# *A Theory and Experiment of how Competitive Bargaining can Lead to Efficient Coordination*

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**Abstract**

Synergies in production are ubiquitous in shared production processes such as those involving individuals within a team, departments within a firm, or industries within a country. Using a weakest-link game with ex post bargaining to redistribute the joint surplus we study a situation in which no central manager (or principal) can induce coordination through contracts, but instead team members themselves decide how to compensate each other. We show that standard bargaining theory (stationary equilibria) predictions do not provide a rationale for selecting efficient outcomes among the multiple Pareto-ranked equilibria. Nevertheless, we propose history-dependent bargaining strategies based on members' contributions which refine the set of equilibria selecting only the most and least efficient outcomes. An experiment shows that ex post bargaining leads to enhanced efficiency compared to the benchmark weakest link game. This is a particularly strong result since we implement a random subject rematching protocol. When efforts are not publicly known (due to monitoring costs for example) average effort levels fall close to those observed in the control. Our results provide a rationale for the role of democracy in attaining efficient economic outcomes and explain why firms and partnerships might implement ex post profit-sharing or other participatory compensation mechanisms within them.

# I. Introduction

Collectivities often operate under conditions in which coordinated actions among their members are crucial for attaining highly efficient aggregate outcomes. The need to coordinate is particularly salient in productive processes characterized by the presence of complementarities or synergies between inputs which are often present in joint tasks performed by partners in a team, departments within a firm, or sectors within an economy.[1] It is well-established that when shared production processes display both complementarities in strategic decisions and externalities, game theoretic models usually display multiplicity of equilibria (Cooper and John 1988, Milgrom and Roberts 1995), rendering standard notions of equilibrium ineffective for predictive purposes. Since teams, firms, and countries can end up steady in suboptimal outcomes, it becomes crucial to understand which mechanisms or institutional variables are conducive to selecting equilibria that are better for the collectivity in terms of welfare.

In this article we provide a theoretical framework and conduct laboratory experiments to study coordination possibilities when claims to the total joint surplus are defined ex post via bargaining in the absence of a central authority and where no ex ante contracts can be credibly (or feasibly) specified. Can a group of individuals achieve efficient coordination by governing themselves through ex post negotiations? Can a democratic and participatory system foster efficient outcomes? This line of inquiry diverges from previous studies that have highlighted the role of centralized management[2], such as Milgrom and Roberts (1995) who state that their "results also suggest a reason why change in a system marked by strong and widespread complementarities may be difficult and why centrally directed change may be important for altering systems (pgs. 190-191)."[3] Our experimental investigation

[1] At the aggregate economic level, the role of synergies across productive sectors are essential to attain high productivity levels as evidenced in the seminal paper by Hirschman (1958) on the role of backward and forward linkages. See also Rodríguez-Clare (1996a,b) for the role of production complementarities in economic outcomes of small open economies.

[2] The role of the entrepreneur as a centralized, non-market coordination device was seminally proposed by Coase (1937) when he described the nature of the firm.

[3] Similarly, Alchian and Demsetz (1972) argue that in a team production process "[o]ne method of

also distinguishes itself from studies that have focused on the effect of centralized decisions with ex ante commitment such as the exogenous implementation of financial incentives to coordinate on efficient outcomes (e.g. a performance bonus) as in Brandts and Cooper (2005) or the role of a manager in endogenously fostering coordination through bonuses and communication channels as in Brandts and Cooper (2006). The experiments conducted here provide an affirmative answer to our question on the effectiveness of ex post multilateral bargaining to coordinate on *better equilibria*: subjects achieve high efficiency gains when they can negotiate the division of a jointly produced surplus compared to the implicitly preestablished equal division.

We interpret our setting as a team production process through a voluntary contributions or effort choices with a democratic redistributive institution: ownership rights over the surplus created are undefined but all members have *equal bargaining rights*.[4] Thus, collective production yields a surplus from which agents can be excluded ex post but all are equally likely to influence the final outcome ex ante. Specifically, we endogenize the origin of the fund to distribute through a weakest-link game (Bryant 1983, Hirschleifer 1983, van Huyck et. al 1990), an extreme case of productive synergies in which the player exerting the lowest effort (or investment) determines the total output. As Knez and Camerer (1994) argue, the weakest-link game serves as an abstraction that captures a wide range of shared production processes in firms and teams.

After production has taken place, team members negotiate according to the protocol of alternating offers and voting developed by Baron and Ferejohn (1989; BF hereafter).[5]

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reducing shirking is for someone to specialize as a monitor to check the input performance of team members (pg. 781)".

[4]In our model we abstract away from the formation process of the alliance, team, or firm. Moreover, we study the case where all of production is subject to ex post renegotiation. It would be straighforward to extend our model to the case where part of the surplus is allocated according to some preestablished property rights.

[5]One can implement other bargaining protocols such as an offer and exit model by Krishna and Serrano (1995) or the demand bargaining game by Morelli (1999). We focus on the Baron and Ferejohn closed-rule bargaining game because it has received wide attention within the theoretical literature (Eraslan 2002, Yildirim 2007; Merlo and Wilson , Eraslan and Merlo 2002; Baranski 2016) and the experimental literature (Fréchette, Kagel, and Morelli 2005a,b,c; Agranov and Tergiman 2014; Baranski and Kagel 2015; Bradfield and Kagel 2016).

It is well known that multilateral bargaining games of sequential offers and voting such as the BF studied here, display multiplicity of subgame perfect equilibrium outcomes (Sutton 1986; BF 1989; Eraslan 2002), namely that any division of the surplus can be sustained. Thus, which equilibrium is selected (coordinated upon) in the bargaining game can in turn affect which effort levels are provided in the weakest-link surplus-creation stage. In this sense our game presents a unique setting to study a *dual equilibrium selection problem*: how bargaining strategies affect initial efforts and vice-versa. One natural conjecture is that adding a strategically complex bargaining game further complicates the possibility of coordination in the production game. Moreover, the plurality of fairness ideals which have been identified in previous divide-the-dollar experiments with production (Capellen et al. 2007) may lead to bargaining outcomes which are viewed as fair by some subjects and unfair by others, which in turn may attenuate incentives to exert effort into the joint task. In the article, we explore theoretically how various bargaining strategies based on previously documented fairness ideals can affect the set of equilibrium effort choices.

We show that bargaining strategies that stem from an egalitarian fairness ideal, either an equal split or a split that minimizes final payoff differences, do not refine the set of equilibrium effort choices and neither does the stationarity refinement typically assumed in multi-stage models of multilateral of bargaining. However, efficient coordination can be selected under bargaining strategies that resemble ideals of fairness in which higher contributors are rewarded with larger shares of the fund. These bargaining strategies are rooted in psychological notions of inequity (Adams 1963; Selten 1987) and punishment (Fehr and Gächter 2000, 2002). Importantly, the proposed strategies do not rule out the secure equilibrium of zero effort which implies that our experimental inquiry of the weakest-link game remains one of equilibrium selection.[6]

[6] We can show that regardless of the bargaining strategies employed, the risk-dominant action of no effort always remains an equilibrium of the game. This only holds when the total surplus is zero if at least one player chooses the lowest effort which is the case in our main treatments. In a follow-up treatment, we introduced an exogenous component such that the total fund to distribute would be positive even if the minimum effort was zero and find evidence of a reduction in the choice of zero effort and an increase in amount of maximum effort choices, with average investments being marginally higher.

Three main experimental treatments were conducted to test the role of redistributive bargaining on effort choice. In the first treatment, subjects made effort decisions (or investments) and proceeded to bargain over the distribution of the fund with public information about the everyone's investment decision. In a second bargaining treatment individual investments were not observable, only the total fund. Next, we conducted a benchmark treatment corresponding to the canonical weakest link game without bargaining. Based on previous studies we believe that our experimental design is such that coordination (i.e. all group members making the same effort choice) is difficult to achieve, more so at efficient levels. First, we implement a strangers matching protocol so that reputation concerns within the experiment are mitigated. Second, the effort choice set is typically restricted to seven or less choices in the previous studies, but our experiment allows a much larger range of effort choices which substantially diminishes the possibility to coordinate on any given level.

Our results show that ex post bargaining gives rise to large efficiency gains as measured by subjects' investments which are close to 65 percent of their endowment on average. In the control treatment, investments rapidly decline and average 5 percent of endowment (both results are for the last 5 out of 10 games played by subjects). Most subjects assign shares of the fund based on a punishment and reward strategy where the lower contributors are usually excluded from the allocation. We also find evidence for the implementation of a proportionality standard of redistribution in which a player's share is proportional to her investment relative to the aggregate investments.[7] Both of these strategies roughly approximate our theoretical characterization and largely explain the efficiency gains of the bargaining treatment with observable investments. Opportunistic behavior represents less than 10 percent of observed bargaining outcomes, and equal splits of the fund are rare too. As further evidence in favor of our investment-based bargaining theory we find that in the absence of a collective and public history of efforts, competitive bargaining does not lead to efficient coordination.

[7] The proportionality standard is also referred to as *liberal egalitarianism* in Capellen et al. (2007) which "holds that only inequalities that arise from factors under individual control should be accepted. (pg. 818)"

We developed two variations in which contributions also directly influenced bargaining institutional variables that were exogenously fixed in our main treatments. In the first variation, a member's probability of proposing was determined proportionally to her contribution. For instance, this modification can capture an important social norm in which higher contributors are more likely to guide the bargaining process or a formal agreement in which proposal rights are positively related to efforts. The struggle for proposal rights is modelled as a contest (Tullock 1980) where higher efforts lead to proportionally higher chances of being the agenda setter, with the caveat that efforts are productive. In the second variation, a member's voting weight is endogenously determined proportionally to her effort choice, potentially altering the set of winning coalitions (e.g. the number of players whose vote is needed for approval). We find that in both treatments the proportion of subjects choosing the highest effort increases. Nevertheless, the dispersion of efforts is larger in the endogenous voting shares treatment, leading to a fall in efficiency while in the endogenous proposal rights treatment, efficiency increases relative to the main treatment. Thus, we argue that endogenous asymmetries on proposing rights seem to be beneficial for the democratic redistributive process but the one-player one-vote principle fares better with respect to the endogenous voting shares.

The article proceeds as follows. Section 2 presents a literature review on the weakest link game, bargaining a la Baron and Ferejohn, and other experiments on bargaining over an endogenous fund. Next, we provide the theoretical setup in Section 3 followed by our equilibrium predictions in Section 4 which will serve as our testable hypotheses for experimental evaluation. Section 5 describes the experimental procedures. The results for the main treatments are presented in Section 6 and Section 7 contains the endogenous proposer and voting weights treatments. Finally, section 8 concludes the article.

## *II. Previous Literature*

To study synergies in production we employ the classical weakest-link game (also known as the minimum effort game) in which the total surplus available to a group is determined by the member exerting the lowest effort. This game, as proposed by Hirshleifer (1983), was originally formulated in the context of a public good provision problem in which the surplus was shared equally among all members of the group. Simultaneously, Bryant (1983) proposed it as the production process of an intermediate good in a Keynesian model with multiple sectors in the economy. In the words of Bryant, "[t]his production technology is, of course, very artificial and simple. Nevertheless, it may capture the essence of the specialized, multi-staged, and decentralized production that characterizes an advanced economy" (pg. 526). Importantly, it can be shown that the fixed proportions characteristic of this technology is a limiting case of the well-known Cobb-Douglas production function, which Cornes (1993) labels as a "weaker-link" game.

Besides its relevance in the fields of Political Economy, Macroeconomics, and Organizational Behavior, the weakest-link game has been a workhorse model in game theory and experimental economics to study coordination and equilibrium selection. It predicts multiple Pareto-ranked equilibria ranging from the lowest to the highest attainable efficiency. Since higher levels of effort are more costly than lower levels, members who seek to be safe and maximize their well-being in the worst case scenario will actually exert the lowest level of effort (as predicted by the risk dominance selection criterion). Some might argue that the efficient outcome can be focal in the sense of Schelling (1960), but ultimately which equilibrium will be played is an empirical question suitable for study under controlled experimentation.

The experimental literature has offered strong evidence in favor of the risk-dominant equilibrium given the low effort levels typically observed after a few repetitions of the game (see Weber (2006) for a concise review), except in very small groups in which efficient coordination is modal. Several mechanisms that promote coordination on the efficient equilibrium have been studied in the laboratory such as intergroup competition (Bornsteing, Gneezy, and

Nagel 2002), implementing a bonus (Brandts and Cooper 2006a), starting in small groups and expanding to larger groups (Weber 2006), and endogenous group formation (Riedl, Rhode, and Strobel 2016).[8] This latter study by Riedl, Rhode, and Strobel is particularly relevant to ours because it allows for ex ante exclusion on the benefits produced, while our game allows for ex post exclusion through bargaining. The enhanced efficiency levels they observe are explained through social ostracism based on history: those who exerted low effort in the past are excluded from the possibility to take part in productive endeavors with others. Our experiments reveal that a similar mechanism is at play with ex post bargaining, namely the fear of exclusion based on the expectation that bargaining outcomes will punish low contributors, an expectation which materializes through an implicit coordination on bargaining strategies.

As previously stated, the Baron and Ferejohn model of bargaining has multiple equilibria: any allocation of the surplus can be sustained as a subgame perfect Nash equilibrium given that players are patient enough. The theoretical literature has mainly focused on history-independent strategies since a unique subgame perfect equilibrium outcome is derived which yields an expected value equal to the total surplus divided by the number of members in the committee. This expected value coincides with the same payoff structure as the standard weakest-link game with preestablished equal shares. As such, there is no role for ex post bargaining in equilibrium selection of the weakest-link game under the stationarity refinement.

While history-independent bargaining strategies have been universally adopted in the theoretical bargaining literature[9], and have been the object of multiple experimental inquiries (Fréchette, Kagel, and Morelli 2005a,b,c) the experiments in Baranski (2016) show that when the fund to distribute is endogenous in the BF game, such strategies do not accurately describe subjects' behavior in the laboratory. In the Baranski (2016) experiments, the

[8] Croson, Fatas, Neugebauer (2005) show that an unexpected restart of the experimental session will also lead to an increase in effort provision, which will decay with repetition.

[9] See for example Merlo and Wilson (1995), Eraslan (2002), Britz, Herings, and Predtetchinski (2013) all who assume stationarity.

total fund was endogenized via individual investments which were summed up to determine the total fund (investments are efficiency enhancing). Importantly, the linear aggregation technology is tantamount to the inexistence of synergies in production, thus the dilemma faced at the production stage is not one of coordination. Those experiments revealed that redistribution strategies were largely conditioned on initial efforts: higher efforts were rewarded with higher shares of the collective fund.[10] Besides the principle of proportionality, another strategy employed by subjects was that members contributing below the group's median investment were typically excluded from the allocation of the surplus (given a majority voting rule, redundant members' votes were not required for approval).

Under the weakest link production technology the exclusion of low investors and the proportional redistribution strategies are also plausible but might not always entail effort-inducing incentives because the available fund may could be insufficient to cover the aggregate effort costs. In the extreme case in which one player exerts no effort, there is no surplus to disburse among the remaining members. Thus, the dynamics that gave rise to full efficiency in the Baranski (2016, 2017) experiments are quite fragile with extreme partner synergies as in the minimum effort game.

Our experiment is also related to a growing literature on distribution of an endogenous fund. In simple dictator games, Capellen et al. (2007) assign subjects to different marginal productivities in a linear production setting in order to identify various fairness ideals from observing subjects' ex post allocations. For example, the libertarian ideal would imply a distribution of the joint production according to individual production. Importantly, this ideal can only be concretely applied in an additively separable production setting, but not in the weakest-link setting in which it is not clear *who produced what*. The liberal egalitarian principle disregards differences in productivities and assigns the output proportionally based on individual contributions. In our theoretical setting, we propose a proportional re-

[10] In the linear setting, the proportional redistribution strategies are equivalent to a piece-rate contract. Since there are no complementarities in production, each player can fully appropriate the surplus she generated. Hence, the unique equilibrium under proportional redistribution strategies is fully efficient.

distribution scheme in which the total surplus is split according to the ratio of own effort to aggregate effort, much in line with this principle. Capellen et al. (2007) also consider the egalitarian outcome which they characterize as an equal split of the total fund.[11] The main finding that they report is that there is considerable plurality in fairness ideals even among a relatively homogeneous population of business students and that standard models of inequality aversion (Fehr and Schmidt 1999; Bolton and Ockenfels 2000) are not useful in explaining the results. Konow (2000) and Frolich, Oppenheimer, and Kurki (2004) also investigate behavior in dictator games with joint production and Gantner, Güth, and Königstein (2001) implement ultimatum and demand bargaining protocols. All these studies report a significant tendency of subjects to derive entitlements from their own investments.

