined. Endogenous strength depends on an individual's contributions in the group stage. In one case, higher group stage contributions translate to higher strength, while in another case, higher group stage contributions translate to lower strength. I also consider benchmark cases in which strength is exogenously assigned and either symmetric or asymmetric across agents. I solve the model for each case and develop testable hypotheses and comparative statics.

I then conduct a laboratory experiment in which subjects play the two-stage game for 20 repeated rounds. I analyze data on contributions in each stage and find two main sets of results. First, within each stage, contributions differ depending on the method for assigning strengths, while total contributions over both stages remain constant. Consequently, from the perspective of a social planner or a manager, the most efficient or profitable way to assign individual strengths depends on which type of effort, collective or individual, is considered productive rather than wasteful.

Second, in analyzing the individual stage, I am able to study asymmetric contests with different origins of asymmetry. Contrary to theoretical predictions, I find that individuals competing in asymmetric Tullock contests are sensitive to how asymmetry arises. Specifically, I find that individuals behave more competitively when an advantage comes from low contributions to the group rather than from high contributions. Within firms and other organizations, unevenly matched agents frequently interact and often compete. My results suggest that managers and policymakers overseeing such situations should pay close attention to the origins of asymmetry when designing incentive schemes.

This paper is the first to theoretically and experimentally study the relationship between group contributions and individual strength in competition between and within groups. My findings shed light on how groups of individuals coordinate and compete within organizations. The theory and results contribute to the vast literature on group and individual contests and offer new insights into how people behave in asymmetric situations.

References

Altmann, S., Falk, A., & Wibral, M. (2012). Promotions and incentives: The case of multistage elimination tournaments. *Journal of Labor Economics*, *30*(1), 149–174.

Baik, K. H. (1994). Effort levels in contests with two asymmetric players. *Southern Economic Journal*, 367–378.

Bhattacharya, P., & Rampal, J. (2024). Contests within and between groups: Theory and experiment. *Games and Economic Behavior*, *145*, 467–492.

Cameron, A. C., Gelbach, J. B., & Miller, D. L. (2008). Bootstrap-based improvements for inference with clustered errors. *The Review of Economics and Statistics*, *90*(3), 414–427.

Cappelen, A. W., Hole, A. D., Sørensen, E. Ø., & Tungodden, B. (2007). The pluralism of fairness ideals: An experimental approach. *American Economic Review*, *97*(3), 818–827.

Cherry, T. L., Frykblom, P., & Shogren, J. F. (2002). Hardnose the dictator. *American Economic Review*, *92*(4), 1218–1221.

Choi, J. P., Chowdhury, S. M., & Kim, J. (2016). Group contests with internal conflict and power asymmetry. *The Scandinavian Journal of Economics*, *118*(4), 816–840.

Chowdhury, S. M., Esteve-González, P., & Mukherjee, A. (2023). Heterogeneity, leveling the playing field, and affirmative action in contests. *Southern Economic Journal*, *89*(3), 924–974.

Cross, R., Rebele, R., & Grant, A. (2016). Collaborative overload. *Harvard Business Review*, *23*, 2019.

Dechenaux, E., Kovenock, D., & Sheremeta, R. M. (2015). A survey of experimental research on contests, all-pay auctions and tournaments. *Experimental Economics*, *18*(4), 609–669.

Drugov, M., & Ryvkin, D. (2025). Hunting for the discouragement effect in contests: M. drugov, d. ryvkin. *Review of Economic Design*, *29*(3), 387–413.

Fischbacher, U. (2007). z-tree: Zurich toolbox for ready-made economic experiments. *Experimental Economics*, *10*(2), 171–178.

Fonseca, M. A. (2009). An experimental investigation of asymmetric contests. *International Journal of Industrial Organization*, *27*(5), 582–591.

Franke, J., Kanzow, C., Leininger, W., & Schwartz, A. (2013). Effort maximization in asymmetric contest games with heterogeneous contestants. *Economic Theory*, *52*(2), 589–630.

Fu, Q., & Lu, J. (2012). The optimal multi-stage contest. *Economic Theory*, *51*(2), 351–382.

Gradstein, M., & Konrad, K. A. (1999). Orchestrating rent seeking contests. *The Economic Journal*, *109*(458), 536–545.

Greiner, B. (2015). Subject pool recruitment procedures: organizing experiments with orsee. *Journal of the Economic Science Association*, *1*(1), 114–125.

Hoffman, E., McCabe, K., Shachat, K., & Smith, V. (1994). Preferences, property rights, and anonymity in bargaining games. *Games and Economic Behavior*, *7*(3), 346–380.

Katz, E., Nitzan, S., & Rosenberg, J. (1990). Rent-seeking for pure public goods. *Public Choice*, *65*(1), 49–60.

Katz, E., & Tokatlidu, J. (1996). Group competition for rents. *European Journal of Political Economy*, *12*(4), 599–607.

Kirkegaard, R. (2012). Favoritism in asymmetric contests: Head starts and handicaps. *Games and Economic Behavior*, *76*(1), 226–248.

Lazear, E. P., & Rosen, S. (1981). Rank-order tournaments as optimum labor contracts. *Journal of Political Economy*, *89*(5), 841–864.

Mealem, Y., & Nitzan, S. (2016). Discrimination in contests: a survey. *Review of Economic Design*, *20*(2), 145–172.

Münster, J. (2007). Simultaneous inter-and intra-group conflicts. *Economic Theory*, *32*(2), 333–352.

Münster, J. (2009). Group contest success functions. *Economic Theory*, *41*(2), 345–357.

Oxoby, R. J., & Spraggon, J. (2008). Mine and yours: Property rights in dictator games. *Journal of Economic Behavior & Organization*, *65*(3-4), 703–713.

Rogerson, W. (1982). The social costs of monopoly and regulation: A game-theoretic analysis. *Bell Journal of Economics*, *13*(2), 391–401.

Ryvkin, D. (2011). Fatigue in dynamic tournaments. *Journal of Economics & Management Strategy*, *20*(4), 1011–1041.

Schmitt, P., Shupp, R., Swope, K., & Cadigan, J. (2004). Multi-period rent-seeking contests with carryover: Theory and experimental evidence. *Economics of Governance*, *5*(3), 187–211.

Schotter, A., & Weigelt, K. (1992). Asymmetric tournaments, equal opportunity laws, and affirmative action: Some experimental results. *The Quarterly Journal of Economics*, *107*(2), 511–539.

Sheremeta, R. M. (2010a). Expenditures and information disclosure in two-stage political contests. *Journal of Conflict Resolution*, *54*(5), 771–798.

Sheremeta, R. M. (2010b). Experimental comparison of multi-stage and one-stage contests. *Games and Economic Behavior*, *68*(2), 731–747.

Sheremeta, R. M. (2018). Behavior in group contests: A review of experimental research. *Journal of Economic Surveys*, *32*(3), 683–704.

Skaperdas, S. (1996). Contest success functions. *Economic Theory*, *7*(2), 283–290.

Stein, W. E. (2002). Asymmetric rent-seeking with more than two contestants. *Public Choice*, *113*(3), 325–336.

Stein, W. E., & Rapoport, A. (2004). Asymmetric two-stage group rent-seeking: Comparison of two contest structures. *Public Choice*, *118*(1), 151–167.

Tsoulouhas, T., Knoeber, C. R., & Agrawal, A. (2007). Contests to become ceo: incentives, selection and handicaps. *Economic Theory*, *30*(2), 195–221.

Tullock, G. (1967). The welfare costs of tariffs, monopolies, and theft. *Economic Inquiry*, *5*(3), 224–232.

Tullock, G. (1980). Efficient rent seeking. In *Toward a theory of the rent-seeking society* (p. 97-112). Texas A&M University Press.

Wärneryd, K. (1998). Distributional conflict and jurisdictional organization. *Journal of Public Economics*, *69*(3), 435–450.

