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2022-02

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June 13, 2022

Abstract

We report experimental results from a dynamic real-time bargaining experiment. Players earn flows of income from the assets they control at any point in the bargaining process (*concord*), while they incur costs which are proportional to the size of the conflict between players' current claims (*contention*). We find that most bargaining interactions are characterised by small but non-zero amounts of contention, which arises from the process of tacitly coordinating claims, including from negotiating turn-taking approaches. Interactions with large losses from contention occur in a sizeable minority of interactions. We find differences across participants in how much contention they engage in, and the number of assets they hold.

Keywords: Bargaining; continuous time; turn-taking; locus of control; experiment.

JEL Classification Codes: C72; C91; C92.

*The authors thank the Centre for Behavioural and Experimental Social Science at the University of East Anglia for financial support for the experimental sessions reported. Turocy acknowledges the support of the Network for Integrated Behavioural Science (Economic and Social Research Council Grants ES/K002201/1 and ES/P008976/1). The standard disclaimer applies.

1 Introduction

Bargaining interactions are integrated in many parts of the flow of day-to-day life. A child setting up a mock tea party and another child making a simulated construction site may be in contention over whether a teddy bear will be the guest of honour or the foreman, while each carries on their play activity even while pursuing the dispute. Companies may dispute intellectual property rights over an innovation while the remainder of the business carries on. Countries contest control over territory, and oil, gas, mineral, and fishing resources, while economic activity in undisputed regions carries on largely unaffected. The flows of benefits from the assets controlled by each player continue in parallel to the costs incurred due to arguing, litigating, or fighting militarily over the objects under dispute.

Such interactions offer rich opportunities for agents to take different approaches to claiming resources and to resolving (or not) conflicts among claims. However, the flip side of the potential richness of interaction is that, as is often the case in repeated games, there is a large set of behaviours which are consistent with strategic equilibrium. Placing additional structure on bargaining can sometimes produce sharper theoretical predictions, such as the alternating-moves approach of Rubinstein (1982) or the legislative bargaining model of Baron and Ferejohn (1989). But, most bargaining is not done under a formal set of rules as in a legislature, and partial, tentative bargains may be made - and then subsequently un-made - as the overall interaction progresses. The less constrained the bargainers are to change their claims, and the less constrained they are provisionally to settle and un-settle parts of the bargain, in general the larger the set of equilibrium strategy profiles.

In this paper, we take an empirical approach to the question of how people approach these types of bargaining situations, through the use of a laboratory experiment. In our experiment, pairs of participants interact for intervals of 100 seconds, during which they divide between themselves 9 objects. A participant earns a flow of income proportional to the number of objects they hold uncontested by the other participant in the pair, while incurring costs proportional to the number of objects that both they and the other participant claim. Participants are free to adjust the set of objects they claim at any point in the progress of the interaction. Each participant is therefore free at any moment to decrease the amount of conflict, by removing their claim to a contested asset, or to increase it by adding a claim to an asset currently controlled by the other participant.

The largely unstructured and open-ended design of our bargaining game leaves it to the participants to decide what to make of the game, and how to respond to the environment and to each other. On the one side, bargaining over a set of indivisible objects has elements of a coordination game, and has been studied in one-shot interactions by Isoni et al. (2013) among others; successful coordination, in which each object is claimed by exactly one of the players, results in *concord* between the players. However, unlike one-shot interactions, the introduction of the time dimension presents participants with a challenge in the event of *contention*, in which there is one or more objects which both participants are laying claim to. If contention arises, the participants find themselves in a situation akin to a war of attrition (Smith, 1974), in the sense that both players suffer costs until one of them chooses to yield. Wars of attrition arise in economic contexts, for example, in market exit situations (Fudenberg and Tirole, 1986; Bulow and Klemperer, 1997), and there are a few papers which study these games experimentally, including Oprea et al. (2013) and Bilodeau et al. (2004). However, those models start with players inherently being in a war-of-attrition situation, with the only decision being when to exit. Because of the presence of the aspect of potential coordination and concord, our experiment does not impose a war of attrition as the sole experimental decision task; if participants do engage in lengthy contention, it is an endogenous result of the approaches to bargaining taken by the participants.