In bilateral negotiations with unstructured protocols, the experimental study of Gächter and Riedl (2005) is relevant to ours with the caveat that the total fund is portrayed in the instructions as if it was jointly produced, but no production function is explicitly described. In their study, subjects participated in quiz in which the highest performer would earn 1660 tokens and the lowest performer only 830. However, there was a chance that the total budget for both payments was lower (2050 tokens) case in which the experimenter would not impose a division and subjects would have to reach an agreement themselves. In other words, when the claims of 1660 and 830 were infeasible, free-from negotiations would take place. The authors find that initial entitlements have a strong impact in bargaining outcomes by altering initial offers and concessions throughout the process. In a similar quiz design, Karagözoglu and Riedl (2014) did not provide exogenous entitlements, but allowed them to form endogenously. They varied the information available about individual quiz performance and found that subjective claims are more likely to be derived in settings with high information and less likely to be derived and subsequently impact bargaining outcomes when subjects are unaware of who performed better in the team.

In structured multilateral bargaining, Gantner, Horn, and Kerschbamer (2016) designed

[11] We depart from this definition and instead characterize the egalitarian outcome as the distribution of the fund which equalizes *final wealth holdings.*

an experiment to test how different bargaining protocols perform when the total surplus is jointly generated. Subjects participated in an individual quiz but were graded according to their performance relative to members of their cohort. Afterwards, subjects from different cohorts were matched in three-person committees and the total surplus was determined through a non-linear function of the points earned in the previous quiz. The goal of the researchers was to create an environment conducive to the emergence of conflicting subjective views on how to split the total fund in order to investigate which protocols would lead to more efficient bargaining outcomes (i.e. less delay). Answers to survey questions (from stakeholders and also from impartial spectators using a vignette technique) clearly showed that there were conflicting views especially when all group members earned different points in the quiz. The authors find that the bargaining protocol proposed by Shaked (an extension of the Rubinstein (1982) to three players in which players sequentially take turns at making proposals and voting) performed better compared to the others in terms of fairness since it leads to outcomes which are closer to the elicited fair outcomes. In terms of efficiency, all protocols were quite similar.[12] The authors did not consider the Baron and Ferejohn (1989) model, and furthermore, subjects were unaware of the bargaining protocol they would face prior to answering quiz questions, thus no expectations about bargaining outcomes were formed at the surplus creation stage.

# III. The Model

Let there be $n$ (odd) number of players indexed by $i$ which are endowed with a unit of wealth normalized to 1. The game has two main stages. In the first stage, players simultaneously and independently choose an effort level $e_i \in [0, 1]$. The total fund is determined as follows

$$F(\mathbf{e}) = \alpha n e_{\min}$$

[12] The other protocols were the models of multilateral bargaining by Krishna and Serrano (1996) and demand bargaining by Torstensson (2009).

where $\alpha > 1$, $e_{\min} = \min\{e_1, ..., e_n\}$, and bold letters denote vectors as usual (the dimension of the vector can be inferred from the context). The parameter $\alpha$ can be interpreted as a productivity measure. We will only consider linear costs in this article, thus we normalize the marginal cost of effort to 1.

Subsequently, if $F(\mathbf{e}) > 0$, players proceed to a bargaining stage which is divided into bargaining rounds denoted by $t \in \{1, 2, ...\}$. In each round, a player $i$ is recognized as the proposer with probability $\pi_i$. The proposer submits an allocation $(s_1^t, ...s_n^t) \in S(\mathbf{e})$ where $s_j^t$ denotes the monetary amount offered to player $j$ and $S(\mathbf{e}) := \{(s_1^t, ...s_n^t)$ s.t. $\sum_{i=1}^n s_i^t = F(\mathbf{e})\}$ is the set of feasible, non-wasteful allocations. Next, players proceed to vote by choosing $v \in \{yes\ , no\}$, and if the proposal received $q$ votes, then it is approved and the result is binding. If the proposal is rejected, a new bargaining round takes place, with the proposer again being randomly selected. The process continues until approval.

In order to properly define the strategy space we let $h_t$ be the history of play up to bargaining round $t$ which includes all the previously rejected proposals, the identity of the proposers, and the distribution of votes. At the start of the bargaining stage, the history contains only the vector of efforts. At the voting stage, the history also contains the current proposal and proposer's identity. We denote by $H_t$ the set of all possible histories up to period $t$.

Formally, a proposal pure strategy in round $t \geq 1$ is defined as a function $s^t : H_t \rightarrow S(\mathbf{e})$ and a voting strategy is defined by $v^t : \{H_t, S(\mathbf{e})\} \rightarrow \{yes\ , no\}$.[13] A strategy profile $\boldsymbol{\sigma}^\tau = (\mathbf{e}, s^\tau, v^\tau)$ which leads to approval of a proposal in round $\tau$ yields to player $i$

$$u_i(\boldsymbol{\sigma}^\tau) = \delta^{\tau-1} s_i^\tau + 1 - e_i$$

where $\delta^{\tau-1} s_i^\tau$ is the discounted value of the share received from the common fund and $1 - e_i$ is the amount not invested (alternatively, the leisure enjoyed). The interpretation of this model is that players consume or enjoy their leisure (or the amount not invested) immediately while

[13] The standard assumption in the literature is the players vote in favor whenever indifferent.

the returns from the total fund are realized only after reaching an agreement. If the strategy profile never leads to approval, each player earns $1 - e_i$. As usual, $\delta \in [0, 1]$ represents the discount factor.

# IV. Equilibrium Characterizations

In this section we present our theoretical hypotheses based on different specifications of equilibrium behavior in the bargaining subgame. Our focus will be on pure strategies in the effort stage unless noted otherwise.

## *IV.a Stationary Subgame Perfect Equilibria*

We start by restricting attention to strategies which are subgame perfect, i.e. from which there is no profitable deviation at any point in time, and also stationary meaning that strategies are not dependent on the current period or history of play. This last assumption selects a unique equilibrium outcome in the bargaining subgame up to a permutation of the players' identities (see Baron and Ferejohn 1989; Eraslan 2002).

In this equilibrium, the proposer offers $\delta F(\mathbf{e})/n$ to $q - 1$ coalition members chosen randomly and keeps the rest. Proposals only depend indirectly on the effort vector $\mathbf{e}$ because efforts determine the size of the fund to distribute and the sum of shares must exhaust the fund.[14] All coalition partners vote in favor including the proposer and the proposal is approved without delay.[15]

Now that we have characterized equilibrium in the bargaining subgame we can compute the resulting ex ante value of the game (i.e. the expected payoff prior to the first proposer being selected) which equals the average fund given by $\alpha e_{\min}$. Hence, a player's total expected payoff is $\alpha e_{\min} - e_i + 1$ which is the standard payoff in the weakest link game with a unit

[14] One can express amount received as a percentage share of the total fund through a normalization, thus making it salient that bargaining strategies are independent of $\mathbf{e}$.

[15] Delay can be sustained in equilibrium for the case $\delta = 1$, yet the characterization of equilibrium remains.

cost of effort.[16] The lemma we present next follows from the analysis above.

Lemma 1. Under the stationary subgame perfect equilibrium of the bargaining game, any symmetric vector of efforts $\mathbf{e}$ can be sustained in equilibrium.

While stationarity selects a unique equilibrium configuration in the bargaining subgame it does not reduce the set of equilibria in the effort stage.

### *IV.b Subgame Perfect Equilibria*

We now allow for bargaining strategies to be history dependent, yet still require them to be subgame perfect. As Baron and Ferejohn show in Proposition 2 of their article, any allocation of the surplus can be sustained as a subgame perfect Nash Equilibrium as long as $n \geq 5$ and $\delta$ is large enough. In other words, for any given distribution of the total fund $\mathbf{s} = (s_1, ..., s_n)$, there exists a punishment strategy for players that deviate from making such proposal or enforcing the punishment strategy. Given the multiplicity of subgame perfect equilibria, a natural question to ask is if the initial efforts can aid in the selection of a particular allocation. Our goal is to identify strategies in which the redistribution of the surplus is conditioned on effort levels in such a way that coordinating on the efficient effort vector is selected as an equilibrium of the game. Formally, we wish to characterize $\mathbf{s}(\mathbf{e}) = (s_1(\mathbf{e}), ..., s_n(\mathbf{e}))$ such that $e_i = 1 \ \forall i$ is an equilibrium given that $\mathbf{s}(\mathbf{e})$ is the selected equilibrium of the bargaining subgame.[17]

[16] The result is trivially generalized for other cost structures.

[17] It is straightforward to notice that regardless of the bargaining strategies, the vector $\mathbf{e} = \mathbf{0}$ is always an equilibrium in our setting.

**Proportional Allocations**

We start by inspecting the proportional allocation rule. Under such allocation heuristic, a player's share of the fund in percentage is determined by

$$\bar{s}_i(e_i, e_{-i}) := \frac{e_i}{\sum_{j=1}^{n} e_j}$$

and the share of the fund in monetary terms is $\bar{s}_i(\mathbf{e})F(\mathbf{e})$.[18] This strategy yields payoffs of $\bar{s}_i(\mathbf{e})F(\mathbf{e}) - e_i + 1$.

The principle of proportionality fits the definition of an equitable allocation according to Adams (1963). Inequity arises when the proportion of rewards to costs for an individual differs to the proportion of rewards to costs of other individuals in the comparison group.[19] Selten (1987) argues that such principle is a natural prediction for bargaining games with entitlements. Thus, it is worth exploring how such bargaining outcomes would alter investment decisions in the weakest link game.

Lemma 2. Under the Proportional Allocation Rule in the bargaining game:

**1.** If $\alpha > \frac{n}{n-1}$ the only symmetric equilibria of the game are $\mathbf{e} = \mathbf{1}$ and $\mathbf{e} = \mathbf{0}$.

**2.** If $\alpha \in \left(1, \frac{n}{n-1}\right]$ any symmetric vector $\mathbf{e}$ is an equilibrium.

Proof. Consider any symmetric effort vector $\mathbf{e} = (e, ..., e)$ where $0 < e \leq 1$ from which we obtain that $F(\mathbf{e}) = \alpha n e$ and $\bar{s}_i(\mathbf{e}) = 1/n$. The resulting payoff is given by $\Pi(\mathbf{e}) = \alpha e - e + 1$. We will now prove that there exists $\epsilon > 0$ such that the resulting payoff for player $i$ from choosing $e + \epsilon$ is greater than $\Pi(\mathbf{e})$. Denote by $\bar{s}_i(e + \epsilon, \mathbf{e})$ the percentage share received from deviating which is given by

$$\bar{s}_i(e + \epsilon, \mathbf{e}) = \frac{e + \epsilon}{\sum_{j=1}^{n} e_j + \epsilon} \quad .$$

[18] Clearly, $s_i$ is undefined when $e_j = 0 \forall j$, however this case is immaterial because $F = 0$.

[19] In this article, inequity and inequality refer to different concepts because an equitable allocation may lead to inequality of final payoffs in the sense of Fehr and Schmidt (1999) or Bolton and Ockenfels (2000).

Notice that the total fund does not change because the minimum is still $e$. As such, the payoff from deviating is given by

$$\Pi(e+\epsilon,\mathbf{e}) = \left(\frac{e+\epsilon}{\sum_{j=1}^{n} e_j + \epsilon}\right)\alpha n e - (e+\epsilon) + 1 \quad .$$

We compute the difference in payoffs and show that

$$\begin{aligned}
\Pi(e+\epsilon,\mathbf{e}) - \Pi(\mathbf{e}) &> 0 \iff \\
\alpha e\left[\frac{n(e+\epsilon)}{ne+\epsilon} - 1\right] - \epsilon &> 0 \iff \\
e\left[a(n-1) - n\right] &> \epsilon \ .
\end{aligned}$$

From the last inequality we conclude that there exists a profitable positive deviation of size $\epsilon$ if and only if $a(n-1) - n \iff \alpha > \frac{n}{n-1}$. Note that at $\mathbf{e} = \mathbf{1}$ there is no possibility to increase effort, hence there is no positive profitable deviation in that case.

We now proceed to show that there is no negative profitable deviation from any symmetric vector of efforts. Consider the payoffs of decreasing by $\epsilon$ one's effort. These are given by

$$\Pi(e-\epsilon,\mathbf{e}) = \bar{s}(e-\epsilon,\mathbf{e})F(e-\epsilon,\mathbf{e}) - (e-\epsilon) + 1$$

and note that $\Pi(e-\epsilon,\mathbf{e}) < \bar{s}(\mathbf{e})F(e-\epsilon,\mathbf{e}) - (e-\epsilon) + 1$ because $\bar{s}(\mathbf{e}) = \frac{1}{n} > \bar{s}(e-\epsilon,\mathbf{e})$. Hence, we have that

$$\Pi(\mathbf{e}) - \Pi(e-\epsilon,\mathbf{e}) > \Pi(\mathbf{e}) - \left[\bar{s}(\mathbf{e})F(e-\epsilon,\mathbf{e}) - (e-\epsilon) + 1\right] \ .$$

We now show that

$$
\begin{aligned}
\Pi(\mathbf{e}) - [\bar{s}(\mathbf{e})F(e-\epsilon,\mathbf{e}) - (e-\epsilon) + 1] &> 0 \iff \\
\bar{s}(\mathbf{e})\left[F(\mathbf{e}) - F(e-\epsilon,\mathbf{e})\right] - \epsilon &> 0 \iff \\
\frac{1}{n}\left[an\epsilon\right] - \epsilon &> 0 \iff \\
\epsilon(\alpha - 1) &> 0
\end{aligned}
$$

and it follows that $\Pi(\mathbf{e}) - \Pi(e-\epsilon,\mathbf{e}) > 0$ for all $\epsilon$.

To show that $\mathbf{e} = \mathbf{0}$ is an equilibrium it suffices to note that it is not profitable to increase effort because $F(e_i + \epsilon, \mathbf{0}) = 0$ for all $\epsilon \geq 0$, thus increasing effort will only add costs and no benefits. ■

**Exclude the Lowest and Include the Highest**

One of the most salient characteristics of the bargaining environment is that only $q$ votes are needed for approval, and as multiple experiments have shown, minimum winning coalitions are often formed by excluding redundant members from the allocation. In fact, in experiments with an exogenous fund (Fréchette, Kagel, Morelli 2005a,b,c), such allocations are modal. Based on previous experiments, we conjecture that efforts can be used as a cue for whom to exclude or include in the coalition. Thus, we propose the following simple heuristic in which only the highest $q$ contributors are offered a share of the fund, a rule that we label as "Exclude the lowest, include the highest" (ELIH). This heuristic will only be meaningful when the voting requirement is less than unanimity ($q < n$) which we will assume here (our experiments implement a majority rule $q = \frac{n+1}{2}$).

Under ELIH bargaining strategies a minimum winning coalition is formed and members of the coalition split the fund in equal parts (each share is equal to $1/q$). The $n - q$ members exerting the lowest efforts are excluded from the coalition with certainty and the $q$ members exerting the highest efforts share the surplus. We presume that using this strategy might be more salient when all members have different investments and less likely to take place if all members had the same investment.

The experiments by Fehr and Gächter (2000, 2002) provide strong evidence for the effectiveness of ex post punishment for attaining highly efficient outcomes in a linear public goods game. Ex post bargaining can serve such purpose in our setting and ELIH strategies embody the notion of punishment to low contributors and rewards to higher contributors.

Formally, let $r_q$ be the $q^{\text{th}}$ order statistic of the set $\{e_1, ..., e_n\}$. We must specify a tie-breaking rule for entering the winning coalition whenever more than $q$ members are at or above $r_q$. For this purpose, let $E = \{e_i | e_i > r_q\}$ and $\underline{E} = \{e_i | e_i \geq r_q\}$ where $|E|$ and $|\underline{E}|$ represent the number of elements in each set. We denote by $s_i^{\text{ELIH}}$ the share received from the fund with probability $\theta_i$. An allocation under ELIH is defined by

$$s_i^{\text{ELIH}} := \begin{cases} 1/q & \text{with probability} \quad \theta_i \\ 0 & \text{with probability} \quad 1 - \theta_i \end{cases}$$

where

$$\theta_i := \begin{cases} 0 & \text{if} \quad e_i < r_q \\ \frac{q - |E|}{|\underline{E}| - |E|} & \text{if} \quad e_i = r_q \\ 1 & \text{if} \quad e_i > r_q \end{cases}.$$

Lemma 3. Under ELIH bargaining strategies, the only equilibria of the game are $\mathbf{e} = \mathbf{1}$ and $\mathbf{e} = \mathbf{0}$.