A Additional Theoretical Results and Proofs

A.1 Individual stage equilibrium with binding budget constraints

This section characterizes the Nash equilibrium of the individual stage when players may be budget constrained. Suppress group indices for this analysis. Let remaining endowments after the group stage be

$$r_i \equiv w - x_i \geq 0, \qquad i \in \{1, 2\},$$

and let strengths be (θ_1, θ_2), where $\theta_i > 0$. In the individual stage, agents choose $y_i \in [0, r_i]$ to maximize

$$u_i(y_i, y_j) = \frac{\theta_i y_i}{\theta_i y_i + \theta_j y_j} V - y_i + r_i \tag{13}$$

The unconstrained first-order condition for agent i given the contribution of agent j is

$$\frac{\partial u_i}{\partial y_i} = \frac{V \theta_i \theta_j y_j}{(\theta_i y_i + \theta_j y_j)^2} - 1 = 0,$$

and the unconstrained best response function is

$$y_i(y_j) = \frac{\sqrt{V \theta_i \theta_j y_j} - \theta_j y_j}{\theta_i}. \tag{14}$$

Imposing the budget constraint $y_i \leq r_i$ implies the constrained best response

$$BR_i(y_j) = \min \left\{ r_i,\ \max(y_i(y_j)) \right\}. \tag{15}$$

If budgets do not bind for either player, the unique interior Nash equilibrium is the standard outcome characterized in Lemma 1:

$$y_1^* = y_2^* = \frac{V \theta_1 \theta_2}{(\theta_1 + \theta_2)^2}. \tag{16}$$

Suppose the budget constraint binds only for agent 1. Then the Nash equilibrium satisfies

$$y_1^* = r_1, \qquad y_2^* = \frac{\sqrt{V \theta_1 \theta_2 r_1} - \theta_1 r_1}{\theta_2} \tag{17}$$

Suppose both agents are constrained. Then both constraints bind in equilibrium:

$$y_1^* = r_1, \qquad y_2^* = r_2. \tag{18}$$

Note that in our experiment, budget constraints never bind on the equilibrium path. However, budget constraints may bind off the equilibrium path. Deviating to a group stage contribution that makes budget constraints bind in the individual stage is unprofitable. Therefore, even if budget constraints can bind in the individual stage for certain group stage contributions, the main analysis of the subgame perfect equilibria given my experimental parameters remains unchanged.

A.2 Proofs

Proof of Lemma 1

Proof. Assume for all (x_{1a}, x_{2a}) that arise in equilibrium, budget constraints do not bind in the individual stage:

$$w - x_{ia} \;\geq\; \frac{V\theta_{1a}\theta_{2a}}{(\theta_{1a}+\theta_{2a})^2} \quad \text{for } ia \in \{1a, 2a\},$$

and $f(x) > 0$ on $[0, w]$. The payoff function is strictly concave in y_{ia} for $y_{ja} > 0$, so first-order conditions are sufficient and yield the unique interior Nash equilibrium. The FOCs are

$$\frac{V\theta_{1a}\theta_{2a}y_{2a}}{(\theta_{1a}y_{1a}+\theta_{2a}y_{2a})^2} - 1 = 0 \qquad \frac{V\theta_{1a}\theta_{2a}y_{1a}}{(\theta_{1a}y_{1a}+\theta_{2a}y_{2a})^2} - 1 = 0$$

which implies $y^*_{1a} = y^*_{2a}$. Substitution gives the winning probabilities and continuation payoffs. □

Proof of Lemma 2

Proof. Consider agent $1a$. Differentiate π_{1a} with respect to x_{1a} and impose the first-order condition. The simplified FOC results in

$$2\frac{X_a}{X_a+X_b}\left(\frac{f(x_{1a})f(x_{2a})f'(x_{1a})}{(f(x_{1a})+f(x_{2a}))^3}\right) + \frac{X_b}{(X_a+X_b)^2}\frac{f(x_{1a})^2}{(f(x_{1a})+f(x_{2a}))^2} = \frac{1}{V} \tag{19}$$

A symmetric FOC exists for each agent. Consider a symmetric profile

$$x_{1a} = x_{2a} = x_{1b} = x_{2b} = x.$$

Then $X_a = X_b = 2x$ and $f(x_{1a}) = f(x_{2a}) = f(x_{1b}) = f(x_{2b}) = f(x)$. Within the winning group,

$$U_{1a} = U_{2a} = \frac{V}{4}.$$

Imposing symmetry and simplifying the above FOC further results in the symmetric equilibrium condition. □

Proof of Proposition 1

Proof. Because the individual stage equilibrium is unique and yields $U_{ig} = V/4$ for both agents in the winning group, the equilibrium reduces to the Nash equilibrium of the group stage game.

Differentiating expected payoff with respect to x_{ig} yields

$$\frac{\partial \pi_{ig}}{\partial x_{ig}} = -1 + \frac{V}{4}\cdot\frac{\partial}{\partial x_{ig}}\left(\frac{x_{ig}+x_{jg}}{x_{ig}+x_{jg}+X_{-g}}\right) = -1 + \frac{V}{4}\cdot\frac{X_{-g}}{(X_g+X_{-g})^2}.$$

Since

$$\frac{\partial^2 \pi_{ig}}{\partial x_{ig}^2} = \frac{V}{4}\cdot X_{-g}\cdot\frac{\partial}{\partial x_{ig}}(X_g+X_{-g})^{-2} = -\frac{V}{2}\cdot\frac{X_{-g}}{(X_g+X_{-g})^3} < 0 \quad \text{whenever } X_{-g} > 0,$$

the objective function is strictly concave in x_{ig} for $X_{-g} > 0$, and the first-order condition is sufficient for a unique best response.

An interior best response satisfies the following FOCs:

$$-1+\frac{V}{4}\cdot\frac{X_b}{(X_a+X_b)^2}=0 \qquad -1+\frac{V}{4}\cdot\frac{X_a}{(X_a+X_b)^2}=0$$

which implies $X_a = X_b$. An equilibrium can only pin down aggregate group stage contributions. Within each group g, any split (x_{1g}, x_{2g}) with $x_{1g}, x_{2g} \geq 0$ and $x_{1g} + x_{2g} = V/16$ constitutes mutual best responses given that the opposing group's total is also $V/16$.

The individual stage equilibrium follows from Lemma 1 and is unique. □

Proof of Proposition 2

Proof. By Lemma 1, the individual stage has a unique Nash equilibrium in which

$$y^*_{1g}=y^*_{2g}=\frac{V\theta_{1g}\theta_{2g}}{(\theta_{1g}+\theta_{2g})^2}, \qquad p^*_{ig}=\frac{\theta_{ig}}{\theta_{1g}+\theta_{2g}}, \qquad U_{ig}=\frac{V\theta^2_{ig}}{(\theta_{1g}+\theta_{2g})^2}.$$

In particular, under symmetric group stage contributions, $\theta_{1g} = \theta_{2g}$, so $y^*_{1g} = y^*_{2g} = V/4$ and $U_{1g} = U_{2g} = V/4$.

The two-stage expected payoff is

$$\pi_{ig}(x_{ig}, x_{jg}, X_{-g}) = w - x_{ig} + p_g(X_g, X_{-g})\, U_i\big(f(x_{ig}), f(x_{jg})\big).$$

By Lemma 2, any symmetric interior equilibrium $x^* > 0$ must satisfy the first order condition

$$\frac{V}{32x^*}+\frac{V}{8}\frac{f'(x^*)}{f(x^*)}-1=0.$$

The FOC is continuous on $(0, w]$. For $\gamma \in (0, 1)$ and for all $\alpha > 0$, the derivative of the FOC is strictly negative:

$$-\frac{V}{32x^2}-\frac{V\gamma}{8(x+\alpha)^2}<0.$$

For $\gamma \in (-1, 0)$, the condition holds for $\alpha > 2$. So FOC is strictly decreasing. Therefore, the symmetric interior equilibrium is unique.

Individual stage equilibrium is uniquely pinned down by Lemma 1 for every realized vector of strengths. □

Proof of Corollary 1

Proof. Let $V = 600$ and $w = 300$, and recall $X_g = x_{1g} + x_{2g}$, $\theta_{ig} = f(x_{ig})$, and $p_a = X_a/(X_a + X_b)$.