In our open-ended approach, we can examine not only how the population of our participants balances concord and contention, but also look across participants to see how much difference there is in their approaches and their corresponding outcomes in the experiment. Our experiment allows latitude for individual traits influencing cooperativeness and competitiveness to operate. A large number of studies, both theoretical and experimental, have examined the factors influencing individual cooperativeness and competitiveness in bargaining environment where two parties have conflicts of interests (e.g. Isoni et al., 2013, 2014; Lau and Mui, 2008; Silby et al., 2015; Cason et al., 2013; Ponsati and Sákovics, 1995). We focus on two characteristics which have been studied in other contests: a participant's gender, and their locus of control.

The evidence of the role of gender in competitive environments is mixed. Cadsby et al. (2013) showed that in contest games, females are more prone than males to the winner's curse. Chowdhury et al. (2016) reported that females are more likely to exert higher efforts in group contest games when identity about race is revealed. In a similar finding in auction games, Ham and Kagel (2006) reports women are found to bid more aggressively. In non-physical conflict situations, Björkqvist (1994); Hyde (2005) find that females are at least as or more aggressive than males. In contrast, Gneezy et al. (2003); Gneezy and Rustichini (2004) find that females shy away from competitive environments relative to their male counterparts.

Rotter (1966) introduced a *locus of control* (LOC) scale, which is intended to capture a person's perception of causality in their immediate environment. This scale classifies people as tending to have an internal or external LOC. A person with an *internal* LOC perceives herself to be in control of or capable of influencing events affecting her. In contrast, a person with an *external* LOC believes that events influencing her life are determined predominantly by chance or other factors beyond her control. Previous studies have found that a person's LOC can have an observable influence on her approach to bargaining (e.g. Lefcourt, 1972, 2014; Assor and O'Quin, 1982; Cupach et al., 2009). Specifically, Bobbitt (1967) and Wall (1977) have shown that when participants are exposed to a competitive stance, those who have an internal LOC bargain more cooperatively (concede more) than those who have an external LOC. However, when participants encounter a cooperative bargaining stance, those with an internal LOC bargain more competitively than those with an external LOC.

The closest previous study to ours is that of Luhan et al. (2017). Similar to our experiment, participants bargain tacitly over assets which deliver flows of income. Their experiment explores settings in which there are a very small number of assets, and where the values of those assets are very different from each other; they focus on whether focal points can help players achieve agreement. Our experiment, in contrast, is focused more on the dynamics of play in an environment in which contention incurs additional financial costs, and where players are able to adjust the amount of contention on a much finer scale. Another study that examines explicit real-time bargaining is Van Dolder et al. (2015), who use data from a television program. In that interaction, three participants bargain over who will receive each of three unequal shares. The bargaining stakes are decreased by 1% per second until the participants reach agreement. Our experiment does not impose any restrictions on the allocation, and the costs of "delay" in any agreement are those which arise from allowing contention to continue on an asset.

The rest of the paper is organised as follows. Section 2 introduces the bargaining game and illustrates why standard solution concepts do little to constrain predictions on behaviour. Section 3 explains our experimental design and procedure. Section 4 outlines the research questions we address with the experimental design. Section 5 reports our results, and Section 6 concludes with a discussion of the potential for further work.

2 The dynamic bargaining environment

Two players, A and B, bargain over a set of indivisible assets $\mathcal{D} = \{1, \ldots, D\}$. The bargaining takes place over a finite number of periods $T \geq 1$, indexed by $t = 1, \ldots, T$. In each period, the players $i \in \{A, B\}$ make simultaneous *claims*, each consisting of a subset of the assets. Formally, a claim is an action $a_i \in 2^{\mathcal{D}}$, where $2^{\mathcal{D}}$ denotes the set of subsets of $\mathcal{D}$. We use $\#a_i$ to denote the number of discs in a claim a_i.