Proof. Consider any symmetric vector $\mathbf{e}$ where $e \in (0, 1)$ so that profits are given by

$\Pi(\mathbf{e}) = \theta_i s_i^{\text{ELIH}} \alpha n e - e + 1 = \alpha e - e + 1$. We now show that there exists $\epsilon > 0$ such that exerting $e + \epsilon$ yields a higher payoff. Notice that such player is invited with certainty to a coalition of $q$ players. Thus she receives $1/q$ of the surplus. This yields

$$\Pi(e + \epsilon, \mathbf{e}) = \frac{\alpha n e}{q} - e - \epsilon + 1$$

and clearly

$$\Pi(e+\epsilon,\mathbf{e})-\Pi(\mathbf{e})=ae\left(\frac{n}{q}-1\right)-\epsilon>0$$

for some $\epsilon$.

A player that deviates downward from a symmetric effort choice is excluded with certainty thus receiving

$$\Pi(e+\epsilon,\mathbf{e})=-e+\epsilon+1$$

which is strictly smaller than $\Pi(\mathbf{e})$. At $\mathbf{e}=\mathbf{0}$ it is straightforward to verify there is no profitable deviation.

Now consider any asymmetric vector $\mathbf{e}$ such that $e_{\min}>0$. If there exists $i$ such that $e_i<r_q$, it is easy to show that member $i$ has an incentive to choose 0, since being below $r_q$ only generates an individual cost and no benefits. If there exists $i$ such that $e_i>r_q$ then player $i$ would benefit from choosing $e_i-\epsilon>r_q$ because she still receives $1/q$ of the fund with certainty and reduces her individual cost without affecting the total fund. If there does not exist $i$ such $e_i<r_q$ or $e_i>r_q$ then it means $e_i=e_j\ \forall i,j$ which is the symmetric case discussed previously. Finally, if $e_{\min}=0$, then all other players are better off by choosing 0. Thus, there are no asymmetric equilibria. ■

### *Other Strategies*

One can also conceive of alternative bargaining strategies which would be more in accordance with opportunistic behavior. For example, a proposer might be willing to exclude the highest and include the lowest into a winning coalition. It is straightforward to show that the unique equilibrium resulting from these strategies will be $\mathbf{e}=\mathbf{0}$.

Strategies like the equal split among all partners (regardless of effort choices) or randomly chosen partners in a minimum winning coalition both yield an ex ante value of the bargaining game equal to the average total fund, thus leading to no refinement of the equilibrium set of effort provision.

Potentially, players may hold a strictly egalitarian view in which everyone is equally deserving in society, regardless of effort choice. According to this redistribution ideal, the total fund should be split in such a way that wealth is equalized (or differences are minimized) among all members. One can show that any symmetric vector of efforts is an equilibrium and that no asymmetric equilibria exist (see Online Appendix A).

## V. Experimental Design

We conducted four sessions per bargaining treatment, with and without observable investments, with fifteen subjects in each session. Three sessions of a control treatment without bargaining were conducted for comparison with previous weakest link experiments. We also conducted a treatment labeled *Exogenous Component* which corresponds to the bargaining observable treatment with the difference that groups posses a initial account equal to 150 tokens regardless of effort choices. In the *Proportional Recognition Probability* and *Proportional Voting Weights* we endogenize the proposer's recognition probability and the voting shares, the details are given in Section 7. In all other aspects, the PRP and PVW treatments are equivalent to the bargaining observable treatment.

Within each session, subjects were matched in groups of five for one period (also called game). A period in the bargaining treatments corresponds to an investment stage and a bargaining stage (in the control treatment a period is only composed of an investment stage). Subjects were randomly rematched each of the ten periods of play and compensated for one randomly chosen period. At the end of each game, subjects were informed of their group members' investments, shares of the total fund, and resulting payoffs. Thus, the interperiod information structure is constant across treatments.[20]

Each game, subjects were endowed with 60 tokens and could invest any integer up to their endowment. Here we departed from the standard weakest-link experimental design in

[20] Brandts and Cooper (2006b) report that full observability of every subject's payoff and choice after each period may enhance the effectiveness of bonuses in achieving efficient coordination in the weakest-link game.

which subjects typically choose an effort level out of a few choices (most studies restrict choice sets to only seven actions). Given that we do not find any difference in behavior between our benchmark (no bargaining treatment) and previously reported experimental results, we do not believe that our design choice could be altering behavior in a systematic way. If anything, an enlarged choice set might reduce the chances of coordination on any particular level of effort.

The productivity parameter ($\alpha$) equals 2 which means that the lowest investment would be doubled and then multiplied times five (the number of members in the group) in order to determine the total fund. This was explicitly told to subjects.

In the bargaining stage we implemented a simple majority rule requiring three out of five votes for approval ($q = 3$). Subjects were informed that they could bargain until an agreement was reached and there was no discounting ($\delta = 1$). However, it was specified that the experimenter could move a group unto the next period in case of excessive duration in reaching an agreement in order to meet the scheduled time for the experiment.[21]

Experiments were conducted at the BEELab of Maastricht University between March and September 2017. Subjects were recruited via ORSEE (Greiner 2007) and a 6 euro show up fee was offered. Participants who had previous experience in Baron and Ferejohn bargaining experiments and the weakest link game experiment according to our database were excluded from participating.

In each session, subjects were given instructions and a comprehension quiz which was later checked. The answers were also read aloud accompanied by a verbal explanation. A dry run was conducted before each session so that subjects were completely familiarized with all the screens. Payments were done in private by the experimenter. Table 1 contains information about the number of sessions, subjects, and duration of the sessions.

[21] The highest round of approval was round 9, and the experimenter never forced a group to the next game.

Table 1: Treatments and Sessions

| Treatment | Session # | Subjects per Session | Mean Duration |
|---|---|---|---|
| Observable Bargaining | 1-4 | 15 | 75 min |
| Unobservable Bargaining | 5-8 | 15 | 60 min |
| No Bargaining | 9-11 | 15 | 40 min |
| Proportional Recognition Probability (PRP) | 12-15 | 15 | 75 min |
| Proportional Voting Weights (PVW) | 16-19 | 15 | 85 min |
| Exogenous Component | 20-23 | 15[1] | 70 min |

[1] Session 22 had only 10 subjects due to an unusually low show-up rate.

# VI. Experimental Results of the Main Treatments

We first present the results on investments and efficiency in each treatment. We then investigate bargaining strategies and the incentives that arise in each treatment.

## *VI.a Investments*

Average investments as depicted in Panel A of Figure 1 start at 33 tokens out of 60 (55 percent of endowment) with no significant difference between treatments.[22] The fact that all treatments start at the same level reflects that there is no anticipation of the bargaining or observability effect. Average investment diverge quite rapidly. To analyze and compare investment behavior we conducted a linear regression of investments on a period trend variable, treatment and session dummy variables, and their interactions with the period variable. The results are reported in Table 6 in the Appendix.

In the observable bargaining treatment average investments rise on average by 1 token each period to nearly 41 tokens. Our results show that there are session trend differences: the first two session have an upward trend, while sessions three and four we cannot reject the hypothesis that there is no change in average investments over periods.[23] Investments decrease on average by 3 tokens each period in the unobservable bargaining treatment, and by 3.5 in the control treatment without bargaining. In these two treatments, the unravelling of

[22] Table 8 in Appendix A presents the coefficients of a linear regression of period one investments on treatment dummies. Regardless of whether session fixed effects are included or not, the treatment coefficients are not significant.

[23] Wald tests for $Period \times Session\ 3 = 0$ and $Period \times Session\ 4 = 0$ yield $p$-values$> 0.1$.

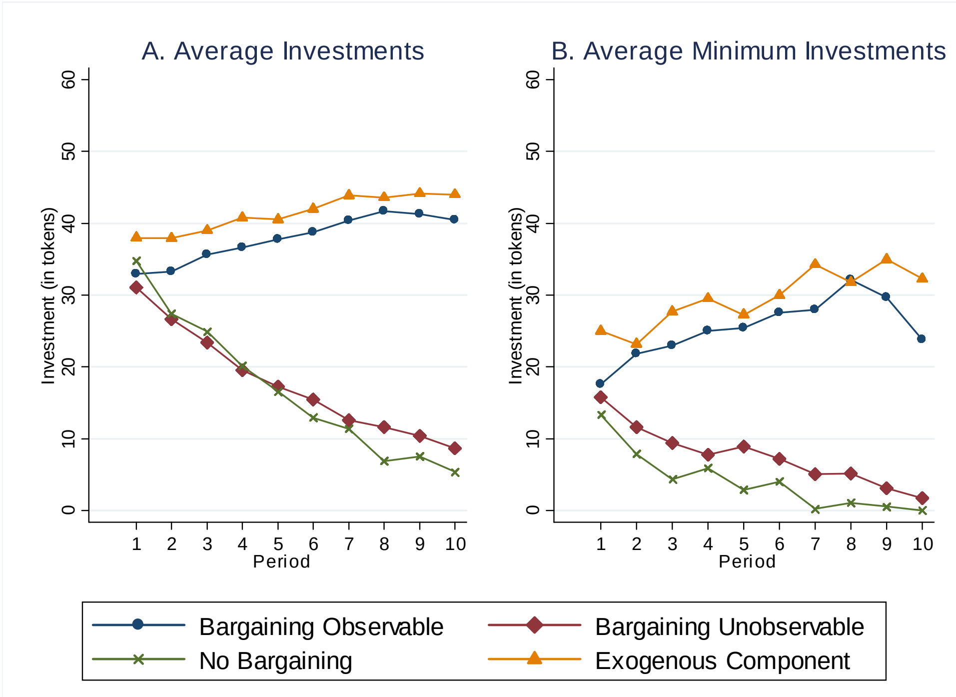



Figure 1: Investments

investments is quite homogeneous across sessions as we do not observe significant differences in the trend and session interactions.

Panel B in Figure 1 shows the evolution of the minimum investment. Notice that for the observable bargaining treatment the maximum average fund is attained in period 8 and starts to fall thereafter. This dynamic is mainly driven by the fourth session in which all bargaining groups met with one member that did not invest in the last period.

Figure **??** (Appendix A) presents the frequency of investments by treatment. In the bargaining observable treatment 40 is the modal choice (with almost 80 percent of investments being between 30 and 50 tokens). One can see that although the unobservable bargaining and control treatments have a similar pattern for average investments over time, the control treatment shows a larger dispersion of investment choices.

After conducting our main treatments, we considered a variation of the observable bargaining treatment in which groups were endowed exogenously with 150 tokens (exogenous component). This addition eliminates the risk of not having a surplus to distribute if at least one member abstains from investing. While average investments are higher in the exogenous component treatment, we do not find these differences to be significant.[24] However, a two-sample Kolmogorov-Smirnov test reveals that there are significant differences in the distribution of investments between both treatments (p-value$<$0.001), with the exogenous component treatment having a higher weight on the right tail.

We are interested in the deleterious effect that uncoordinated actions can have in an economy, so we now turn to inspect two notions of net efficiency in which we will impute the costs of effort exerted by each member. The first notion of efficiency is graphed in Panel A of Figure 2 which measures the total fund plus endowments minus the sum of individual investments divided over the most efficient outcome (i.e. in which every member invests fully). For example, if no one invests we obtain a net efficiency level of 50 percent, and groups below this threshold make net economic losses. We find that the control and unobservable bargaining treatments yield social losses in both halves of the experiment[25], while the observable bargaining treatment displays higher levels of economic efficiency reaching 63.3 percent in the second half of the experiment.

Another measure of efficiency, but in absolute terms, is presented in Panel B of Figure 2. For a given group, this measure is the total surplus created minus the sum of individual investments.[26] A positive value means that there was an aggregate economic gain because the value of production exceeds the cost of inputs. One can see that the net surplus for the Observable Bargaining treatment increases by almost 70 percent between the first and second half of the experiment. This is driven by two effects: an increase in the average minimum investment and an increase in coordination as measured by a lower dispersion of

[24] A Mann-Whitney test for equality of session mean investments between bargaining observable and exogenous component yields a p-value of 0.387.

[25] We cannot reject the hypotheses that there are social losses in both the Unobservable Bargaining and No Bargaining treatments (i.e. that net efficiency is below 50 percent) in the last five games. The respective $p$-values are 0.997 and 0.997. These correspond to a Wald test on the coefficients of a linear regression with treatment dummies and clustered standard errors at the session level. We also cannot reject the hypothesis that No Bargaining yields lower net efficiency than Unobservable Bargaining ($p$-value=0.983).

[26] The maximum feasible total surplus (when all members invest 60 tokens) is 300. The lowest would be if one member invests 0 and the rest invest 60 (-240).

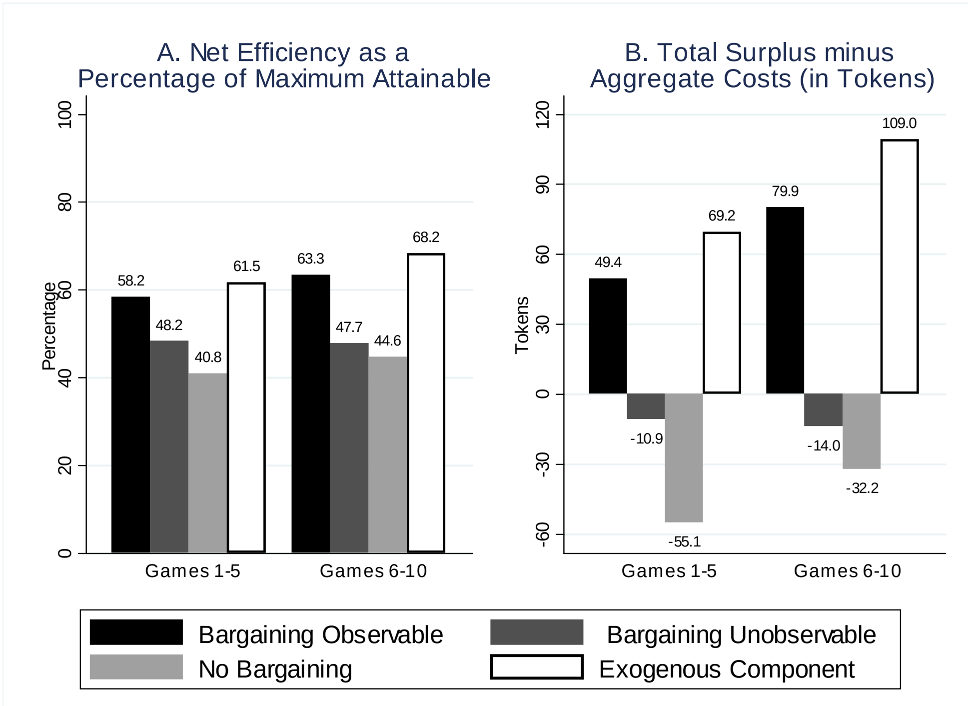



Figure 2: Efficiency

investments.[27] In the unobservable bargaining treatment, both the total surplus and the variance in investments fall between the first and second half.[28] The increase in coordination exactly counteracts the fall in the average total fund which explains why the net surplus does not change significantly between the first and second half of the experiment. In the treatment without bargaining there is also an increase in coordination after the first half[29] but the variance in investments is always higher compared to the unobservable bargaining treatment.

Conclusion 4. Ex post bargaining increases efficiency in the weakest link game. When the group can perfectly monitor its members by observing individual investment decisions,

[27] We conducted Levene's test for equality of variances between investments in the first and second half and obtained a $p$-value=0.051, thus rejecting the null hypothesis that the variances are equal. The test statistic was computed using the group median. Since Levene's test is valid under non-normality we performed a normality test for the distribution of investments which yields a $p$-value for the skewness and kurtosis of 0 and 0.003 respectively. Thus, we reject the null hypothesis that investments are normally distributed.

[28] We reject the null hypothesis of Levene's test that the variances of the first and second half of the experiment are equal ($p$-value$<0.001$).

[29] Idem.

the largest efficiency levels are attained. When monitoring is not possible, bargaining still yields efficiency gains compared to the standard weakest link game without bargaining.

We now turn to analyze bargaining outcomes in order to understand the pronounced difference in investments between treatments.