Towards a contradiction, suppose $x_{1a} \neq x_{2a}$. Since f is strictly monotone, $\theta_{1a} \neq \theta_{2a}$. First consider the case when $\theta = (x+3)^{\frac{1}{3}}$. Using Lemma 1 and rearranging first order conditions for members of group a, we have

$$\frac{(\theta_{1a}+\theta_{2a})^2}{V\theta^2_{1a}}=\frac{X_b}{(X_a+X_b)^2}-\frac{2p_a\,\theta^3_{1a}\theta_{2a}}{3(\theta_{1a}+\theta_{2a})} \tag{20}$$

$$\frac{(\theta_{1a}+\theta_{2a})^2}{V\theta^2_{2a}}=\frac{X_b}{(X_a+X_b)^2}-\frac{2p_a\,\theta_{1a}\theta^3_{2a}}{3(\theta_{1a}+\theta_{2a})}. \tag{21}$$

Subtract the second equation from the first, divide by $\theta_{2a} - \theta_{1a} \neq 0$ and solve for $\frac{1}{V}$ to get:

$$\frac{1}{V} = \frac{2p_a(\theta_{1a}^2 + \theta_{2a}^2)}{3\,\theta_{1a}\theta_{2a}(\theta_{1a} + \theta_{2a})^3} \tag{22}$$

Then substitute into player a's FOC to get

$$\frac{X_b}{(X_a + X_b)^2} = \frac{2p_a}{3\,\theta_{1a}\theta_{2a}(\theta_{1a} + \theta_{2a})} \tag{23}$$

By $\theta_{1a} \neq \theta_{2a}$, we have $(\theta_{1a} - \theta_{2a})^2 > 0$. Expanding the left hand side implies

$$\theta_{1a}\theta_{2a} < \tfrac{1}{4}(\theta_{1a} + \theta_{2a})^2 \qquad \text{and} \qquad \theta_{1a}^2 + \theta_{2a}^2 > \tfrac{1}{2}(\theta_{1a} + \theta_{2a})^2. \tag{24}$$

Since $\theta_{ia}^3 = x_{ia} + 3$ by definition of f, we have $X_a = \theta_{1a}^3 + \theta_{2a}^3 - 6$. With $V = 600$, rearranging (22) gives

$$p_a = \frac{\theta_{1a}\theta_{2a}(\theta_{1a} + \theta_{2a})^3}{400(\theta_{1a}^2 + \theta_{2a}^2)}. \tag{25}$$

Since $X_b/(X_a + X_b) = 1 - p_a$, the left hand side of (23) can be written as

$$\frac{X_b}{(X_a + X_b)^2} = \frac{X_b}{X_a + X_b} \cdot \frac{1}{X_a + X_b} = \frac{1 - p_a}{X_a + X_b}. \tag{26}$$

Substituting this into (23) and solving for $X_a + X_b$ gives

$$X_a + X_b = \frac{3(1 - p_a)\,\theta_{1a}\theta_{2a}(\theta_{1a} + \theta_{2a})}{2p_a}. \tag{27}$$

Replacing p_a with (25),

$$\frac{\theta_{1a}\theta_{2a}(\theta_{1a} + \theta_{2a})}{p_a} = \theta_{1a}\theta_{2a}(\theta_{1a} + \theta_{2a}) \cdot \frac{400(\theta_{1a}^2 + \theta_{2a}^2)}{\theta_{1a}\theta_{2a}(\theta_{1a} + \theta_{2a})^3} = \frac{400(\theta_{1a}^2 + \theta_{2a}^2)}{(\theta_{1a} + \theta_{2a})^2}. \tag{28}$$

and

$$X_a + X_b = \frac{3}{2}(1 - p_a) \cdot \frac{400(\theta_{1a}^2 + \theta_{2a}^2)}{(\theta_{1a} + \theta_{2a})^2} = \frac{600(1 - p_a)(\theta_{1a}^2 + \theta_{2a}^2)}{(\theta_{1a} + \theta_{2a})^2}. \tag{29}$$

By (24), $(\theta_{1a}^2 + \theta_{2a}^2)/(\theta_{1a} + \theta_{2a})^2 > \frac{1}{2}$, and $1 - p_a > 0$, so

$$X_a + X_b > 300(1 - p_a). \tag{30}$$

and multiplying (23) through by $X_a + X_b$ gives

$$X_a = \tfrac{3}{2}(1 - p_a)\,\theta_{1a}\theta_{2a}(\theta_{1a} + \theta_{2a}). \tag{31}$$

Claim: $p_a < 4/9$. Towards a contradiction, suppose instead that $p_a \geq 4/9$. Equating (31) with $X_a = \theta_{1a}^3 + \theta_{2a}^3 - 6$, and using

$$\theta_{1a}^3 + \theta_{2a}^3 = (\theta_{1a} + \theta_{2a})^3 - 3\theta_{1a}\theta_{2a}(\theta_{1a} + \theta_{2a}), \tag{32}$$

we get

$$(\theta_{1a} + \theta_{2a})^3 - \tfrac{23}{6}\,\theta_{1a}\theta_{2a}(\theta_{1a} + \theta_{2a}) \leq 6. \tag{33}$$

and

$$p_a < \frac{144}{800} < \frac{4}{9}, \tag{34}$$

which is a contradiction.

If both groups have asymmetric contributions, the same logical argument applies to group b which implies $p_a + p_b < 8/9$, which is a contradiction since it must be that $p_a + p_b = 1$.

Now assume members of group b contribute symmetrically. Now, given $x_{1b} = x_{2b} = X_b/2$, $p_b = 1 - p_a$, and $p^*_{ib} = \frac{1}{2}$, first order condition for a member of group b is

$$1 = \frac{150\, p_a}{X_a + X_b} + \frac{100(1 - p_a)}{X_b + 6}. \tag{35}$$

Since $(1-p_a)/(X_b+6) < (1-p_a)/X_b = 1/(X_a+X_b)$, this is less than $(100+150p_a)/(X_a+X_b)$. By (30), it is less than

$$\frac{100 + 150p_a}{300(1 - p_a)}. \tag{36}$$

In equilibrium, this bound must be at least 1, which we can rearrange to $p_a > 4/9$, a contradiction if members of group a contribute asymmetrically.

A parallel structure can be used to show for the case of $\gamma = -\frac{1}{3}$ that an equilibrium cannot exist when either one or both groups have asymmetric contributions. Finally, I show that group totals cannot be asymmetric. Without loss of generality, assume $X_a - X_b > 0$. We have already shown that each group splits its total evenly: $x_{1a} = x_{2a} = X_a/2$ and $x_{1b} = x_{2b} = X_b/2$.

Take the first order condition for each group, subtract, and multiply by $X_a + X_b$. This gives

$$(X_a - X_b)\left[\frac{12\gamma}{(X_a + 6)(X_b + 6)} - \frac{1}{X_a + X_b}\right] = 0. \tag{37}$$

If $\gamma = -\frac{1}{3}$, the bracketed term is negative. If $\gamma = \frac{1}{3}$, the bracketed term is always positive. Therefore it must be that $X_a - X_b = 0$. □

Proof of Remark 2

Proof. Consider two strengths $\theta' > \theta$. Suppose, toward a contradiction, that

$$x(\theta') \leq x(\theta). \tag{38}$$

In equilibrium, given realized strengths, group stage contribution satisfies the first order condition in (11). Therefore, for type θ' and θ, the marginal benefit of increasing group stage contribution equals 1, $MB(\theta') = 1$ and $MB(\theta) = 1$. The marginal benefit strictly increases in strength and decreases in group stage contribution. Therefore, if $\theta' > \theta$ and $x(\theta') \leq x(\theta)$, then $MB(\theta') > MB(\theta) = 1$. But in equilibrium, $MB(\theta') = 1$, so we have a contradiction.