A pair of actions (a_A, a_B) partitions the set of assets into four categories. Define $\pi_i(a_i, a_{-i}) = |a_i \cap a_{-i}^C|$ as the number of discs which player i claims and the other player $-i$ does not.[1] We say that player i *possesses* these assets under that action profile, and refer to the proceeds player i receives as income. Let $\kappa(a_i, a_{-i}) = |a_A \cap a_B|$ be the number of discs claimed by both players A and B; we say these assets are *in contention*. Assets which are claimed by neither player are said to be *idle*.

[1]We follow the standard abuse of notation that $-i$ denotes the coplayer of i.

Each player's payoff from the game is given by summing over all periods t the number of assets possessed, minus the number of assets which are in contention. Formally, let $\mathbf{a} = (\{a_A^t, a_B^t\})_{t=1}^T$ denote the sequence of action pairs realised during a play of the game. Then the payoff to player i is

$$u_i(\mathbf{a}) = \sum_{t=1}^{T} \pi_A(a_i^t, a_{-i}^t) - \kappa(a_i^t, a_{-i}^t). \tag{1}$$

In each period t, both players know the full history of claims in periods $1, \ldots, t-1$. Let $\mathcal{H}_t$ denote the set of possible histories prior to period t, and let $\mathcal{H} = \cup_{t=1}^T \mathcal{H}_t$ be the set of all histories. A *strategy* s_i for player i specifies an action for each possible history, $s_i : \mathcal{H} \to 2^{\mathcal{D}}$.

We now develop the observation that the set of pure-strategy subgame-perfect equilibria (SPE) of this game is very large, and that there exist SPE which are efficient, as well as SPE in which contention and/or idleness occur on the path of play.

We begin with a straightforward observation about the one-shot version of the bargaining game.

Observation 1. *If $T = 1$, then a pure-strategy profile (a_A, a_B) is a Nash equilibrium if and only if it partitions the set of assets: $a_A \cup a_B = \mathcal{D}$ and $a_A \cap a_B = \emptyset$. These equilibria are all efficient; there is no contention and no idleness.*

This multiplicity of equilibria in the stage game generates in turn a multiplicity of SPE in the general case of $T > 1$. As is standard, we can construct a SPE by specifying, for each period t, an action profile which forms a Nash equilibrium of the game with $T = 1$, and specifying that that action profile is played in period t irrespective of the history of play. Observe that we are free to choose which stage-game equilibrium is played unconditionally at each period. Based on constructions of this form, we can make this observation.

Observation 2. *In an efficient play of the game, the sum of the players' payoffs is $D \cdot T$. For any division of $D \cdot T$ between the two players, there exists a SPE which achieves that division. In particular, if T is even, there exist SPE with equal division between the players.*

All efficient allocations are attainable by a suitably constructed SPE; however, there also generically exist SPE in which idleness and/or contention occur. We can construct these SPE by again using the technique of choosing which stage-game equilibrium is played (unconditionally) in continuations.

Example 3 (Idleness: a "DMZ"). *Let $D = \{1, 2, 3\}$ and $T = 2$. At $t = 1$, the players claim $a_A = \{1\}$ and $a_B = \{3\}$, leaving asset 2 idle. Play at $t = 2$ depends on the claims made at $t = 1$:*