## *VI.b Bargaining Outcomes*

In this section we are mainly concerned with the relationship between initial investments and the distribution of the surplus. As a raw measure of profitability, we calculated the proportion of investments resulting in a positive return (i.e. those in which the share received is greater than the invested amount) as displayed in Table 2. This happened for 63 percent of investments in the bargaining treatment with observability and 39 percent of the time with unobservable investments. Positive returns occur only 19 percent of the time in the control treatment.[30]

Table 2: Percentage of Investments Yielding a Positive Return by Treatment

| | Games 1-5 | Games 6-10 |
|---|---|---|
| Bargaining Observable | 62.5 | 62.5 |
| Bargaining Unobservable | 44.8 | 33.6 |
| Control | 25.4 | 10.9 |

An investment is counted as yielding a positive return if the share received is strictly greater than the investment.

A second measure of profitability that we explored consisted of the relative return defined as the ratio of share to investment. Conditional on making a positive investment, the average return is 1.28 in the observable bargaining treatment, 0.97 in the unobservable treatment, and

[30] The differences are significant between treatments. We regressed a dummy variable equal to one when a subject makes a positive return on treatment dummies and clustered standard errors at the session level. The estimated coefficient for the unobservable bargaining treatment dummy was -0.297 ($p$-value=0.01), -0.544 for the control ($p$-value$<$0.001), and a constant of 0.606 ($p$-value$<$0.001). The observable bargaining treatment was the base level.

0.51 in the control. Both measures of profitability largely explain the pattern of investments in Figure 1. The question we seek to answer is: what type of bargaining strategies give rise to the high levels of profitability in the observable bargaining treatment?

***No Evidence for Stationary Subgame Perfect Equilibrium Strategies.*** — In the theoretical section we explained that the stationary strategies (SSPE) do not refine the set of equilibria in the investment stage. As expected, we do not find strong evidence in favor of such strategies in either bargaining treatment. For example, the SSPE predicts that proposers keep 60 percent of the fund while in the experiments the mean proposer's share is close to 30 percent in both bargaining treatments (the treatment difference is not significant).[31]

Concerning the overall allocation of the fund, we first broadly categorized proposals as three, four, and five-way splits depending on how many members received a meaningful share of the common profits.[32] Although for our particular purposes such proposal classifications are not essential to studying history-dependent bargaining strategies, they do reveal a divergence from previous experimental findings of bargaining over an exogenous fund. Three-way splits represent 47 and 35 percent in the observable and unobservable treatments. This proportion is far below the levels observed in BF experiments with an exogenous fund (above 80 percent in Fréchette, Kagel, and Morelli (2005a)). Five-way splits, which are virtually inexistent in Fréchette, Kagel and Morelli, account for almost 38 percent of the approved proposals in both the observable and unobservable bargaining treatments.

***Investment-dependent Bargaining Strategies.*** —

We now turn to examine *who gets what* in order to understand the divergence in investment patterns. Figure 3 presents a scatter plot in which each point represents an investment and share pair (in tokens) for a subject in a given period of play. The dotted line is the

[31] We regressed the proposers' shares as a percentage of the total fund on treatment dummies with standard errors clustered at the session level. The coefficient for the unobservable bargaining dummy is not significant ($p$-value=0.934).

[32] A member receiving more than 5 percent of the fund is counted as included. For example, the allocation (30,30,30,5,5) if the total fund is 100 tokens counts as three-way split (MWC) while (30,30,25,10,5) is a four-way split.

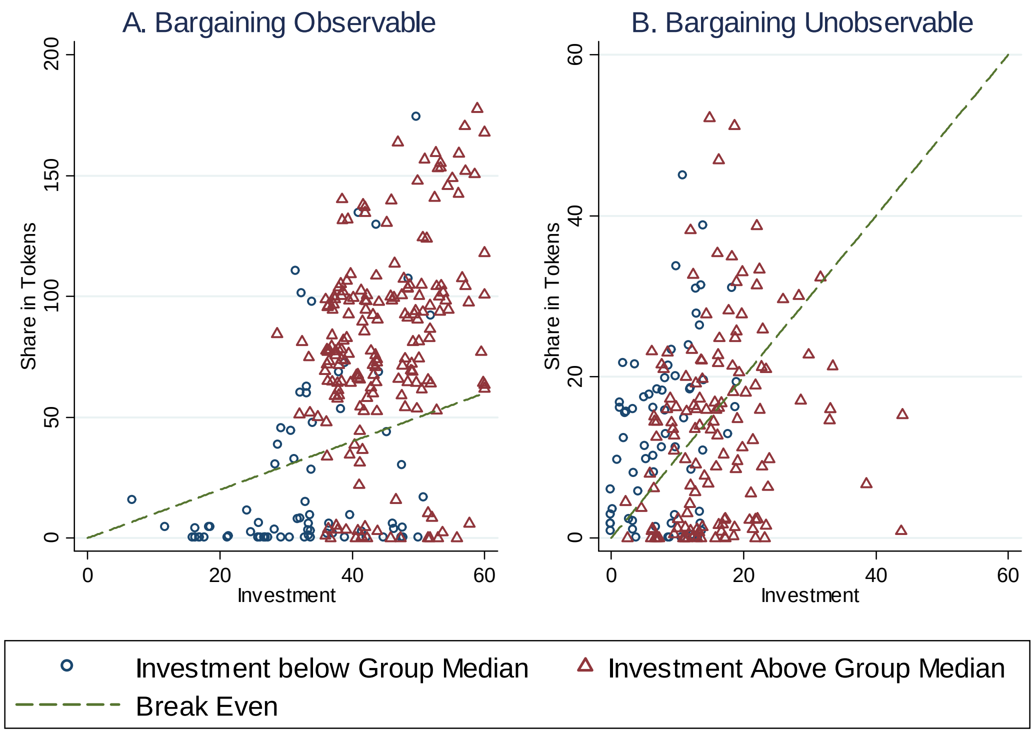



Figure 3: Investments and Shares in Approved Allocations of Games 6-10

identity relation denoting a player that exactly recovers her investment; observations above it represent a net gain. Investments are classified into two groups: those below the group's median (denoted by a circle) and those at or above the median (denoted by a triangle). Panel A of Figure 3 shows that 59 percent of below-median investments (circles) lie in the horizontal axis where the share received is equal to zero while this is only true for 11 percent of higher contributions. Moreover, 85 percent of investments which are greater than or equal to the group's median yield a positive return while only 27 percent of below-median investments (triangles) do so.[33] This pattern contrasts with what we observe in Panel B for the unobservable treatment where below-median investments face a 66 percent chance of making a positive return and at- or above-median investments only a 35 percent chance.[34] Probit

[33]If we include those who break even the percentage of above-median investors who make a non-negative return remains at 85 while the below-median investors making a return slightly increases to 29 percent.

[34]The analysis in this paragraph and in Figure 3 excludes observations from groups in which there was no bargaining due to at least one member investing zero.

models reported in Table 9 of the Appendix robustly confirm the statistical significance of these results.

As expected, we find a significant positive correlation ($\rho = 0.502$, $p$-value<0.001) between the share received as a proportion of the total fund ($s_i/F$) and the member's investment as a proportion of the sum of investments ($e_i/\sum e_j$) in the observable bargaining treatment. The correlation coefficient for the unobservable bargaining treatment is 0.073 and not significantly different than zero ($p$-value>0.1), more in line with a random choice of coalition partners.[35] This provides further evidence in favor of contribution-dependent bargaining strategies.

In Section 4 we discussed potential investment-dependent bargaining strategies: the proportional redistribution rule and the "exclude the lowest include the highest" heuristic (ELIH). Both of these can only be effectively implemented in the observable bargaining treatment. We start by examining whether or not subjects abide by the proportionality standard. In order to measure how close a given proposal is to the proportional redistribution strategy we compute a proportionality index (PI) as follows:

$$PI := \sqrt{\sum_{i=1}^{5} \left( \frac{s_i}{F} - \frac{e_i}{\sum_{j=1}^{5} e_j} \right)^2} \tag{1}$$

which yields the Euclidean distance of an allocation (where shares are measured as a percentage of the fund) to the proportional allocation. When $PI = 0$, a proposal exactly follows the proportional redistribution rule. To give the reader an idea, if all members contribute the same amount and an equal three-way split is implemented the $PI = 0.365$ and a four-way equal split yields $PI = 0.224$.

We counted how often each subject made a proposal which was close to a proportional scheme with two threshold measures: $PI < 0.05$ and $PI < 0.1$. This analysis includes all proposals made in the first round of bargaining of a given period, including those that

[35] Recall that strategies based on a random choice of coalition partners do not refine the set of equilibrium efforts.

were not selected for voting (i.e. one observation per subject per period) and the results are presented in the first two columns of Table 3.[36] Our data show that 29 out of 60 subjects redistribute proportionally (for $PI < 0.05$) in at least one game and 31 subjects never do ,so. Approximately 15 percent of approved allocations are close to the proportionality standard.

Table 3: Frequency of Investment-Dependent Bargaining Strategies in the Bargaining Observable Treatment[1].

| # of times used by a given subject[2] | Proportional | | ELIH Theory | | ELIH Retrieve | | Opportunistic |
|---|---|---|---|---|---|---|---|
| | Strict | Weak | Strict | Weak | Strict | Weak | |
| Never | 31 | 13 | 26 | 22 | 7 | 1 | 37 |
| 1 time | 14 | 10 | 11 | 10 | 15 | 3 | 10 |
| 2 times | 7 | 10 | 1 | 4 | 5 | 3 | 6 |
| 3 times | 4 | 8 | 7 | 6 | 10 | 1 | 3 |
| 4 times | 2 | 6 | 4 | 5 | 7 | 9 | 3 |
| 5 or more times | 2 | 13 | 11 | 13 | 16 | 43 | 1 |

[1] A detailed description of the bargaining strategies can be found in body of the article.
[2] We only consider the first proposal submitted by a subject in each bargaining game.

We now turn to analyze if there is evidence for ELIH strategies being used by subjects in the experiment. The two columns under the header *ELIH Theory* in Table 3 refer to proposals that satisfy the characterization presented in the theory section. The strict version requires the proposal to include only a minimum winning coalition and that the division of the fund within the minimum winning coalition should be approximately an equal split.[37] In the weak version, the allocation need not be a minimum winning coalition, but only members who contribute at or above the median are eligible partners. For example, this measure includes an equal split in which all members invested the same amount. In total, 34 subjects implemented the strict ELIH at least once, and 15 subjects did so 4 or more times during the experiment. An important observation is that ELIH strict proposals were never

[36] In the experiment we implemented the strategy method at the proposal stage reason for which we have data on all proposals, even those that were not selected to be voted on.

[37] In the theory section such strategies specified an equal split of the fund among coalition members. In our empirical measurment we allow for wiggleroom by requiring that a partner's share be above 80% of the share resulting from an equal split among the coalition.

rejected. While the theoretical ELIH strategies are indeed used by subjects, they are not an overwhelming majority of the approved proposals with the weak version representing only 31 percent of all allocations.

We inspected alternative characterizations of bargaining strategies. Under *ELIH Retrieve* strategies, a member is counted as included in the coalition if she obtains a share greater than or equal to her investment. Importantly, only those investing at or above the median are eligible under the strict measure, which represents about 40 percent of approved proposals. Under the weak measure, players contributing below the median may also be invited to the coalition, however the allocation may not exclude any member contributing at or above the median if players below the median are to be invited.[38] In other words, this latter measure defines a priority rule based on the ranking of investments for assigning shares to coalition partners. Noticeably, 70 percent of approved allocations fit the description with 43 subjects submitting such proposals five or more times during the experiment and only 1 subject never doing so.

We find little evidence for opportunistic behavior. Our measure of opportunism is a minimum winning coalition in which the three members with the lowest efforts receive a share greater than or equal to their investments and those above the median do not. As the last column in Table 3 shows, 37 subjects never implemented them.

Conclusion 5. Investment-dependent bargaining strategies largely explain the efficiency levels in the weakest-link game in the observable bargaining treatment. Allocations of the common fund in which subjects are included in the winning coalition based on the relative ranking of their investments represent almost 70 percent of bargaining outcomes. Opportunistic proposals in which above-median contributors are excluded from the allocation are rare and represent only 8 percent of approved allocations.

***Dynamics of Investment Behavior.*** — Although we have provided ample evidence

[38] For example if investments are (20,30,30,30,50), the allocations including players 3,4, and 5 or 2,3,4 and 5 are the only strict ELIH retrieve schemes. The previous allocations and the allocation including all players are weak. Any allocation including player one, must also include all other players to count as ELIH weak.

for how bargaining strategies foster investments in the observable bargaining treatment, we have not shown how a subject's experience in a previous period affects her future investment decision. We now turn to examine dynamic behavior within the experiment for which we propose a very simple model.

We define $\Delta C_{i,t} := C_{i,t} - C_{i,t-1}$ where $C_{i,t}$ is subject $i$'s investment in period $t$ and $R_{i,t-1} := Share_{i,t-1} - C_{i,t-1}$ as the net return to investment in tokens in the previous period. Let $\delta_{i,t-1}^{\text{Below Median}}$ be a dummy variable that takes the value 1 when subject $i$'s investments was below her group's median investment in period $t-1$ and let $\delta_{i,t-1}^{\text{Minimum}} = 1$ when her investment was the minimum one. The econometric linear models we estimate for the observable bargaining treatment are

$$\Delta C_{i,t} = \beta_0 + \beta_1 R_{i,t-1} + \beta_2 \delta_{i,t-1}^{\text{Below Median}} + \beta_3 R_{i,t-1} \times \delta_{i,t-1}^{\text{Below Median}} + \epsilon_{i,t} \tag{2}$$

$$\Delta C_{i,t} = \beta_0 + \beta_1 R_{i,t-1} + \beta_2 \delta_{i,t-1}^{\text{Minimum}} + \beta_3 R_{i,t-1} \times \delta_{i,t-1}^{\text{Minimum}} + \epsilon_{i,t}$$

where $\epsilon_{i,t}$ is the error term.[39]

For the unobservable bargaining treatment we estimate

$$\Delta C_{i,t} = \beta_0 + \beta_1 R_{i,t-1} + \epsilon_{i,t} \quad . \tag{3}$$

Table 4 presents the estimated coefficients for the models specified in equations (2) and (3). In columns (1),(3) and (5) we introduced period dummies but these did not alter the qualitative results of our analysis.

In the observable bargaining treatment one can see that contributing below the median in the previous period has a strong positive impact in next period's investment adjustment decision. The fact that below-median investors are typically excluded from the allocation (or do not make a positive return) certainly sparks subjects' willingness to invest. The negative

[39] In the online Appendix we also present the estimation results for random and fixed effects specifications which result from adding the subject specific effect $\alpha_i$ to the equations above. The qualitative results are the same.

Table 4: OLS Regression for Investment Adjustment based on Previous Game Performance.

| | Observable Bargaining | | | | Unobservable Bargaining | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Return | 0.0339* | 0.0295* | 0.0388** | 0.0337* | 0.203*** | 0.200*** |
| | (0.0136) | (0.0124) | (0.0139) | (0.0130) | (0.0268) | (0.0260) |
| $\delta^{BelowMedian}$ | 8.712*** | 8.654*** | | | | |
| | (1.217) | (1.205) | | | | |
| Return $\times\delta^{BelowMedian}$ | -0.100** | -0.0915** | | | | |
| | (0.0334) | (0.0309) | | | | |
| $\delta^{Minimum}$ | | | 9.397*** | 9.091*** | | |
| | | | (1.251) | (1.232) | | |
| Return $\times\delta^{Minimum}$ | | | -0.134*** | -0.130*** | | |
| | | | (0.0303) | (0.0295) | | |
| Constant | -2.148 | -2.201*** | -1.372 | -1.954*** | -4.522** | -2.051*** |
| | (1.321) | (0.589) | (1.258) | (0.526) | (1.378) | (0.219) |
| Period Dummies | Yes | No | Yes | No | Yes | No |
| Num. Obs. | 540 | 540 | 540 | 540 | 540 | 540 |
| $R^2$ | 0.174 | 0.162 | 0.196 | 0.181 | 0.123 | 0.107 |
| F-statistic | 6.056 | 17.78 | 6.480 | 19.54 | 10.49 | 59.35 |

***,**,* denote significance at 0.1%, 1%, and 5% respectively. Standard errors are clustered at the subject level and reported in parentheses below coefficient values.

interaction coefficient ($\hat{\beta}_3$) reveals that when a player's investment is below his group's median, making a negative profit creates an incentive to invest more in the next round (the overall effect of the return is negative in that case ($\hat{\beta}_1 + \hat{\beta}_3 = -0.066$, based on column 1 estimates). Similarly, making a loss conditional on being a below-median contributor correlates with an increase in next period's investment. Our estimations also show that subjects who invest above the group median in the previous game are less sensitive to their returns when adjusting their investment decisions. In fact, if a player makes a net return of 10 tokens and her contribution was above the median in the previous period, we cannot reject the hypothesis that she will invest the same amount as before.[40] A similar analysis to the one presented in this paragraph holds for a model in which we replace the regressor of being below the median by being equal to the minimum investment in the previous period (see columns (3) and (4)).