□

B Supplementary Results

Table 5: Summary Statistics, All Rounds

	Group Stage		Individual Stage	
Treatment	Mean	SPE	Mean	SPE
Increasing	68.41	42.09	125.05	150.00
	[42.02, 98.28]		[108.96, 151.44]	
Decreasing	25.37	4.19	147.18	150.00
	[11.63, 45.94]		[115.94, 174.20]	
Symmetric	42.63	18.75	162.79	150.00
	[34.42, 49.87]		[138.62, 175.00]	
Random	59.66	27.55	123.22	143.25
	[39.64, 82.27]		[99.53, 143.72]	

Notes: Mean contributions by stage and treatment with theoretical predictions. Data from all rounds. 95% wild cluster bootstrap confidence intervals in brackets.

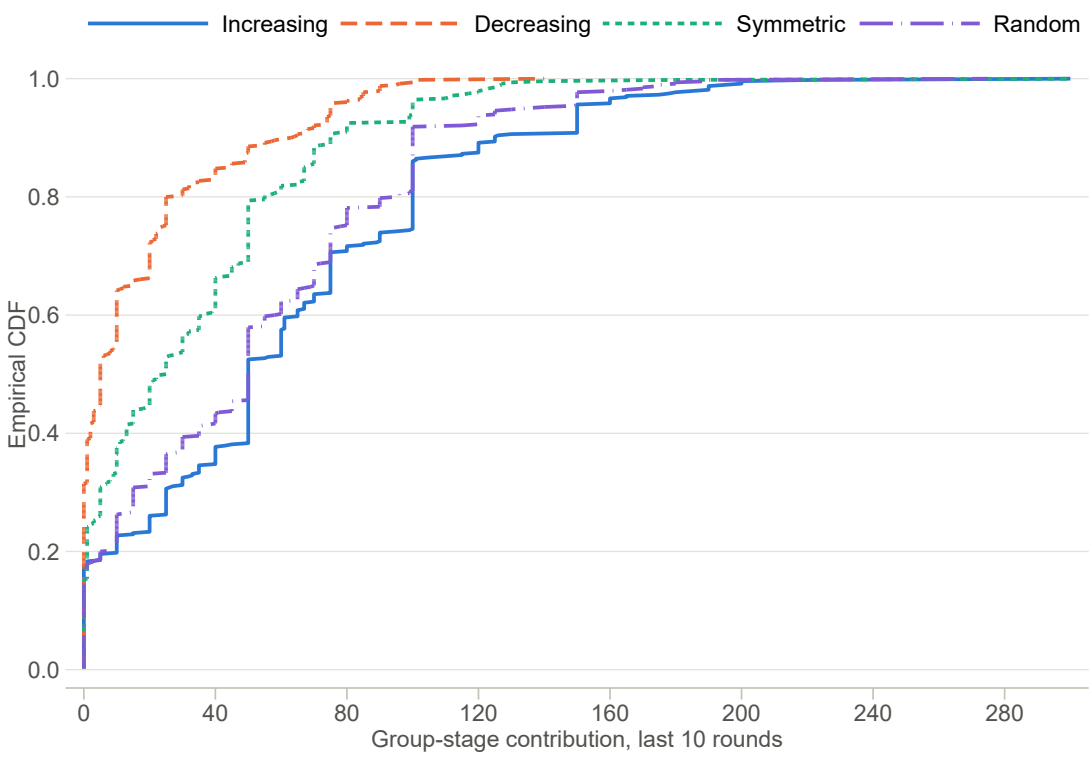


Figure 7: Distribution of Group Stage Contributions, Last 10 Rounds

Notes: Empirical CDF of group stage contributions by treatment. Data from last 10 rounds.

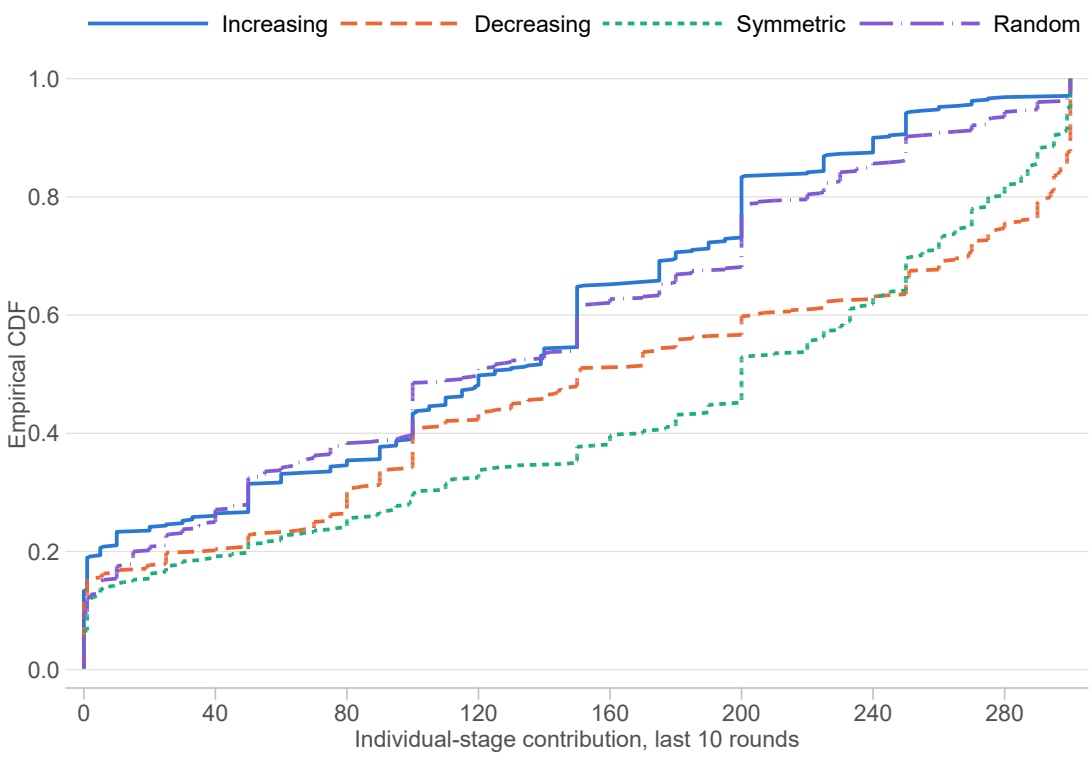


Figure 8: Distribution of Individual Stage Contributions, Last 10 Rounds

Notes: Empirical CDF of individual stage contributions by treatment. Data from last 10 rounds.