- *If at $t = 1$ the players' claims were $a_A = \{1\}$ and $a_B = \{3\}$, then at $t = 2$ player A claims $\{1, 2\}$ and player B claims $\{3\}$.*
- *If at $t = 1$ player B claims $\{3\}$ and player A makes any claim other than $\{1\}$, then at $t = 2$ player B claims $\{1, 2, 3\}$ and player A claims $\emptyset$.*
- *If at $t = 1$ player A claims $\{1\}$ and player B makes any claim other than $\{3\}$, then at $t = 2$ player A claims $\{1, 2, 3\}$ and player B claims $\emptyset$.*
- *If at $t = 1$ both players deviated, choose any stage-game equilibrium to be played.*[2]

In this example, asset 2 serves as a "demilitarised zone" which the players tacitly agree to leave idle. This tacit agreement is enforced by the understanding that if a player claims the asset, then play will revert to the stage-game equilibrium that gives her a continuation payoff of zero. This construction generalises immediately to $|\mathcal{D}| > 2$ and $T > 2$, by again specifying that the first player to deviate is "punished" by receiving a further payoff stream of zero for the remainder of the game.

We can use a similar technique to construct a SPE which features contention:

Example 4 (Contention). *Let $D = \{1, 2, 3, 4, 5\}$ and $T = 2$. At $t = 1$, the players claim $a_A = \{1, 2, 3\}$ and $a_B = \{3, 4, 5\}$, resulting in contention on asset 3. Play at $t = 2$ depends on the claims made at $t = 1$:*

- *If at $t = 1$ the players' claims were $a_A = \{1, 2, 3\}$ and $a_B = \{3, 4, 5\}$, then at $t = 2$ player A claims $\{1, 2, 3\}$ and player B claims $\{4, 5\}$.*

[2]What occurs in this contingency is not important, as it can only be reached by a joint deviation at $t = 1$ and therefore all that is required for a SPE is that a stage-game equilibrium is played at that history.

- *If at $t = 1$ player B claims $\{3, 4, 5\}$ and player A makes any claim other than $\{1, 2, 3\}$, then at $t = 2$ player B claims $\{1, 2, 3, 4, 5\}$ and player A claims $\emptyset$.*

- *If at $t = 1$ player A claims $\{1, 2, 3\}$ and player B makes any claim other than $\{3, 4, 5\}$, then at $t = 2$ player A claims $\{1, 2, 3, 4, 5\}$ and player B claims $\emptyset$.*

- *If at $t = 1$ both players deviated, choose any stage-game equilibrium to be played.*

This construction likewise can be generalised to $T > 2$ by the same method of having any deviation "punished" by having the deviating player's least-favoured stage-game equilibrium implemented for the remainder of the game.

The analysis above shows that, even considering only material payoffs of the game, a wide variety of outcomes are consistent with SPE. For even T, efficient and equal outcomes are possible. However, if D is odd, the SPE supporting efficient and equal outcomes involve playing different stage-game equilibria in different periods. This raises a challenge or players. How can they coordinate on when to shift between the stage-game equilibria as required? The simplest solution is for one player, say player A, to claim $\lfloor \frac{D}{2} \rfloor + 1$ assets for periods $t = 1, \ldots, \frac{T}{2}$, with player B claiming the remaining $\lfloor \frac{D}{2} \rfloor$ assets. For periods $t = \frac{T}{2}, \ldots, T$, the players then reverse the size of their claims. This results in equal payoffs after T periods, but requires trust on the part of player B. There are after all multiple SPE which start out with such an arrangement. In one, A continues claiming $\lfloor \frac{D}{2} \rfloor + 1$ assets in the second half of the game; in another, A intends to change her claim $\lfloor \frac{D}{2} \rfloor$ assets to implement the efficient and equal outcome. By the time the interaction reaches $t = \frac{T}{2}$, player B is therefore exposed to a substantial amount of uncertainty, if she is not confident in player A's intentions. This imbalance can be mitigated by switching off more frequently - for example after each $\frac{T}{4}$ periods - but this is an even more complex strategy to coordinate on.