In the appendix we report the results for an ordered probit specification in which the three outcomes were decreasing, maintaining, and increasing one's investment with respect to the previous period. The independent variables were a dummy for whether a player receives a share greater than or equal to her investment in the previous period, a dummy for being below the median investment in the previous period, and an interaction term. Our estimates reveal that conditional on receiving a share greater than or equal to one's investment in the previous period, subjects whose previous contributions were below their group's median were more likely to increase their investments compared to those who invested at or above the group median in the previous game (55 percent and 20 percent respectively). Our model also predicts a large probability of remaining at the same investment level for those who retrieve their investments, regardless of the relative ranking of their contribution within their groups in the previous period (39 percent for those below the group median and 53 percent for the rest).

The results for the linear regression model concerning dynamic behavior in the unob-

[40] We conducted a test for $10\beta_1 + \beta_0 = 0$ and obtained a $p$-value=0.173.

servable bargaining treatment are presented in columns (5) and (6) of Table 4. The estimated coefficients reflect a positive relationship between a player's return to investing in the previous period and the difference between the current and previous investment. Thus, it is not surprising that we observe an unravelling of efforts given the prevalence of losses.

# VII. Endogenous Proposal Probability and Voting Shares

In our model and experiments thus far, players' *institutional* bargaining positions remain unchanged after investment decisions since all have the same probability of being recognized as the proposer and posses same voting weights. In this section we endogenize each of these dimensions –one at a time– in order to investigate their effect on efficiency.

In the first treatment, labeled *Proportional Recognition Probability (PRP)*, we will first endogenize the recognition probability ($\pi_i$) through a contest success function defined as follows:

$$\pi_i := \frac{e_i}{\sum_j e_j} \ . \tag{4}$$

In our model, we interpret $\pi_i$ as a formal agreement in which higher contributors are more likely to lead bargaining processes.

In the second treatment, labeled *Proportional Voting Weights (PVW)*, we endogenize the voting weights ($w_i$) according to the following rule:

$$w_i := \frac{e_i}{\sum_j e_j} \ . \tag{5}$$

The voting weights can be thought of as an implementation of the "one share one vote" principle which typically underlies joint ownership agreements.

It is straightforward to see that given a symmetric investment vector, players find themselves exactly in the same situation as in the original treatments with exogenous equiprobable recognition and equal voting shares. Thus, any $\epsilon$ deviation downward or upward from a symmetric vector of positive investments generates similar effects to those described in the proofs of Lemma 2. and 3., leading to only the least and most efficient outcomes as symmetric equilibria.[41] Given that we did not see a full convergence to the fully efficient equilibrium in the bargaining observable treatment, we then seek to identify if the PRP and PVW treatments provide additional incentives to invest fully.

One potential line of reasoning is that if contributions increase the likelihood of reaching an agreement closer to one's preferred outcome, investing will be more attractive from an individual standpoint. High investors need to worry less about the impact of low investors on bargaining outcomes. Also, if subjects derive utility from proposing simply because they enjoy the idea of control or influence, this should reflect in higher average investments.

However, the fact that bargaining outcomes already largely discriminate between low and high contributors calls into question the extent to which these formal asymmetries will affect bargaining behavior so that investment incentives are substantially enhanced. Furthermore, by the design of the treatments, subjects can be primed into thinking more about the s*trategic value* of voting weights and proposal power, thus altering their selection of bargaining strategies away from the redistributive standards previously observed in bargaining observable treatment. If new strategies are implemented which work contrary to the incentives arising through ELIH or proportional redistributive strategies, then it could well be that we observe a fall in average effort.

It should be highlighted that the experiments with a linear production setting (Baranski 2016) showed that there was no difference in average investments (nor bargaining outcomes) between a treatment with equal recognition probability and a treatment in which the probability of being the proposer was proportional to one's investment. Importantly, in those

[41] The definition of ELIH strategies must be modified to account for the fact that winning coalitions may be formed by less than three players depending on the voting weights. For example, if the contributions are (10,10,10,10,10) a single player may deviate to 50 and obtain a voting weight of $\frac{50}{90} > 50$ percent. In such case, a unique player forms the MWC thus resulting in a full appropriation of the surplus (absent any preferences for equity). This would be a more profitable deviation than the one we had characterized for the equal voting weights where a player would just deviate slightly (from 10 to 11 in the current example) in order to guarantee himself a spot in a MWC of three players.

experiments almost full efficiency was reached in the treatment with equiprobable recognition leaving little scope for endogenous proposal probability to outperform the fixed recognition treatment in terms of efficiency. In our current setting there are still large efficiency gains to be attained. The effect of endogenous voting shares has been unexplored in the laboratory to the best of our knowledge.

### *VII.b Results*

Figure 4 displays the evolution of average investments in which the PRP treatments seems to dominate the bargaining observable and PVW treatments, but the effect is not that strong for the first moment of the distribution. Regression analysis presented in table 10 shows no significant treatment differences on average investments when regressing investments on a treatment dummy, a period trend variable and their interaction.[42] Non-parametric Mann-Whitney tests further confirm this since we cannot reject the hypothesis that mean investments are equal between the PRP, PVW, and bargaining observable treatments.[43] The only difference we find to be significant is that first period investments are higher in the PRP treatment compared to the other two, thus there is evidence that subjects initially perceive an added value of holding enhanced proposal probability, but such behavior is not sustained over time.[44]

However, we do find significant changes in the distribution of investments. Kolmogorov-Smirnov tests reveal that the distribution of investments in observable bargaining treatment has more weight in the left tail (contains smaller values) than in the PRP treatment ($p$-value$< 0.001$). The PVW treatment has more weight on both tails, as evidenced by a flatter distribution of investments ($p$-value$< 0.001$).

[42] Introducing session level fixed effects reveals that there are significant differences between sessions within a treatment.

[43] Testing for equality of means between the bargaining observable treatment and PRP yields a $p$-value=0248; between bargaining observable and PVW yields a $p$-value=1; and between PRP and PVW we obtain a $p$-value=0.564.

[44] We take the first investment in each sessions as an independent observation. Performing a Mann-Whitney test for equality of means between the bargaining observable treatment and PRP we obtain a $p$-value=0.01 and between PRP and PVW we obtain a $p$-value=0.034.

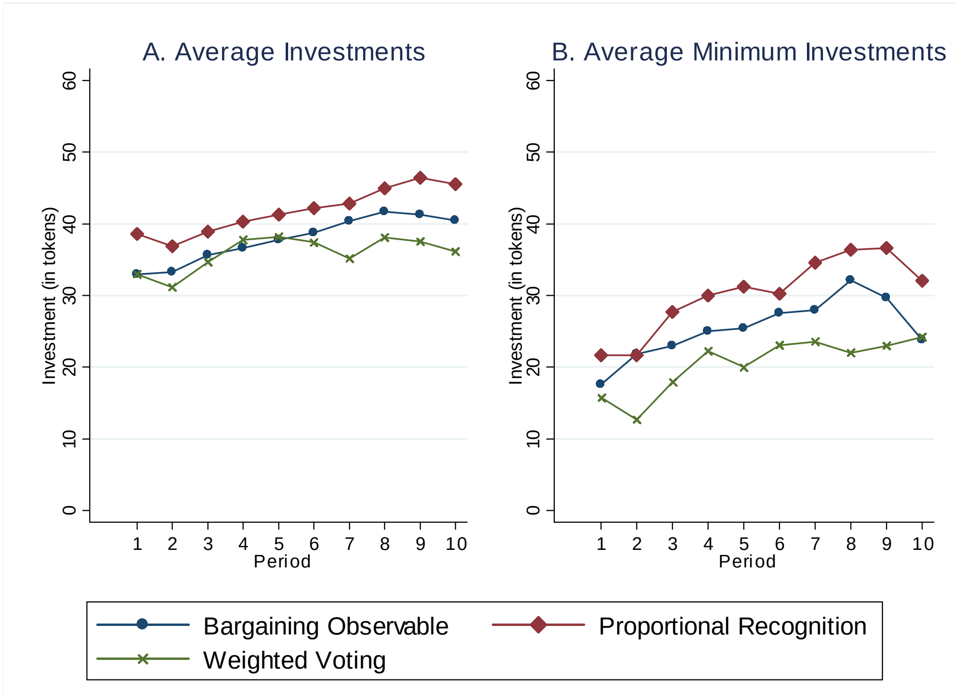
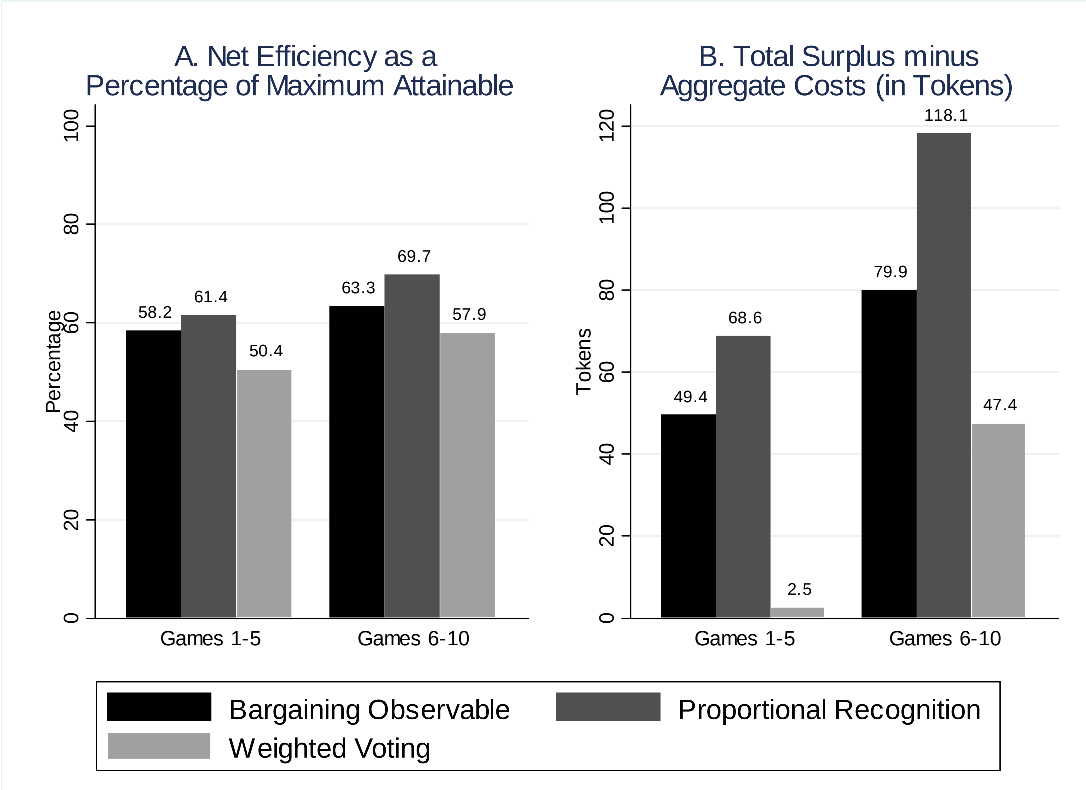



Figure 4: Average Investments in PRP and PVW Treaments.

These differences in the distribution of investments have an substantial impact on efficiency. In the second half of the experiment, efficiency in the PRP treatment is close to 70% of maximum attainable level which corresponds 40 additional tokens in the economy (i.e. group of 5) compared to the bargaining observable treatment. In the treatment with endogenous voting weights, the large dispersion of investments translates into very low efficiency, especially in the first half of the experiment.

Our data reveal that bargaining outcomes are substantially similar between the PRP and observable bargaining treatment, with 70 percent of approved allocations being characterized as weak ELIH Retrieve schemes (same percentage as for bargaining observable). Moreover, dynamic analysis of investment decisions yields similar results to the regressions estimated for the observable bargaining treatment (see Table 11 in Appendix A).

The fact that average investments are not significantly larger in the PRP treatment is quite surprising, however a closer look at the distribution of resources sheds some light on why this is the case. Notice that proposers' shares are not too different compared to those of




partners invited into the winning coalition. Table 7 presents the proportion of the fund kept by proposers and voters who are part of the winning coalition. It is a particularly robust pattern that proposers' shares are close to the average share of a coalition partner in the bargaining treatments with observability. Hence, the additional pecuniary value of proposing is quite low relative to not proposing; what matters is whether a member's contribution is high enough to warrant an inclusion in the winning coalition. In Appendix B we provide a simple mathematical model which captures this dynamic and we show that if there is no difference in shares between proposers and non-proposer included members, then there is no added value to being the proposer.

With regards to the PVW treatment, notice that winning coalitions conformed of less than three members may arise if there is a large difference in investments among group members. In fact, in 52 out 102 observed bargaining games (cases where $c_{\min} > 0$), the two highest contributors owned more than 50 percent of the voting shares. However, holding a voting share advantage did not represent a substantial monetary reward. In those cases, the net surplus of the minimal coalition calculated as the total fund minus the two largest investments amounted to 19 tokens on average. Thus, if players were to abide by ELIH strategies, the returns to investments would not be substantial. For the cases where any three players could approve a proposal, the net surplus available to the minimal coalition calculated as the total fund minus the three largest investments amounted to 230 tokens, which is clearly larger.

Taking a closer look at the strategies used in the PVW treatment, we find that 50 percent of them are ELIH retrieve weak strategies: all members at or above the median are included in the allocation and if anyone below the median is included, this may not be at the expense of an at or above median contributor.[45] While this represents a substantial proportion of allocations, it is far below 70 percent observed in the PRP and observable bargaining treatment. Inspecting for opportunistic behavior, we find only two instances where such allocations are approved. Thus, 48 percent of approved proposals are a hybrid allocation characterized by the exclusion of some of the highest investors and inclusion of some of the lowest investors. Certainly, this bargaining behavior can be sending a mixed message about investment incentives to subjects.

Conclusion 6. Endogenizing the probability of being the proposer leads to enhanced efficiency and an increase in the number of subjects choosing the highest effort compared to the case with equal probabilities of proposing. When voting weights are endogenous, the percentage of subjects choosing the highest effort also increases, but effort levels are more dispersed and this leads to lower overall efficiency compared to the bargaining observable treatment.

[45]For cases where the two largest members can form a winning coalition, this scheme requires that the top two contributors must be part of the coalition. Players below the 2nd highest investment may be invited as long as no one at or above the 2nd highest investment is excluded.

# VIII. Conclusion

In many organizational structures, a coach, manager, or dictator has the discretion to assign tasks and compensations in a way that she perceives will lead to efficient outcomes. Such has been the object of study in contract theory as addressed seminally by Hölmstrom (1982) on how to provide incentives to teams. But coordination through a central authority is not the only way in which collective bodies are managed. A significant amount of firms such as business partnerships are self-governed, a process which naturally requires negotiations and agreements between those involved in the production process. Our setting can also be used to study self-managed (or autonomous) teams such as researchers on a joint project who assign authorship credit after they completed a project. Military, political, and geopolitical alliances often operate in a multilateral framework in which decision-making power is shared among members and so are the benefits that the alliance might reap. Another example may be found in democratic states: taxing and spending decisions can be modelled as a game of multilateral negotiations in which the surplus to redistribute is endogenously created (Battaglini and Coate 2007, 2008). Thus, understanding how a democratic mechanism for the redistribution of resources in an economy can help achieve efficient coordination is an open question on which our main contribution lies.

Our results provide a rationale for the existence of participatory mechanisms in the redistribution of jointly produced profits. Productive efforts, when observable by group members, establish *behavioral property rights* which are largely respected. Despite the well-documented plurality of fairness ideals, and the fact that a non-separable production technology may exacerbate the degree of conflicting views of equity, we find that subjects implicitly coordinate on bargaining strategies which create an atmosphere of trust enforced by punishing and rewarding behavior.