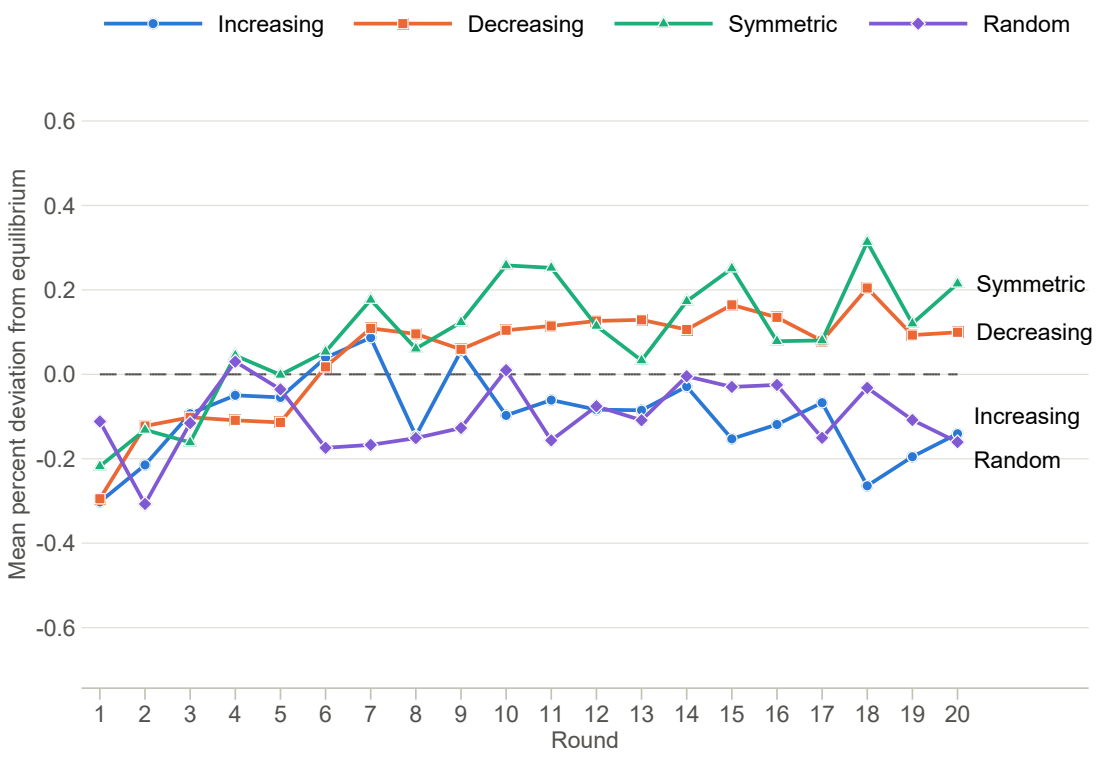


Figure 9: Percent Deviation from Individual Stage Equilibrium (Excluding All-in Groups)

Notes: Mean percent deviation from individual stage Nash equilibrium in each round by treatment. Dashed line shows theoretical prediction of no deviation. Groups in which at least one subject contributes entire endowment in the group stage are omitted.

Table 6: Group Stage Contributions on Strength for Random Treatment, Last 10 Rounds

	(1)
Strength	18.520**
	[4.169, 31.175]
Constant	-3.042
	[-25.133, 31.452]
Observations	480
Clusters	6

Notes: Regression of group stage contributions on strength. Data from Random treatment only. Data from last 10 rounds. 95% wild cluster bootstrap confidence intervals in brackets.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

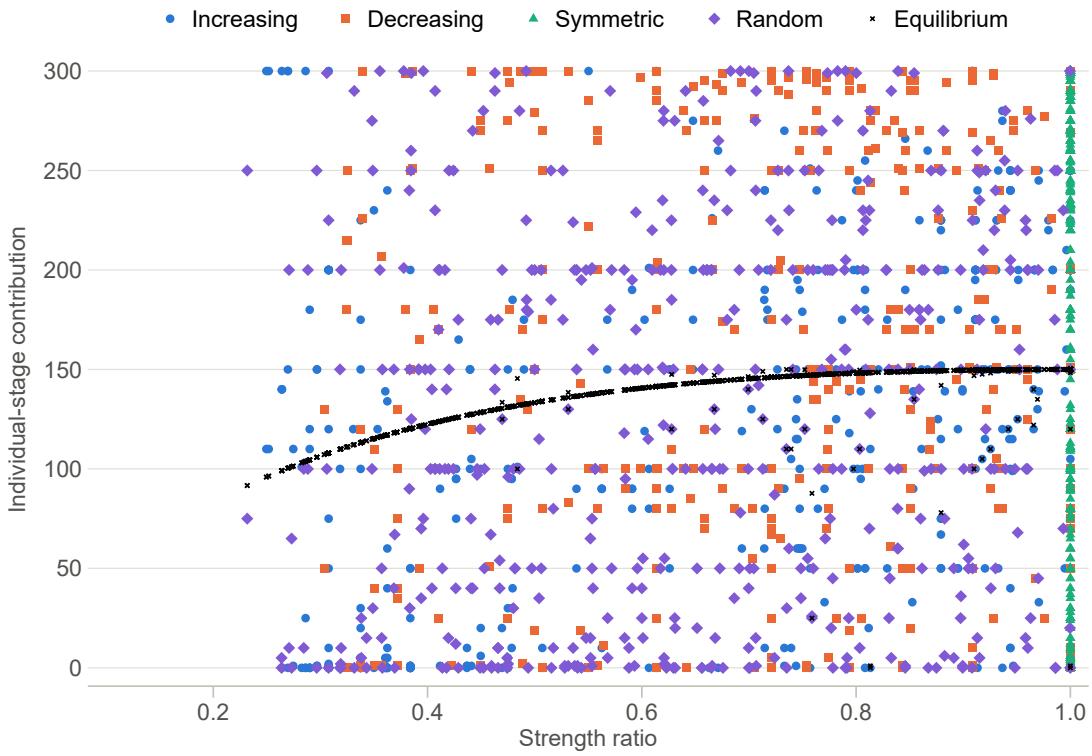


Figure 10: Individual Stage NE by Strength Ratio, Last 10 Rounds

Notes: Raw data on realized strength ratio and corresponding individual stage contribution for each subject by treatment. Black X marks show theoretical individual stage Nash equilibria for given strength ratios. Data from last 10 rounds.

Table 7: Mean Within-Group Total Contributions, Last 10 Rounds

	Mean	Equilibrium
Increasing	362.754	384.18
	[304.125, 446.582]	
Decreasing	356.413	308.38
	[281.961, 426.815]	
Symmetric	413.850	337.50
	[376.688, 446.219]	
Random	355.800	341.60
	[303.686, 415.649]	
Observations	960	
Clusters	24	

Notes: Mean within-group total contributions over both stages and theoretical predictions by treatment. 95% wild cluster bootstrap confidence intervals in brackets. Data from last 10 rounds.

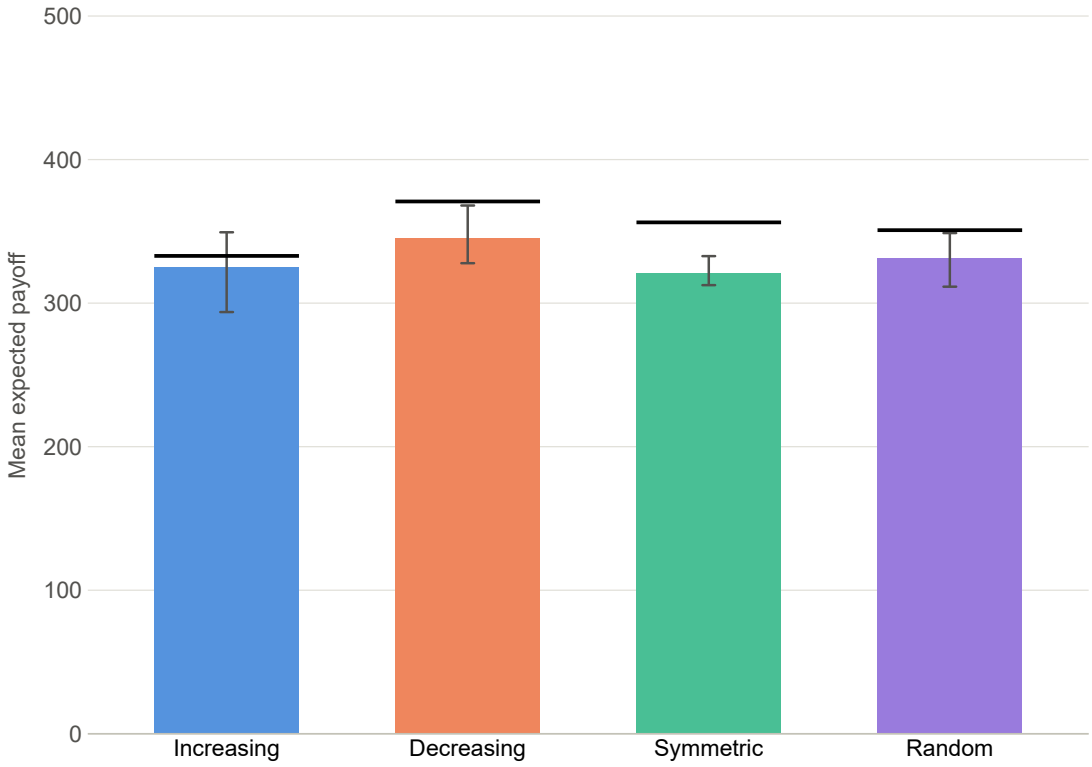


Figure 11: Expected Payoffs, Last 10 Rounds

Notes: Mean expected payoff by treatment given contributions and corresponding probabilities of winning in each stage. Black lines show theoretical predictions. Data from last 10 rounds. Error bars represent 95% wild cluster bootstrap confidence intervals.