Therefore, in this game, in principle almost anything can happen in some equilibrium. Contention leading to interactions that resemble wars of attrition are not foreordained, but are possible even under standard preferences - not to mention the possibility of behavioural motivations such as negative reciprocity or spite. These considerations make this game ideally amenable for experimental study, as it is an empirical question how people will process these considerations raised by the theoretical analysis.

3 Experimental design and procedure

3.1 Representation of the bargaining problem

Our objective in the experiment is to provide an environment in which participants can understand at a glance the current situation in the interaction, and in which they can quickly and easily adjust their claims. These criteria call for a graphical representation, which gives the participants a common way to reference each of the distinct assets. We represent the bargaining environment by laying the discs out on a rectangular display based on the "bargaining table" of Isoni et al.. An example layout is shown in Figure 1. Participants are represented by a coloured square referred to as their *base*. A player's own base is always shown on the left, coloured blue, and labeled with the word "YOU". The base of the other player is always on the right, and coloured red.[3]

The table is marked with a grid pattern intended to suggest a visual separation of the rectangle into three *zones*. The central column does not have horizontal grid lines drawn; this creates a separation in which there is a zone around each player's base which does have a grid pattern, and a central zone which lacks a grid pattern. We refer to the zone in which Player A's base is located as *Zone A*, the zone in which Player B's base is located as *Zone B*, and the central zone as *Zone C*. Discs are arranged into three columns: one column in the middle of the region around each player, and one column in the central column. In each scenario players bargained over $D = 9$ discs.

It has already been shown by Isoni et al. (2014), Crawford et al. (2008), and Luhan et al. (2017), among others, that the physical layout of objects in this type of bargaining setting influences claims in one-shot games. Because our assets are all identical in value, only their physical location distinguishes them.[4] There is no layout of the discs that a priori can be guaranteed to be

[3]Therefore, the two participants in a game saw the same display, only rotated through 180 degrees.

[4]This would be true of any graphical representation, not just the bargaining table-based representation we have chosen.

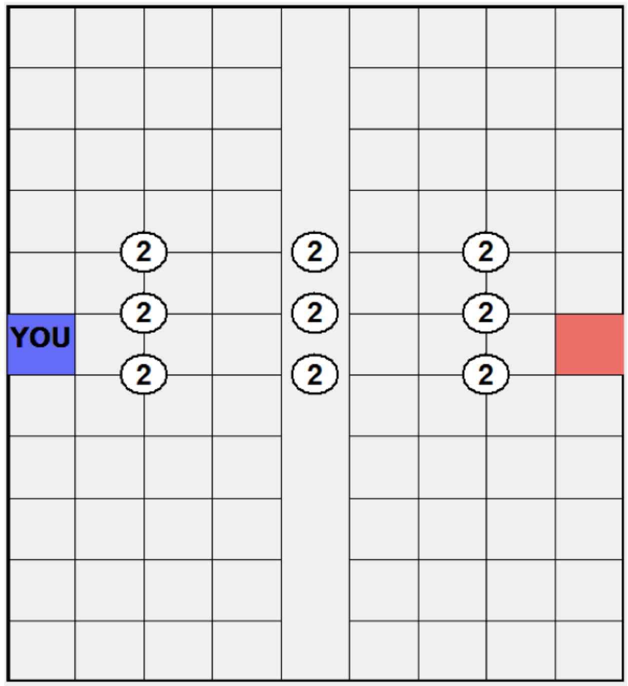


Figure 1: An example of a “bargaining table”.

“neutral”; each representation might suggest certain discs to be more associated with one player than the other, or conversely might suggest certain discs are more contestable. Because our aim is for the environment to be minimally structured, we do not want to by accident pick a representation whose layout happened to drive the dynamics of bargaining. Therefore, participants bargain in different *scenario*s, across which we vary how these discs are distributed among the zones. Write the number of discs in Zone i as D_i, $i \in \{A, B, C\}$. By convention we label players such that $D_A \geq D_B$. Our experiment consists of all 20 scenarios such that each player has at least one disc in their zone ($D_B > 0$).