The model we have explored is simple and tractable. By concatenating the Baron and Ferejohn (1989) model of legislative bargaining with the weakest-link game we bring together several streams of literature including political economy, organizational behavior, public economics, and social preferences. It remains to be studied if our results are robust to alternative bargaining mechanisms as well as production technologies in order to better understand the relationship between redistributive behavior and joint production, in particular how redistribution schemes adjust in order to foster efficiency.

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# Appendix A. Supporting Tables and Figures

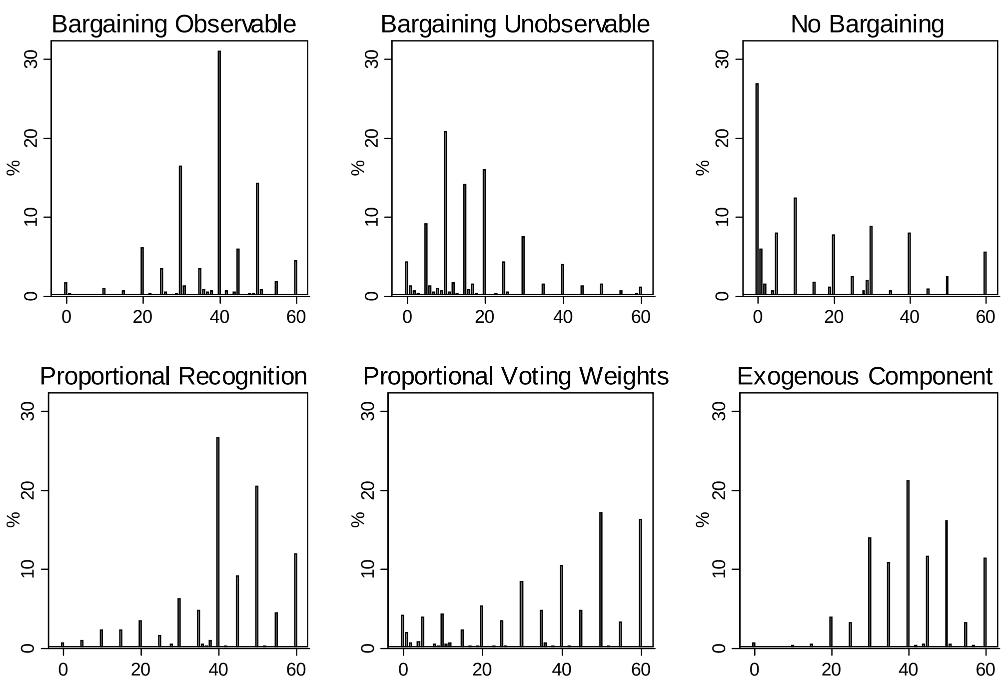


Figure 5: Distribution of Investments by Treatment in all Games.

Table 5: Bargaining Outcomes[1]

| | **SSPE Prediction** | **Observable** | **Unobservable** |
|---|---|---|---|
| **Proposals**[2] | | | |
| *3-way split (MWC)* | 100% | 60.4 | 43.9 |
| *4-way split* | 0% | 15.1 | 36.6 |
| *5-way split* | 0% | 24.5 | 19.5 |
| **Average Shares**[3] | | | |
| *Proposer's Share* | 60% | 29.6 (0.008) | 31.1 (0.011) |
| *Proposer's Share in MWC* | 60% | 33.6 (0.005) | 37.3 (0.008) |
| *Voter's Share (conditional on share>5%)* | 20% | 26.0 (0.007) | 24.9 (0.007) |
| *Voter's Share in MWC* | 20% | 31.7 (0.007) | 31.2 (0.005) |
| **Correlations**[4] | | | |
| *Investments and Shares* | 0 | 0.542* | 0.052 |
| *Investments and Shares (Proposers)* | 0 | 0.387* | -0.027 |
| *Investments and Shares (Voters)* | 0 | 0.553* | 0.091 |
| **Timing of Approval** | | | |
| *Round 1* | 100% | 71.7 | 70.7 |
| *Round 2* | 0% | 18.9 | 19.5 |

[1] Outcomes are reported for accepted allocations of periods 6-10 and excluding groups in which the total fund was zero since no bargaining game is observed.
[2] Members receiving 5% or less are counted as excluded from the allocation.
[3] Standard mean errors reported in parentheses below.
[4] The correlation is between the investment as a proportion of the sum of the group's investments and the share is relative to the total fund. In a stationary equilibrium initial investments are irrelevant for determining shares, thus the model predicts zero correlation. * denotes significance at the 1 percent level. These correlations are computed conditional on bargaining taking place.

Table 6: OLS Regressions for Investment Trends [1]

| | Dep. Var.: Investment | |
|---|---|---|
| | Coefficient | Standard Error |
| Constant | 29.02*** | (2.715) |
| Period | 1.095*** | (0.316) |
| Session 2 | 2.098 | (3.532) |
| Session 3 | 5.867 | (3.584) |
| Session 4 | 5.351 | (4.525) |
| Session 2 × Period | 1.189** | (0.427) |
| Session 3 × Period | -0.825 | (0.477) |
| Session 4 × Period | -0.715 | (0.655) |
| Barg, Unobs. (=1 if yes) | -6.671 | (3.575) |
| Barg. Unobs. × Period | -3.032*** | (0.410) |
| Session 5 | 13.52** | (4.786) |
| Session 6 | 7.516 | (4.239) |
| Session 7 | 13.19** | (4.472) |
| Session 5 × Period | -0.831 | (0.627) |
| Session 6 × Period | -0.249 | (0.505) |
| Session 7 × Period | -0.806 | (0.469) |
| Control (=1 if yes) | 14.53** | (5.218) |
| Control × Period | -3.575*** | (0.493) |
| Session 10 | -6.702 | (6.633) |
| Session 11 | -21.28*** | (5.412) |
| Session 9 × Period | -1.198 | (0.632) |
| Session 10 × Period | -0.882 | (0.729) |
| $N$ | 1650 | |
| $R^2$ | 0.555 | |
| F-Statistic | 84.87 | |

***,**,* denote significance at 0.1%, 1%, and 5%. Standard errors reported in parentheses below coefficient values.

[1] Standard errors are clustered at the subject level (165 clusters in total).

Table 7: Distribution of Resources as a Proportion of the Total Fund by Role.

| **Treatment: Bargaining Observable** | | | | |
|---|---|---|---|---|
| | 2-way Split | 3-way Split | 4-way Split | 5-way Split |
| **Voter** | | 0.32 | 0.24 | 0.19 |
| **Proposer** | | 0.34 | 0.27 | 0.22 |
| **Treatment: Bargaining Unobservable** | | | | |
| | 2-way Split | 3-way Split | 4-way Split | 5-way Split |
| **Voter** | | 0.29 | 0.24 | 0.2 |
| **Proposer** | | 0.35 | 0.28 | 0.21 |
| **Treatment: Proportional Recognition Probability** | | | | |
| | 2-way Split | 3-way Split | 4-way Split | 5-way Split |
| **Voter** | | 0.30 | 0.23 | 0.19 |
| **Proposer** | | 0.34 | 0.28 | 0.22 |
| **Treatment: Proportional Voting Weights** | | | | |
| | 2-way Split | 3-way Split | 4-way Split | 5-way Split |
| **Voter** | 0.48 | 0.32 | 0.23 | 0.20 |
| **Proposer** | 0.48 | 0.35 | 0.29 | 0.21 |
| **Treatment: Exogenous Component** | | | | |
| | 2-way Split | 3-way Split | 4-way Split | 5-way Split |
| **Voter** | | 0.33 | 0.24 | 0.19 |
| **Proposer** | | 0.33 | 0.25 | 0.22 |

A $k$-way split is an allocation in which only $k$ members receive shares that are greater than 5 percent of the fund.

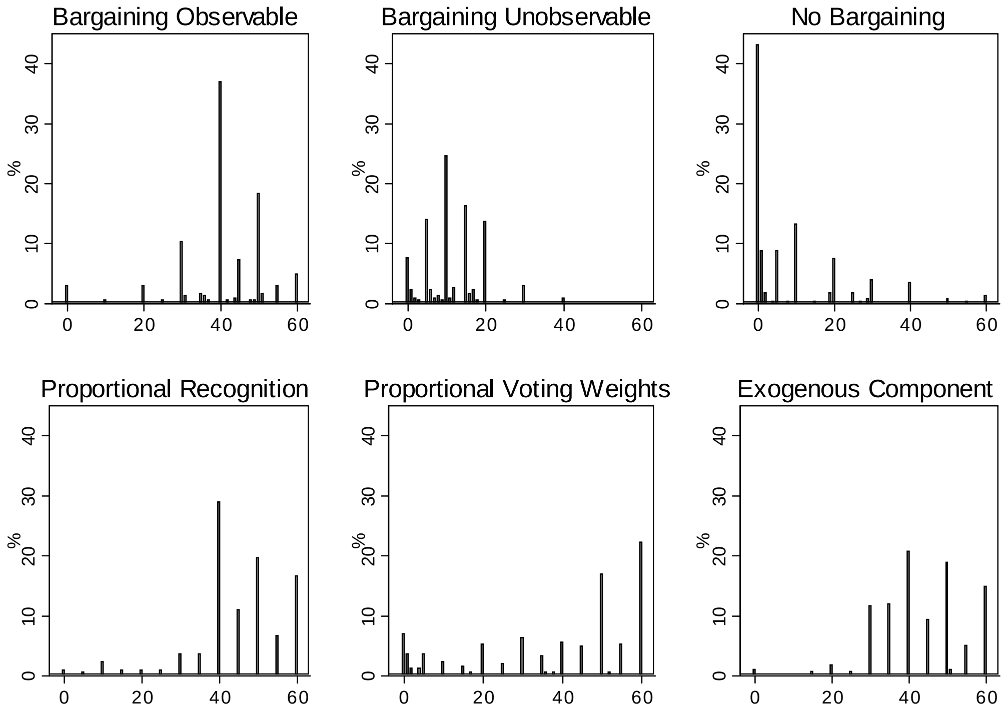


Figure 6: Distribution of Investments by Treatment in Games 6-10.

Table 8: OLS Regressions for Investment Trends [1]

| | Dep. Var. Investment in Period 1 | |
|---|---|---|
| | Session Fixed Effects | No Fixed Effects |
| Bargaining Unobservable | -8.533 | -3.772 |
| | (5.381) | (2.306) |
| Control | -4.467 | -0.0833 |
| | (5.381) | (2.578) |
| Constant | 30.87*** | 34.84*** |
| | (3.805) | (1.153) |
| Num. Obs. | 285 | 285 |
| $R^2$ | 0.153 | 0.00981 |
| F-Statistic | 2.661 | 1.396 |

***,**,* denote significance at 0.1%, 1%, and 5% respectively. Standard errors reported in parentheses below coefficient values.

Table 9: Probit Models for ELIH Strategies

| | Dep. Var. Retrieve Investment | | Dep. Var. Share$\leq$ 5% | | Dep. Var. Share= 0 | |
|---|---|---|---|---|---|---|
| | All Games | Games 6-10 | All Games | Games 6-10 | All Games | Games 6-10 |
| Below-Median Constributor (=1) | -0.943** | -1.575*** | 1.113*** | 1.399*** | 1.030*** | 1.301*** |
| | (0.292) | (0.243) | (0.322) | (0.285) | (0.301) | (0.263) |
| Constant | 0.439** | 0.608* | -1.105*** | -1.071*** | -0.891*** | -0.724** |
| | (0.158) | (0.260) | (0.225) | (0.214) | (0.210) | (0.272) |
| Num. Obs. | 480 | 240 | 480 | 240 | 480 | 240 |
| pseudo-$R^2$ | 0.085 | 0.214 | 0.132 | 0.197 | 0.110 | 0.162 |
| $\chi 2$ | 10.40 | 42.19 | 11.92 | 24.11 | 11.72 | 24.48 |

***,**,* denote significance at 0.1%, 1%, and 5% respectively. Standard errors reported in parentheses below coefficients are clustered at the session level. Results are robust to clustering at the period level.

Table 10: OLS Regression for Treatment Differences in Investments between PRP, PVW and Bargaining Observable.

| | Dep. Var.: Investment | | | | | |
|---|---|---|---|---|---|---|
| | PRP and Bargaining Observable | | | PVW and Bargaining Observable | | |
| | (1) | (2) | (3) | (1) | (2) | (3) |
| Period | 1.008*** | | 1.013*** | | 1.008*** | 0.753*** |
| | (0.225) | | (0.161) | | (0.225) | (0.207) |
| Proportional Recognition (PRP) | 3.841 | 5.063 | 5.127* | | | |
| | (2.187) | (2.892) | (2.010) | | | |
| PRP × Period | 0.0116 | 0.0116 | | | | |
| | (0.321) | (0.322) | | | | |
| Proportional Voting Weights (PVW) | | | | 0.816 | -11.00** | -13.80*** |
| | | | | (2.387) | (3.515) | (2.673) |
| PVW × Period | | | | -0.509 | -0.509 | |
| | | | | (0.411) | (0.412) | |
| Cons. | 32.35*** | 29.50*** | 29.47*** | 32.35*** | 29.50*** | 30.90*** |
| | (1.422) | (2.018) | (1.738) | (1.422) | (2.018) | (1.880) |
| Session Fixed Effects | No | Yes | Yes | No | Yes | Yes |
| Num. Obs. | 1200 | 1200 | 1200 | 1200 | 1200 | 1200 |
| $R^2$ | 0.0796 | 0.268 | 0.268 | 0.0248 | 0.330 | 0.328 |
| F-statistic | 15.57 | 34.00 | 38.21 | 8.021 | 20.47 | 22.21 |

***,**,* denote significance at 0.1%, 1%, and 5% respectively. Standard errors are clustered at the subject level and reported in parentheses below coefficient values.

Table 11: OLS Regression for Investment Adjustment based on Previous Game Performance.

| | Proportional Recognition | | | Proportional Voting Weights | | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Return | 0.0613*** | 0.0603*** | 0.0500** | 0.0475*** | 0.0464*** | 0.0470** |
| | (0.0159) | (0.0154) | (0.0166) | (0.0129) | (0.0124) | (0.0138) |
| $\delta^{BelowMedian}$ | 9.831*** | 9.833*** | | 9.369*** | 9.121*** | |
| | (1.066) | (1.061) | | (1.169) | (1.177) | |
| Return $\times \delta^{BelowMedian}$ | -0.107*** | -0.104*** | | -0.0814** | -0.0880** | |
| | (0.0176) | (0.0171) | | (0.0286) | (0.0285) | |
| $\delta^{Minimum}$ | | | 8.701*** | | | 10.49*** |
| | | | (1.220) | | | (1.320) |
| Return $\times \delta^{Minimum}$ | | | -0.104*** | | | -0.152*** |
| | | | (0.0199) | | | (0.0292) |
| Constant | -4.841* | -3.320*** | -4.040* | -5.194** | -2.954*** | -3.965* |
| | (1.845) | (0.813) | (1.895) | (1.565) | (0.609) | (1.570) |
| Period Dummies | Yes | No | Yes | Yes | No | Yes |
| Num. Obs. | 540 | 540 | 540 | 540 | 540 | 540 |
| $R^2$ | 0.224 | 0.210 | 0.173 | 0.131 | 0.104 | 0.141 |
| F-statistic | 13.41 | 35.01 | 7.195 | 9.556 | 20.99 | 6.843 |

***,**,* denote significance at 0.1%, 1%, and 5% respectively. Standard errors are clustered at the subject level and reported in parentheses below coefficient values.