Table 8: Mean Expected Payoff, Last 10 Rounds

	Mean	Equilibrium
Increasing	325.036	332.91
	[293.782, 349.353]	
Decreasing	344.885	370.81
	[327.807, 367.983]	
Symmetric	320.917	356.25
	[312.527, 332.746]	
Random	330.990	350.83
	[311.452, 348.806]	
Observations	1920	
Clusters	24	

Notes: Mean expected payoff and theoretical predictions by treatment given contributions and corresponding probabilities of winning in each stage. 95% wild cluster bootstrap confidence intervals in brackets. Data from last 10 rounds.

Table 9: Group Stage Contributions on Lagged Variables

	Increasing	Decreasing	Symmetric	Random
Own Group Stage Contribution	0.671***	0.777***	0.589***	0.462***
	[0.363, 0.811]	[0.529, 0.885]	[0.359, 0.887]	[0.344, 0.536]
Mate Group Stage Contribution	0.023	0.023	0.049	0.048
	[-0.019, 0.099]	[-0.027, 0.145]	[-0.012, 0.103]	[-0.061, 0.107]
Opponent Group Total Contributions	0.053**	0.042***	0.038	0.099***
	[0.002, 0.105]	[0.028, 0.058]	[-0.012, 0.095]	[0.054, 0.126]
Won Group Stage	3.781*	-2.950	-2.438	-0.309
	[-0.722, 8.309]	[-9.488, 2.964]	[-5.908, 1.053]	[-9.700, 10.116]
Won Individual Stage	2.078	4.738**	6.117**	2.337
	[-2.685, 7.004]	[1.252, 10.534]	[2.277, 10.024]	[-3.904, 9.213]
Observations	3648			
Clusters	24			

Notes: Regression of group stage contributions on lagged variables. Round 1 data omitted. 95% wild cluster bootstrap confidence intervals in brackets.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 10: Individual Stage Contributions on Lagged Variables

	Increasing	Decreasing	Symmetric	Random
Own Individual Stage Contribution	0.480***	0.513***	0.438**	0.368***
	[0.384, 0.639]	[0.298, 0.788]	[0.300, 0.675]	[0.221, 0.518]
Mate Individual Stage Contribution	0.075**	-0.002	0.082**	0.052
	[0.010, 0.125]	[-0.088, 0.113]	[0.002, 0.132]	[-0.057, 0.138]
Won Group Stage	-6.797	-14.284*	-20.388	-15.759**
	[-21.465, 7.762]	[-29.989, 1.798]	[-45.815, 7.564]	[-30.522, -4.311]
Won Individual Stage	10.716	-9.957	15.701	-3.047
	[-13.452, 37.562]	[-37.182, 24.708]	[-11.179, 38.556]	[-24.748, 12.666]
Current Group Stage Contribution	0.151	-0.036	-0.171	0.097
	[-0.036, 0.549]	[-0.371, 0.418]	[-0.407, 0.182]	[-0.157, 0.427]
Observations	3648			
Clusters	24			

Notes: Regression of individual stage contributions on lagged variables controlling for current period group stage contributions. Round 1 data omitted. 95% wild cluster bootstrap confidence intervals in brackets.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

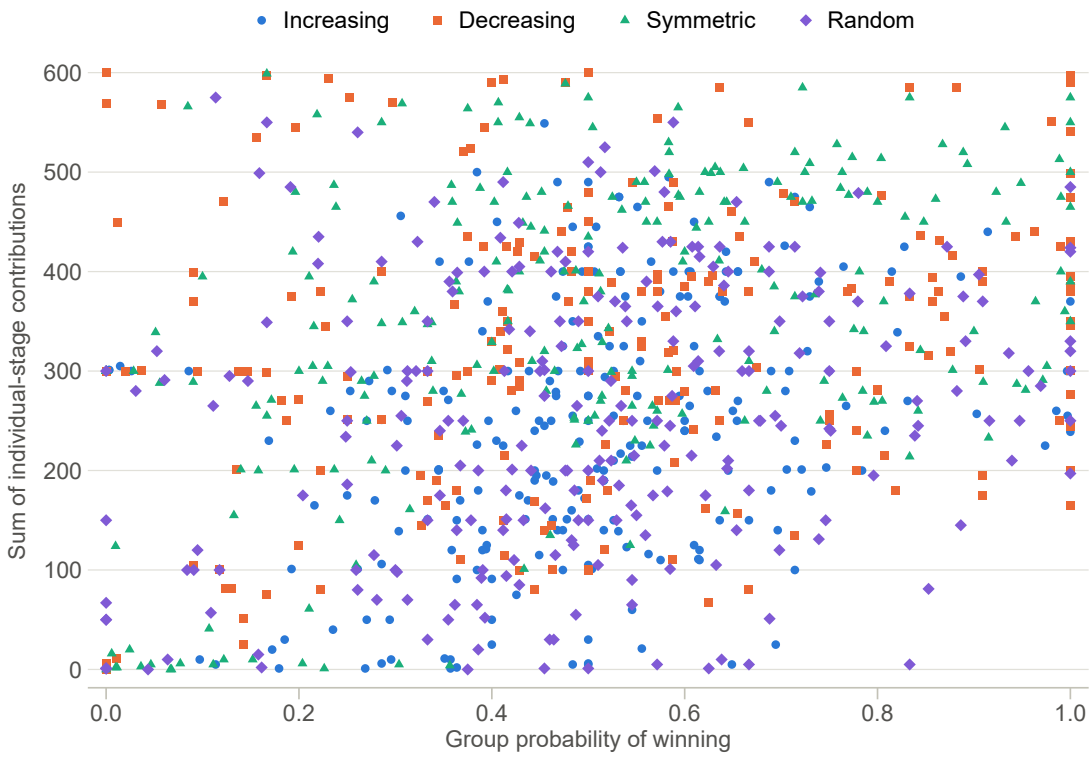


Figure 12: Sum of Ind. Stage Contributions over Group Probability of Winning, Last 10 Rounds

Notes: Raw data on each group's sum of individual stage contributions over their probability of winning the group stage by treatment. Data from last 10 rounds.

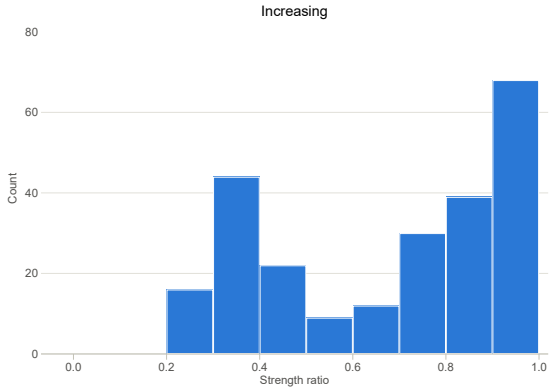


Figure 13: Histogram of Strength Ratios, Increasing, Last 10 Rounds

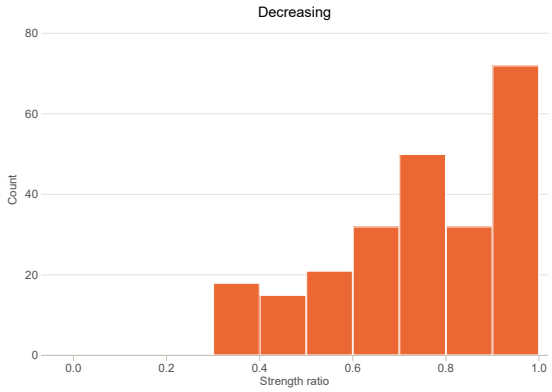


Figure 14: Histogram of Strength Ratios, Decreasing, Last 10 Rounds

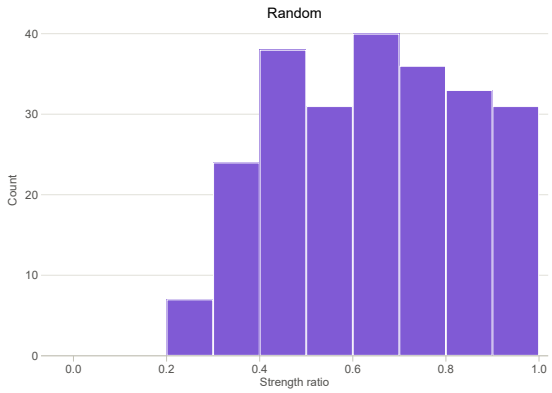


Figure 15: Histogram of Strength Ratios, Random, Last 10 Rounds

Table 11: Individual Stage Contributions on Group Stage Contributions, Last 10 Rounds