In our experiment, we set $V_c = V_e = 2$. This makes the arithmetic for determining earnings simple for the participants, as the flow of earnings at any tick is equal to twice the difference of the number of discs controlled and the number of disks in conflict. We represent this in the interface by labeling all discs with the number “2”.

3.2 The bargaining process

We implemented a rich graphical interface to communicate the current state of the game to the participants. Figure 2 shows a sample of a typical state of bargaining in the scenario shown in Figure 1.[5] The interface provides a concise and easy-to-process representation of both actions - the set of disks each player currently is claiming - and outcomes - how those claims map into the current flow of earnings. Claims are represented by flags, which are coloured to match the claiming player's base, and angled in the direction of that base. Outcomes are represented by the colour of the disc. Discs which are blue are controlled by the participant, while those which are red are controlled by the other player. Discs which are claimed by both players - and therefore in conflict - are coloured yellow. Each scenario began with all discs unclaimed.[6]

The bargaining interactions consisted of $T = 100$ stages; in the experiment we referred to a stage as a *tick*. The scenario lasted for 100 ticks, with a tick occurring once per second. Earnings from each game stage were realised based on the state of claims at the time a tick occurred. Participants could toggle their claim on a disc at any time, by clicking on the disc they wanted to claim, or to un-claim. Changes in claims were reflected immediately in the display of flags, but only had earnings consequences once the next tick occurred.

Panels at the sides of the screen displayed the number of ticks which had occurred so far, and the per-tick earnings calculation for both players based on the current state of claims, along with a cumulative running total of earnings for each player from the scenario so far.

[5] The experiment was computerised using zTree. (Fischbacher, 2007)

[6] As will be seen in the sequel, even with the fluidity of the graphical interface, it does take most participants a few seconds to complete initial claims, a physical consideration we abstracted away from in the stylised definition of the game. An alternative initial condition would be to allow players first to choose initial claims simultaneously and independently, and then start the clock. Results from simultaneous-claim studies such as Isoni et al. (2013) and Xue et al. (2021) suggest many pairs would begin in an initial condition with positive amounts of contention due to coordination failure. The contention arising from the initial conditions would be different than that arising during the course of bargaining, as in the latter case a player can see the adaptations the other player is (or is not) making. We chose our initial condition to focus on the latter kind of contention.

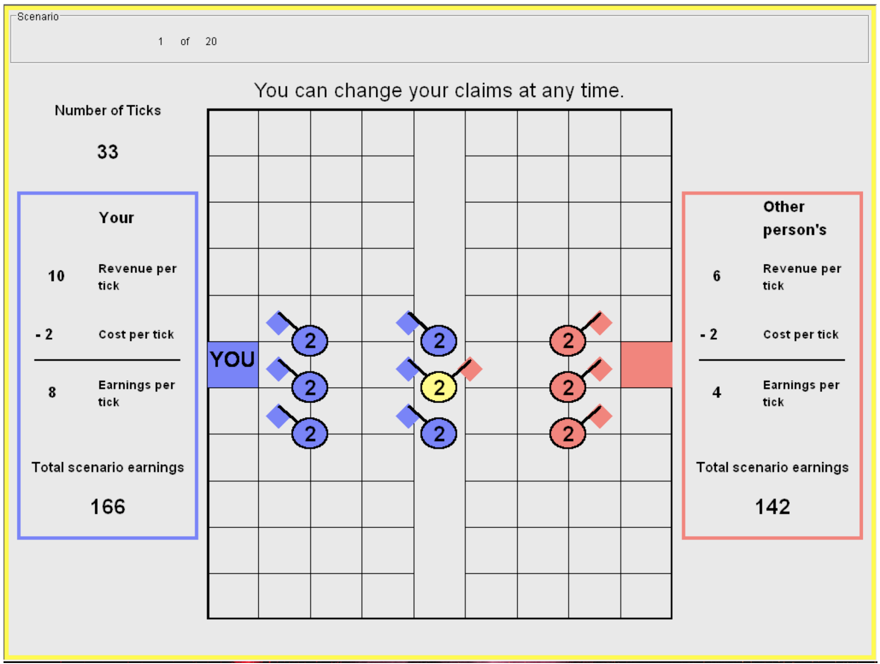


Figure 2: A bargaining interaction in progress, illustrating the principal features of the bargaining interface.