# Appendix B. Simple Model of Incentives in Proportional Recognition Probability Treatment

Consider a simple model in which players abide by weak ELIH strategies. For the vector of efforts $\mathbf{e}$ let $\delta_i(\mathbf{e})$ be the indicator function that takes the value 1 when $e_i \geq e^{median}$ and 0 otherwise. Let $s^{\text{Prop}}$ denote the share that proposer's keep as a proportion of the total fund

$F(\mathbf{e})$. Thus, a risk neutral player's expected payoff given a vector of efforts $\mathbf{e}$ is defined by

$$\Pi_i = \delta_i(\mathbf{e}) \left[ \underbrace{\frac{e_i}{\sum_j e_j} s^{\text{Prop}}}_{\substack{\text{Expected Share in \%} \\ \text{if proposing}}} + \underbrace{\left(1 - \frac{e_i}{\sum_j e_j}\right) \frac{(1 - s^{\text{Prop}})}{|\underline{E}| - 1}}_{\substack{\text{Expected Share in \%} \\ \text{if not proposing}}} \right] F(\mathbf{e}) - e_i + 1 \quad . \tag{6}$$

Recall that $|\underline{E}|$ denotes the number of players whose investment is at or above the median, hence $|\underline{E}| - 1$ is the number of players invited to the coalition (other than the proposer) under weak ELIH strategies. From the results of the observable bargaining treatment we verified that the share received as a percentage of the total fund is quite similar for proposers and voters included in the winning coalition. If such behavioral regularity were to remain with endogenous proposal probability we could substitute $s^{\text{Prop}} = 1/|\underline{E}|$ (an equal split of the pie among coalition partners) into equation (6) which leads to

$$\Pi_i^{\text{Weak ELIH}} = \Pi_i|_{s^{\text{Prop}}=1/|\underline{E}|} = \delta_i(\mathbf{e}) \frac{F(\mathbf{e})}{|\underline{E}|} - e_i + 1 \quad . \tag{7}$$

Equation (7) does not depend on the probability of being the proposer. Hence, if subjects abide by weak ELIH strategies in the PRP treatment and attach no intrinsic value to proposing, an increase in the probability of proposing would be beneficial only if the proposer's share becomes large relative to that of the included coalition partners.

# Online Appendix A. Strict Egalitarian Outcomes

In the body of the paper we loosely referred to egalitarian outcomes as those in which final wealth holdings are equalized, or differences are minimized, among all members. A formal definition of this concept then requires a clear specification a what it means for differences to be minimized and one can think of many measures: variance, coefficient of variation, or Gini Coefficient, among others. For our purposes, it suffices to denote a function $D : \mathbb{R}_+^n \to \mathbb{R}_+$ such that $D(x_1, ..., x_n) = 0$ iff $x_i = x_j \forall i, j$ and such that $D$ is increasing as the dispersion of $\{x_1, ..., x_n\}$ increases.

Back to the weakest link game, given a vector of efforts $\mathbf{e}$, the egalitarian outcome can be stated as the solution to the problem

$$\min_{s_1,\ldots,s_n} D(\Pi_1, ..., \Pi_n) \text{ s.t. } \sum s_j = F(\mathbf{e}) \tag{8}$$

where $s_i > 0$ is the amount player $i$ receives from the total fund and $\Pi_i = s_i - e_i + 1$ are her final earnings.

Before our main result, we define the total amount of wealth available in the economy as

$$W(\mathbf{e}) = \sum_{j=1}^{n} (1 - e_j) + F(\mathbf{e}) \tag{9}$$

simply the sum of endowments, minus efforts, plus the total fund.

Lemma 7. Any symmetric vector of efforts is an equilibrium.

Proof. When all players are exerting equal effort $e$ we have that $s = F(\mathbf{e})/n = \alpha e$ which yields $\Pi = \alpha e - e + 1 = W(\mathbf{e})/n$. If player $i$ deviates to $e - \epsilon$ , then the total fund becomes $\alpha n(e - \epsilon)$. Total wealth in the economy is given by

$$W(e - \epsilon, \mathbf{e}_{-i}) = n - ne + \epsilon + F = n - ne + \epsilon + \alpha n(e - \epsilon) \tag{10}$$

and player $i$ will receive a share $s_i$ such that $s_i - e_i + \epsilon + 1 = W(e-\epsilon, \mathbf{e}_{-i})/n = \Pi_i(e-\epsilon, \mathbf{e}_{-i})$. One can easily see that

$$
\begin{aligned}
W(\mathbf{e})/n - W(e-\epsilon, \mathbf{e}_{-i})/n &> 0 \iff && (11)\\
\alpha n\epsilon - \epsilon &> 0 \iff && (12)\\
\epsilon(\alpha n - 1) &> 0 && (13)
\end{aligned}
$$

which always holds. In the analysis above we have assumed that the $\epsilon$ deviation is small enough such that the fund is large enough as to feasibly attain an equalizing redistribution. Notice that a large deviation may lead to such a small $F$ which then does not allow to equalize payoffs, but this would also harm the deviator because he saves $\epsilon$ but loses the $\alpha\epsilon$. The proof for positive deviations follows a similar procedure. ■

Lemma 8. There are no asymmetric equilibria.

Proof. Let $e_i = \max\{e_1, .., e_n\}$. Then, player $i$ is better off by selecting $e_i = \min\{e_1, .., e_n\}$ because the total wealth in the economy increases. ■

# Online Appendix C. Supplementary Tables and Robustness Checks

Table 12: OLS Regression for Investment Adjustment based on Previous Game Performance

| | Observable Bargaining | | Unobservable Bargaining | |
|---|---|---|---|---|
| | R.E. | F.E. | R.E. | F.E. |
| Return | 0.0333* | 0.0280 | 0.170*** | 0.170*** |
| | (0.0146) | (0.0160) | (0.0271) | (0.0271) |
| $\delta^{BelowMedian}$ | 8.860*** | 12.28*** | | |
| | (0.997) | (1.186) | | |
| Return $\times \delta^{BelowMedian}$ | -0.117*** | -0.142*** | | |
| | (0.0294) | (0.0329) | | |
| Period | -0.332 | -0.318 | 0.381* | 0.381* |
| | (0.173) | (0.174) | (0.173) | (0.173) |
| Constant | -0.0109 | -1.043 | -4.577*** | -4.577*** |
| | (1.137) | (1.149) | (1.130) | (1.130) |
| Num. Obs. | 405 | 405 | 405 | 405 |
| $\rho$[1] | 0 | 0.145 | 0 | 0 |

***,**,* denote significance at 0.1%, 1%, and 5% respectively.

[1] $\rho = \frac{\sigma_\alpha^2}{\sigma_\alpha^2+1}$ where $\sigma_\alpha^2$ is the variance of subject-specific effects. When $\rho = 1$, all the variance in investent changes between periods can be explained by individual subject effects. In the regressions presented here, $\rho = 0$ for columns 1,2, and 4 is due to the fact the estimated variance of the unobserved effect is negative. When this happens, statistical softwares set it equal to zero and estimate a standard OLS, reason for which the results estimated coefficients coincide with those in the main text.

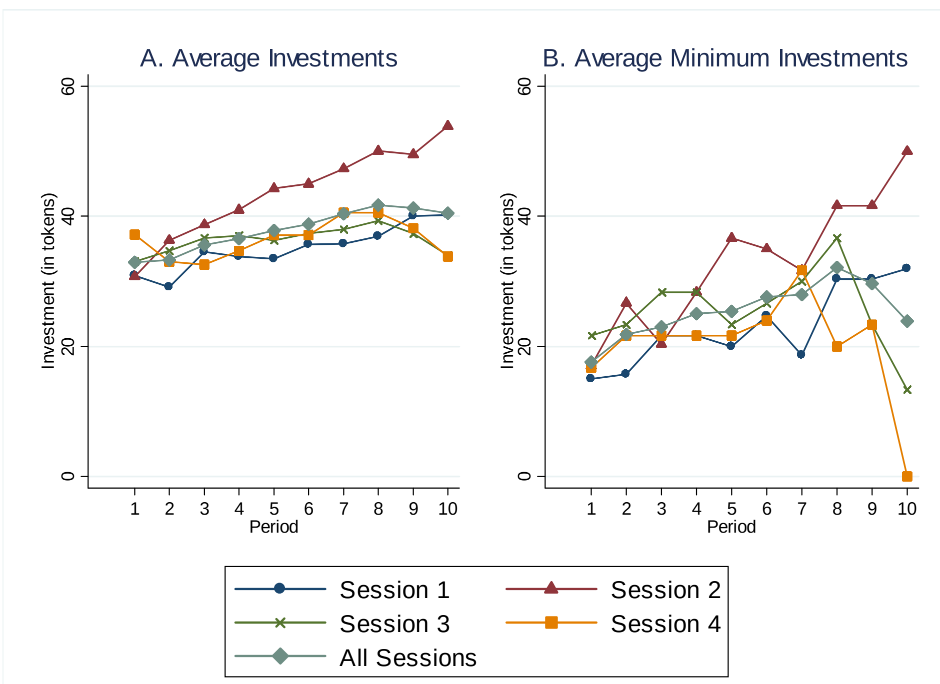


Figure 7: Investments by Session in Bargaining Observable Treatment.

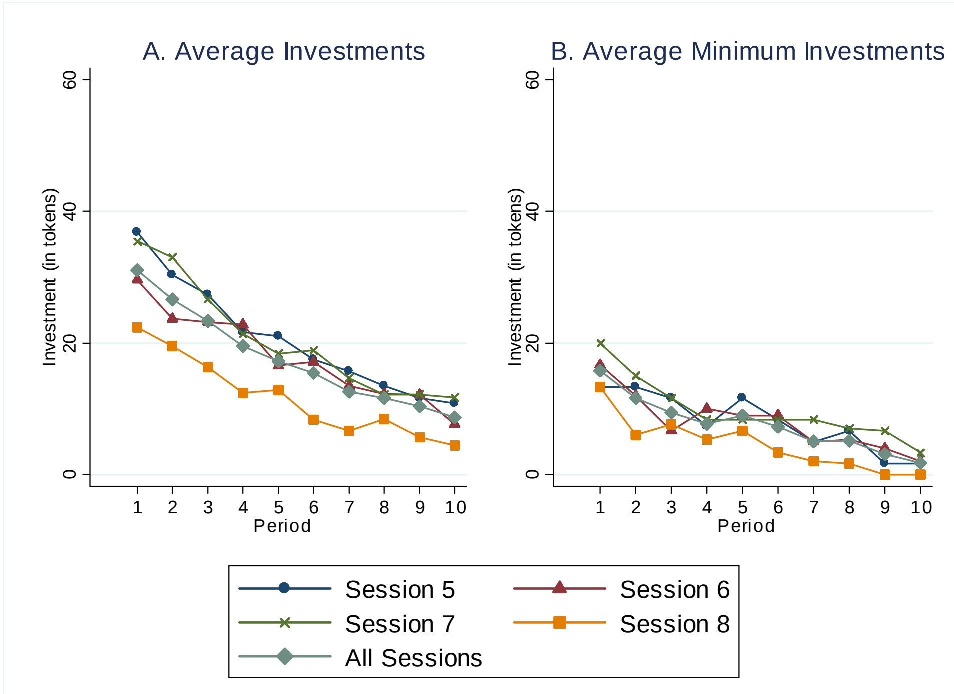


Figure 8: Investments by Session in Bargaining Unobservable Treatment.

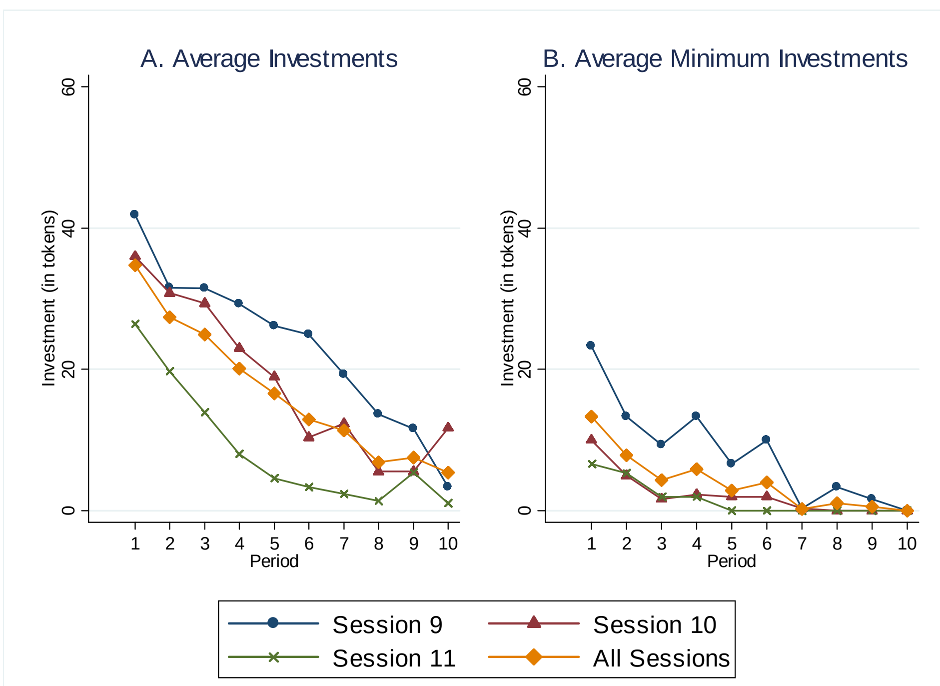


Figure 9: Investments by Session in Control Treatment.

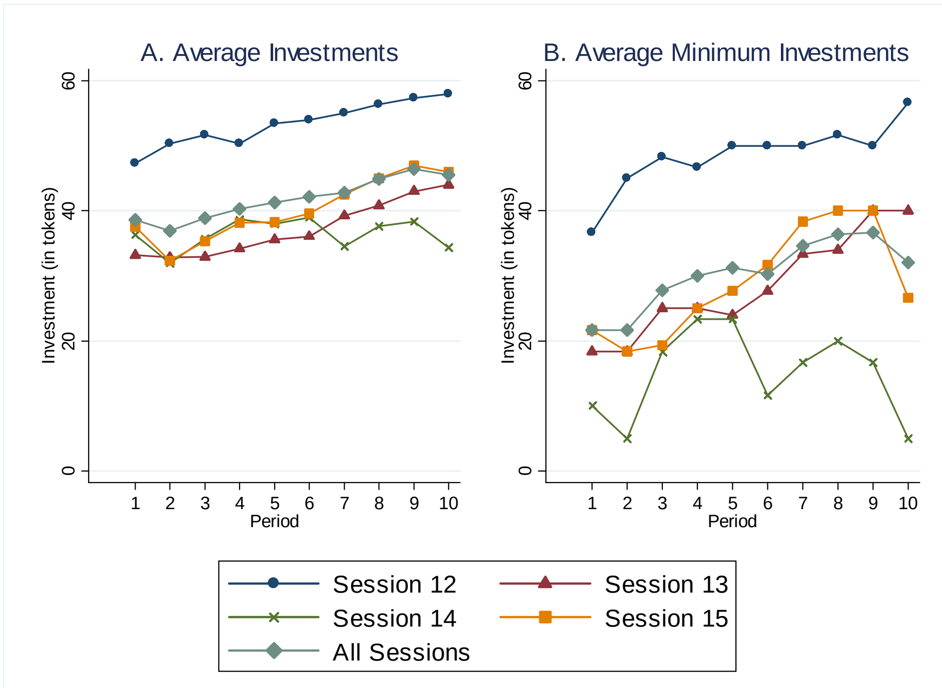


Figure 10: Investments by Session in Proportional Recognition Probability Treatment.