	(1)
Increasing	-27.564
	[-82.407, 22.681]
Decreasing	42.685*
	[-2.710, 85.942]
Symmetric	52.517***
	[20.889, 81.519]
Group Stage Contribution	0.084
	[-0.122, 0.251]
Increasing × Group Stage Contribution	0.365
	[-0.322, 1.355]
Decreasing × Group Stage Contribution	-0.282
	[-0.720, 0.153]
Symmetric × Group Stage Contribution	-0.081
	[-0.390, 0.386]
Constant	121.506***
	[99.595, 152.096]
Observations	1920
Clusters	24

Notes: Individual stage contributions on treatment dummies and group stage contributions plus interaction terms. Data from last 10 rounds. 95% wild cluster bootstrap confidence intervals in brackets. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 12: Sum of Individual Stage Contributions by Strength Ratio, Last 10 Rounds

	(1)
Increasing	-108.532
	[-285.247, 80.160]
Decreasing	148.217
	[-107.076, 391.347]
Strength Ratio	117.558
	[-110.165, 298.427]
Increasing × Strength Ratio	140.208
	[-103.650, 398.266]
Decreasing × Strength Ratio	-120.923
	[-418.055, 187.955]
Constant	175.749**
	[29.989, 319.788]
Observations	720
Clusters	18

Notes: Sum of individual stage contributions in a group on strength ratio. Random is the omitted category. Symmetric treatment not included. Data from last 10 rounds. 95% wild cluster bootstrap confidence intervals in brackets.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 13: Individual Stage Contributions by Treatment and Type, Exact, Last 10 Rounds

Type	Increasing	Decreasing	Symmetric	Random
Equal	133.48	122.90	174.10	.
	[16.08,169.11]	[49.92,177.17]	[151.60,188.34]	
Strong	134.64	182.32	.	138.75
	[109.32,169.79]	[119.49,235.84]		[114.09,165.05]
Weak	105.03	155.18	.	112.97
	[78.40,138.59]	[112.47,205.79]		[88.95,142.33]

Notes: Mean individual stage contributions by treatment and type. Estimates from regressing individual stage contribution on treatment dummy and type dummy. Equal types have exactly equal strengths. Data from last 10 rounds. 95% wild cluster bootstrap confidence intervals in brackets.

Table 14: Individual Stage Percent Deviation by Treatment and Type, Last 10 Rounds

Type	Increasing	Decreasing	Symmetric	Random
Equal	-0.02	-0.11	0.16	-0.16
	[-0.52,0.19]	[-0.36,0.22]	[0.01,0.26]	[-0.44,0.06]
Strong	0.01	0.29	.	0.03
	[-0.22,0.25]	[-0.18,0.72]		[-0.14,0.23]
Weak	-0.28	0.09	.	-0.18
	[-0.50,0.02]	[-0.22,0.42]		[-0.37,0.02]

Notes: Mean percent deviation from individual stage Nash equilibrium by treatment and type. Estimates from regressing percent deviation on treatment dummy and type dummy. Data from last 10 rounds. 95% wild cluster bootstrap confidence intervals in brackets.

Table 15: Individual Stage Percent Deviation by Treatment and Type, Exact, Last 10 Rounds

Type	Increasing	Decreasing	Symmetric	Random
Equal	-0.11	-0.18	0.16	.
	[-0.89,0.10]	[-0.67,0.18]	[0.01,0.26]	
Strong	0.01	0.29	.	0.01
	[-0.19,0.26]	[-0.17,0.71]		[-0.16,0.21]
Weak	-0.25	0.09	.	-0.18
	[-0.46,0.06]	[-0.21,0.42]		[-0.37,0.02]

Notes: Mean percent deviation from individual stage Nash equilibrium by treatment and type. Estimates from regressing percent deviation on treatment dummy and type dummy. Equal types have exactly equal strengths. Data from last 10 rounds. 95% wild cluster bootstrap confidence intervals in brackets.

Table 16: Individual Stage Contributions on Strength Ratio, Type, and Treatment, Last 10 Rounds

	(1)
Increasing	-93.848
	[-223.277, 53.585]
Decreasing	30.445
	[-75.594, 134.591]
Strong	35.167
	[-22.598, 103.623]
Strength Ratio	66.043
	[-67.126, 185.091]
Increasing × Strong	63.421
	[-41.109, 159.908]
Decreasing × Strong	-3.616
	[-342.841, 263.950]
Increasing × Strength Ratio	132.565
	[-46.213, 308.889]
Decreasing × Strength Ratio	12.561
	[-118.031, 154.025]
Strong × Strength Ratio	-14.529
	[-93.849, 56.579]
Increasing × Strong × Strength Ratio	-92.010*
	[-187.445, 1.515]
Decreasing × Strong × Strength Ratio	8.168
	[-329.252, 435.398]
Constant	70.291
	[-32.503, 157.147]
Observations	1314
Clusters	18

Notes: Individual stage contributions on strength ratio, type and treatment dummies. Random and Weak are the omitted categories. Only data on groups with asymmetric strengths included. Data from last 10 rounds. 95% wild cluster bootstrap confidence intervals in brackets.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 17: Slope Coefficients on Strength Ratio by Type, Last 10 Rounds

	Increasing	Decreasing	Random
Weak	198.608***	78.604*	66.043
	[42.427, 313.879]	[-0.715, 151.050]	[-67.126, 185.091]
Strong	92.069**	72.244	51.514
	[2.399, 161.794]	[-230.157, 355.439]	[-47.097, 146.413]
Observations		1314	
Clusters		18	

Notes: Slope coefficients on strength ratio from regression of individual stage contributions on strength ratio, type, and treatment. Data from last 10 rounds. 95% wild cluster bootstrap confidence intervals in brackets.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 18: Strong Player Share of Individual Stage Contributions on Strength Ratio, Last 10 Rounds

	(1)
Increasing	0.327**
	[0.032, 0.584]
Decreasing	-0.259
	[-0.979, 0.323]
Strength Ratio	-0.145*
	[-0.315, 0.071]
Increasing × Strength Ratio	-0.436***
	[-0.723, -0.148]
Decreasing × Strength Ratio	0.242
	[-0.503, 1.146]
Constant	0.694***
	[0.558, 0.839]
Observations	657
Clusters	18

Notes: Stronger player's share of total individual stage contributions in a group on strength ratio and treatment dummies plus interaction terms. Random is the omitted category. Only data on groups with asymmetric strengths included. Data from last 10 rounds. 95% wild cluster bootstrap confidence intervals in brackets. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

C Experiment Instructions (Increasing Treatment)

Introduction

Thank you for participating in today's experiment. You will be participating in a type of market in which your earnings will depend on your own decisions and the decisions of other participants. Your total earnings, including your $7 show-up fee, will be paid to you privately at the end of the experiment. Please remain quiet and do not communicate with other participants.

We would not want anyone's earnings to suffer because you did not understand the rules of how these markets operate. If you have a question or a problem during the experiment, we encourage you to raise your hand and one of the experimenters will do their best to try and answer it for you. We cannot tell you what a good or bad decision is for you, but we will gladly help explain the rules.