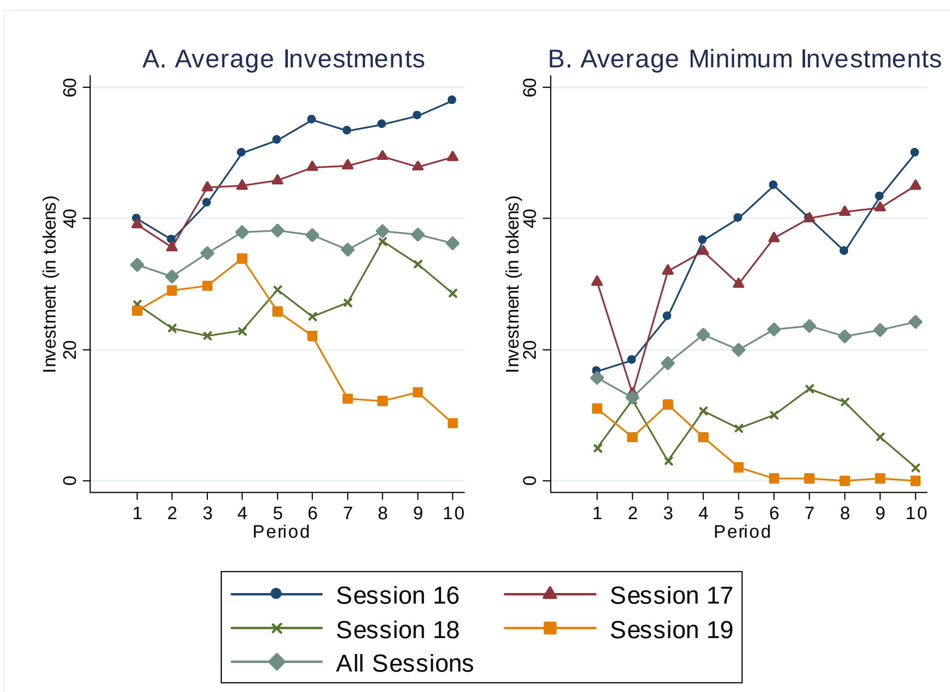


Figure 11: Investments by Session in Proportional Voting Weights Treatment

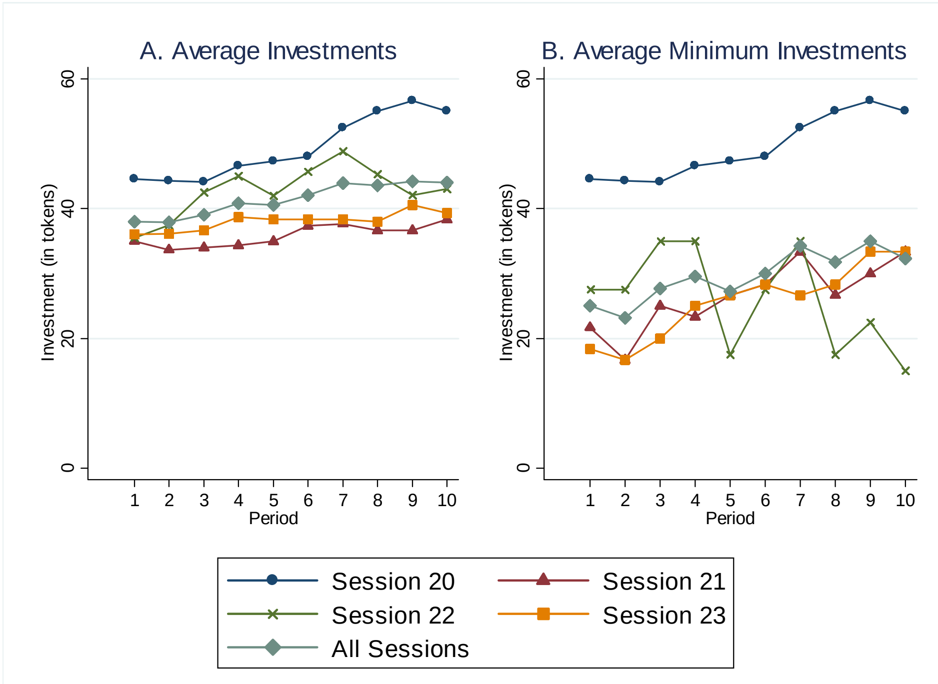


Figure 12: Investments by Session in Exogenous Component Treatment.

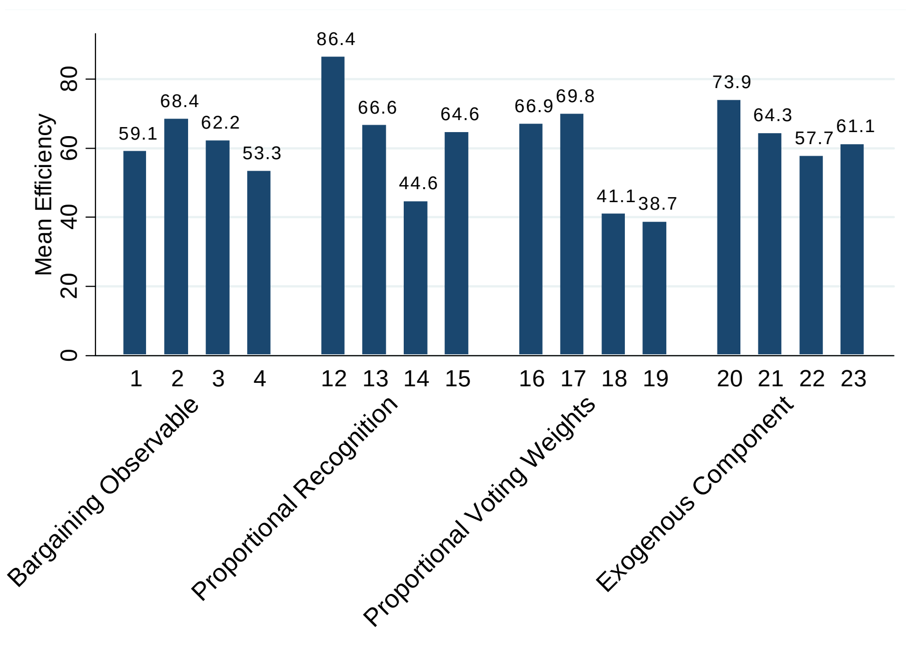


Figure 13: Efficiency as a % of Maximum Attainable by Session.

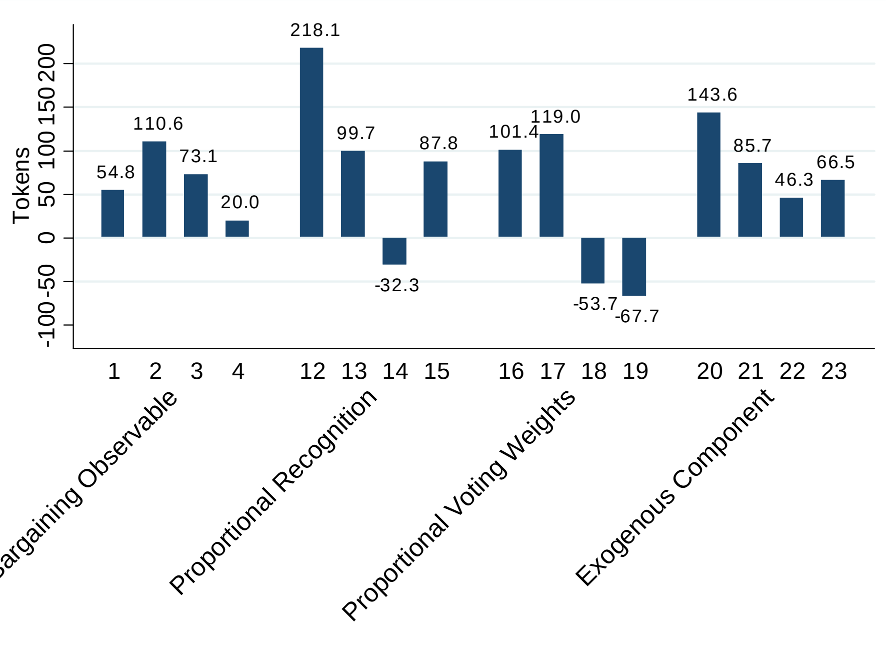


Figure 14: Total Surplus net of Production Costs by Session.

# Online Appendix D. Experimental Instructions Bargaining with Observable Investments

This is an experiment in the economics of decision making. The instructions are simple, and if you follow them carefully and make good decisions, you may earn a CONSIDERABLE AMOUNT OF MONEY which will be PAID TO YOU IN CASH at the end of the experiment. We follow a no-deception ethical policy in this laboratory; hence these instructions fully describe the experiment.

## *A Brief Overview of the Experiment*

In this experiment you will be part of a group of 5 people that must decide on how much to invest into a common fund. You will then proceed to bargain with your group members on how to divide the group's common fund.

## *The Details of the Experiment*

As expressed above, this experiment involves two main tasks: **(1) Investment** and **(2) Bargaining** to divide the fund. We proceed to fully explain each stage.

1. **Investment Stage:**

   (a) You are endowed with 60 tokens and will be asked to enter an amount that you wish to contribute to the group's account. Your investment is multiplied times two and this determines your **contribution**. All decisions are simultaneous. Note that whatever amount you decide to invest is deducted from your initial holdings of 60 tokens.

   (b) Once everyone in your group has chosen an investment level, the computer will pick the smallest contribution and this amount will count as everyone's contribution. The **smallest contribution** is multiplied times the number of member in your group (times 5) in order to determine the **total fund**. Hence, the fund is determined according to the following simple equation:

$$\text{Fund} = 5 \times [\text{Minimum } \{ \text{ Investments in my group } \} \ \times 2] \ .$$

   (c) **Examples:**

   - Your investment is 57. Other's investments are (30,43,60,35). The smallest investment is 30. Hence, the total group fund is 300.
   - Your investment is 40. Other's investments are (50,50,60,60). The smallest investment in your group is 40 (your choice). Hence, the total group fund is 400.
   - Your investment is 25. Other's investments are (50,50,60,0). The smallest investment in your group is 0. Hence, the total fund is 0.

2. **Bargaining** consists of two stages: (2a) Proposal and (2b) Voting. This stage only takes place if the group fund is greater than zero.

    (a) **Proposal**: Each member of the committee will be asked to choose a division of the fund assigning a share to each member including him/herself. We call this division a **proposal.** Naturally, the sum of the shares must equal to the total available fund. Only one of the proposals will be randomly chosen by the computer to be voted on. All proposals have the same chance of being selected.

    (b) **Voting:** After a proposal has been randomly chosen, everyone will proceed to a voting stage. At this point you are asked to "Accept" or "Reject" the distribution of shares that is being proposed. If your proposal is the one selected you also have to vote. A majority (3 or more members) must vote in favor to approve.

        **If Rejected:** every member in your group will proceed to stage **(2.a)** in order to enter a new distribution of shares. Feedback on the previous proposals, the voting result, and who was the proposer, will be displayed below on your screens.

        **If Approved** the result will be binding and your payoffs are determined for that period.

3. **Other Details.** You will participate in 10 periods consisting of stages (1. Investment) and (2. Bargaining). Each period you are again endowed with 60 tokens and your group composition will be determined randomly, meaning that it is unlikely to face the same members from one period to the other. Also, your ID will change when you are assigned into a new group. In one period you can be "Subject 1" and in another period you can be "Subject 3", so that no one can identify you in further periods. Have in mind that, within a period, your ID is always the same and known to others in your group.

### *Your Earnings*

One of the 10 periods will be randomly selected for payment, and all have equal chance of being selected. The period is chosen by the computer and is that same for all subjects in the room. Your earnings ($E$) are given by

$$E = \underbrace{(60 - \text{Your Investment})}_{\text{How much you did not invest}} + \text{ Assigned Share}$$

The conversion rate between tokens and euros is 10 Tokens = 1 euro. Your final payment is given by:

$$\text{Payment in euros} = \text{Show Up Fee (5 euros)} \ + \ E/10$$

**Are there any questions so far?**

### *Examples*

The following examples are meant to guide you through the steps. You are free to make your own choices during the experiment.

**Example 1**. Consider a 5 person committee in which individuals are endowed with 60 tokens. The total fund is determined as described in the separate Table provided to you. If person A invests 30, persons B and C invest 10, and persons D and E invest 20, the smallest investment is 20 which determines a total group fund of 200. Suppose that person A's proposal is chosen to be voted on and specifies 40 for himself, 15 for person B,C,D,and E. If there are three or more votes in favor the proposal is approved and the following table contains the earnings information of each person:

| | Subject A | Subject B | Subject C | Subject D | Subject E |
|---|---|---|---|---|---|
| **Investment** | 30 | 10 | 10 | 20 | 20 |
| **Minimum** | 10 | 10 | 10 | 10 | 10 |
| **Fund** | 100 | 100 | 100 | 100 | 100 |
| **Share** | 40 | 15 | 15 | 15 | 15 |
| **Earnings** | 70 | 65 | 65 | 55 | 55 |

Subject A's earnings are calculated as follows: $60 - 30 + 40 = 70$

Subject B's and C's earnings are calculated as follows:$60 - 10 + 15 = 65$

Subject D's and E's earnings are calculated as follows: $60 - 20 + 15 = 55$

Please make sure you understand each how the earnings are determined. If you have a question please raise your hand and we will come to your cubicle.

This is just an example; you do not have to do this. Instead, alternative investment could have taken place or the proposal could have been voted down and a new proposal round would have taken place.

**Example 2 and Comprehension Quiz.** Consider a 5 person committee in which individuals are endowed with 60 tokens. The total fund is determined as described in the separate Table provided to you. Now suppose that Persons A,B, and C invest 50, Person D invest 40, and Person E invests 60, the smallest investment is 40 which determines the total fund of 400. Suppose that member B's proposal was chosen and each player is assigned a 80 tokens. If votes were "Yes" for persons A,B,C, and D and person E votes against, the proposal is approved. The following table contains the information of each person but you have to calculate the earnings. In about 3 minutes we will check that your answers are correct, and if more than one is incorrect, you may be asked to leave the experiment.

| | Subject A | Subject B | Subject C | Subject D | Subject E |
|---|---|---|---|---|---|
| **Investment** | 50 | 50 | 50 | 40 | 60 |
| **Minimum** | 40 | 40 | 40 | 40 | 40 |
| **Fund** | 400 | 400 | 400 | 400 | 400 |
| **Share** | 80 | 80 | 80 | 80 | 80 |
| **Earnings** | | | | | |

This is just an example. If votes would have been “no”,“no”,“no”, “yes”,“no”, then a new round of proposals and voting would have taken place. Also, different investments could have occurred.

**Are there any questions?**

**What should you do? If we knew the answer to this question we would not be conducting an experiment.**

## *Review of the experiment*

1. Everyone is randomly assigned into groups of 5 people.
2. Out of your 60 token endowment, you will decide how much to invest.
3. Each member will propose a distribution of the common fund.
4. One of the proposals will be chosen for voting, and everyone will cast a vote.
5. If a majority accepts, the allocation is binding.
6. If a majority rejects, everyone in the group will be called to submit a new proposal, and the process repeats itself until a given proposal is accepted.
7. In each period of play you will be randomly matched with new members.
8. 1 of the 10 periods of play will be randomly chosen for payments.

Now we will proceed to a trial period that does not count for payment, it is only meant to familiarize you with the screens and functionalities of the computer program. We ask you to not click or enter anything until we tell you to do so.

# Online Appendix E. Guided Dry Run Instructions for Bargaining Treatments

Subjects were guided through one bargaining period in which the first proposal was rejected and the second proposal was accepted in order to show them what happened in each scenario. The physical layout at the BEELab in Maastricht University does not allow for projecting slides on a screen for all participants to see because they are all in closed cubicles. Hence, the experimenter guided them step by step and explained each screen verbally according to the script below (details are specified in parentheses) and visually verified that subjects were complying with the procedure. Dry runs took around 8 minutes to complete.

- Your screen has three modules: left, middle, and right.
  - On the left-hand side, information is provided to you about your subject identity for this current period and how many tokens you have available for investing. Please take a look at it now.
  - On the right-hand side, you are asked if you wish to perform calculations. Please click yes. A new screen has opened up where you can enter potential investments for each member of the group. Only you will see this, it is meant to help you perform calculations about payoffs. Please enter an investment for each member of the group and click "calculate". (Experimenter verifies everyone is able to enter the data properly). Once you have done so, a new calculation screen will show up which tells you what is the total fund to distribute. Please proceed to enter a

share of the total fund for each member. Only integers are allowed and the sum of shares must equal to total fund that you have calculated in your example. Once you have done so, click “calculate”. (Experimenter verifies everyone is able to enter data properly). Now you can see how much each member would earn if the example you worked out was implemented. You can click “go back” to perform additional calculations. But we will not do this right now.

  – On the middle screen you are asked to enter an investment, and this will be taken into account to determine the total fund to distribute in your group for this dry run. You are free to enter any integer during the experiment, but for our practice purpose please enter any number above zero so that we actually proceed to a bargaining stage. Recall that if anyone invests zero there is no bargaining. Again, during the experiment you are free to enter zero at any point in time. Once you enter a number click “invest”.

- You are now on standby while others in your group invest. Once everyone has invested you will see a new screen where you will enter your proposal.

  – Now please enter a share for each person of your group and click “submit”. Remember that the sum of shares must add up to the total fund which is displayed above the middle module.

- Your are now on standby while others make their proposals. You will next see which proposal was chosen. Below is the ID of the proposer. Please click “reject”. This is just an example, you are free to accept during the experiment whatever share you wish.

- Your are now on standby while others in your group vote. As you can see the allocation was rejected, click “ok” to continue to submit a new proposal.

- Now you can see that below your screens new information has been displayed. It tells you what happened in the previous bargaining round: how much each person was assigned, how each person voted, and who was the proposer.

- We will now proceed to submit another proposal. Once you do so, please click "submit" and then please vote to "accept". (Experimenter makes sure everyone is in the last stage".
- You are now viewing the results of the current period. You can see how much each person invested, what share they received, their voting decision, and the resulting earnings if this period was chosen for payment.
- Once you click proceed, the experiment will start. New groups will be randomly generated by the computer.
- (Experimenter waits to see first investments stage to appear) The experiment has now officially started.