In the experiment, your payoffs will be denominated in points. We will explain in a moment how points are converted into U.S. dollars. All amounts in this experiment are expressed in points. The exchange rate is 1 point = $0.01. This part of the experiment consists of a sequence of 20 decision rounds.

Pairing and matching

At the beginning of the experiment, you will be randomly placed into a pool of 8 participants. You will remain in this pool for the duration of the experiment, and you will only interact with the other members of your pool.

Within each round, you will be paired in a group with one other participant. Your group will then be matched with another group of two different participants. Between rounds, you'll be randomly re-paired with another group member and randomly rematched with another group.

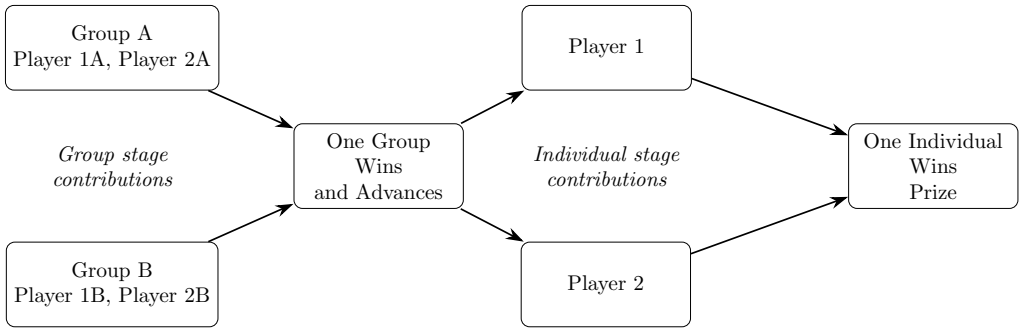
Endowment

At the beginning of each round, you will be given an endowment of 300 points. You may use any number of these points to make decisions in a given round.

Round Overview

Each round consists of two stages: the group stage and the individual stage. In the group stage, two groups will compete to determine which group advances to the individual stage. In the individual stage, members of the winning group will compete with each other for a prize. Your task will be to contribute points from your endowment to the competition in each stage. Ultimately, only one out of the four players that enter a match in each round will win the prize. This player must belong to the winning group and win the individual stage.

The following flow chart summarizes how each round will proceed:



Payoffs

The payoff from each round will depend upon the outcomes in both stages in the following way:

$$\text{Round payoff} = \underbrace{300}_{\text{Endowment}} - \text{group stage contribution} - \underbrace{\text{individual stage contribution}}_{\text{only if group wins}} + \underbrace{600}_{\substack{\text{Prize}\\ \text{only if group wins}\\ \text{\& individual wins}}}$$

In each round, you earn your endowment of 300 points minus the points you contribute to the group stage. If your group wins, you also pay the points you contribute to the individual stage. Finally, if you are the one individual who wins the prize, you receive 600 points.

Group Stage

In the group stage, two groups of two players will compete to determine which group advances to the individual stage. You will decide how many points you wish to contribute to your group. You can contribute any integer number between 0 and 300 (0 and 300 inclusive). Any points which you don't contribute in this stage will remain with you for the next stage. Your group's total contributions will be the sum of the contributions of you and your group mate.

You can't earn any additional points in the group stage. You compete only for the right to advance to the individual stage where you will have the opportunity to compete for a prize.

What is the likelihood that your group wins?

Only one of the two groups can win. Your group's likelihood of winning is computed as the share of your group's contributions in the total contributions from both groups. The **probability that your group wins** is given by:

$$\frac{\text{your group's contributions}}{\text{your group's contributions+other group's contributions}}$$

If all players contribute 0 points, then the probability that your group wins is $\frac{1}{2} = 50.00\%$.

Once every player has submitted their contributions, the computer program will use the probabilities of winning to determine which group advances to the individual stage.

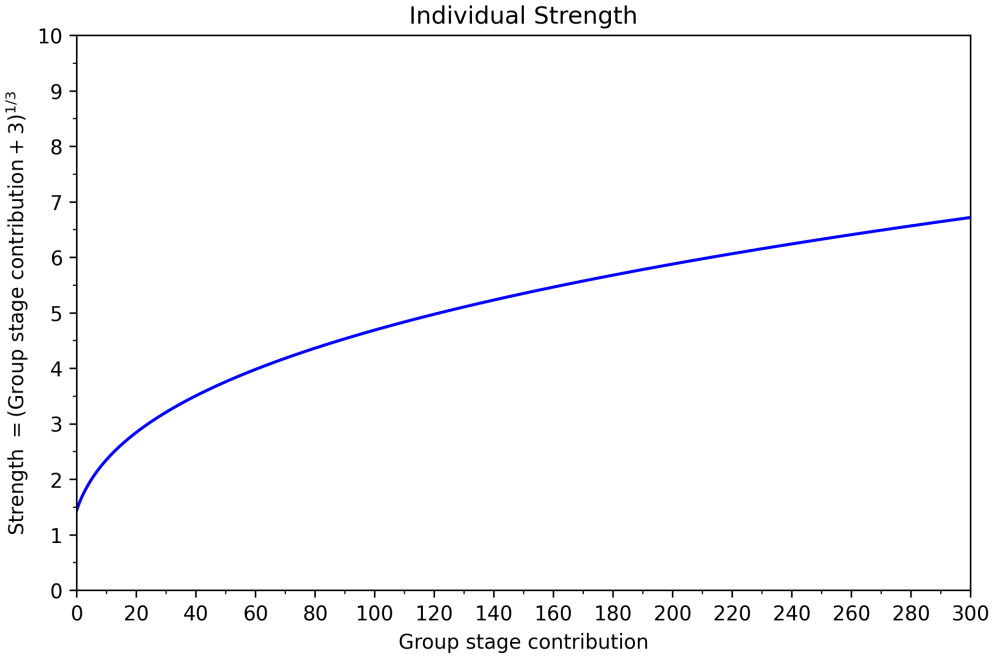
Individual Stage

In the individual stage, you will compete with your group mate for a prize of 600 points. At this point, you won't know whether your group won or lost in the group stage. You will make your decision in the individual stage as if your group won.

You will choose how many points you wish to contribute to the individual competition. You can choose any integer number less than or equal to your **remaining endowment**. Your **remaining endowment** is the share of your endowment that you didn't contribute in the group stage (300 − group stage contribution). The more points you contribute in the group stage, the fewer points you have to contribute in the individual stage.

Individual strength and multiplied contribution

Your contribution in this stage will be multiplied by your individual **strength** which depends on your group stage contribution. The following figure illustrates how group stage contribution determines strength:



Notice, the *more* points you contribute in the group stage, the *higher* your strength will be in the individual stage. Your group mate's individual stage contributions will be multiplied by his/her strength which depend on his/her group stage contributions in the same way.

Your multiplied contribution is the product of your individual stage contribution and your strength:

$$\text{Multiplied contribution} = \text{your individual stage contribution} \times \text{your strength}$$

What is the likelihood that you win the individual stage? Only one of you or your group mate can win the individual stage. The likelihood that you win is the share of your multiplied contribution in the total multiplied contributions of both you and your group mate. The **probability that you win** is given by:

$$\frac{\text{Your multiplied contribution}}{\text{Your multiplied contribution} + \text{your group mate's multiplied contribution}}$$

If you and your group mate both invest zero, then the probability that you win is:

$$\frac{\text{Your strength}}{\text{Your strength + your group mate's strength}}$$

Once every player has submitted their contributions, the computer program will use the probabilities of winning to determine which individual wins the prize.

How are your earnings determined?

You will participate in a series of 20 decision rounds. Before the experiment began, **four** of these rounds were chosen randomly (with all rounds being equally likely to be chosen) to determine your earnings. At the end of the experiment, you will be informed about which four rounds were chosen and your payoff from each of those four rounds. Then your earnings from the experiment will be the sum of your payoffs from the four randomly selected rounds.