3.3 Experimental procedure

We conducted the experiment in the laboratory of the Centre for Behavioural and Experimental Social Science (CBESS) at the University of East Anglia. Participants were recruited from the lab's standing pool of participants, managed using the hRoot system (Bock et al., 2014). Sessions were conducted in February and March 2017.

We conducted four sessions, each with 24 participants. No two participants were matched more than once. We used a different, randomly-drawn ordering of the scenarios in each session.

Sessions lasted from 60 to 75 minutes, including a post-experiment questionnaire which elicited standard demographics questions as well as an inventory to assess the participant's locus of control.[7]

At the end of the experiment, one of the 20 scenarios was selected at random to determine participants' realised earnings. Average earnings (including a £9 participation payment) were approximately £16.[8]

[7]The locus of control questions are included as Appendix A.

[8]Full instructions are available as a separate appendix.

4 Research hypotheses

We established in Section 2 that subgame perfect equilibrium rules out very little in the way of possible outcomes: efficiency, inefficiency, concord, and contention are all possible, in many different patterns. This indeterminacy makes this environment an ideal one to explore using an experiment. Because neither theoretical considerations nor previous experimental results in other games offer clear predictions as to what to expect, our experiment aims to address a series of questions about aggregate and individual behaviour, which we now introduce.

4.1 General patterns of bargaining

Because in our game there are subgame perfect equilibria both with and without conflict on the equilibrium path, conflict is not inevitable. This distinguishes our game from, for example, wars of attrition (e.g. Oprea et al., 2013; Bilodeau et al., 2004) in which conflict is the initial state, and the only way out of conflict is for one of the players to concede. Nevertheless, evidence from a variety of experiments in all-pay auctions (Hörisch and Kirchkamp, 2010; Gelder and Kovenock, 2017), rent-seeking contests (Mago et al., 2013; Deck and Kimbrough, 2015) market entry (Phillips and Mason, 1997), and market exit (Oprea et al., 2013), report that participants take actions that lead to greater amounts of conflict than equilibrium baselines predict.

Question 1. *How much contention will occur overall? Will contention be a persistent feature within a bargaining pair, or will it be resolved over the course of a pair? Will contention increase or decrease over the course of the experiment?*

If we were to restrict attention to strategies in the one-period version of the bargaining game, then concord can only be achieved either by one player receiving a higher payoff than another, or by both players leaving a disc completely unclaimed. However, the dynamic nature of our interaction opens the door to turn-taking strategies, in which the players trade off claiming a majority of the discs at different points during the interaction. Turn-taking strategies have been found in previous studies (Lau and Mui, 2008, 2012; Sibly and Tisdell, 2018) as a coordination device in battle-of-the-sexes games (see also Bhaskar, 2000; Mailath and Samuelson, 2006; He and Wu, 2020). More closely related to our own setting, Luhan et al. (2017) also finds evidence in a real-time tacit bargaining game of players achieving outcomes with more equal payoffs via taking turns holding higher value assets.

Question 2. *When concord is achieved, will pairs leave discs unclaimed, agree on an unequal split of the surplus, or will they be able to coordinate successfully on a turn-taking strategy profile?*

Although each of the nine discs in each bargaining interaction are of equal value, any implementation of the game must necessarily distinguish among them such that players have a common understanding of *which* discs each of them is claiming. Our experiment uses a graphical layout common to both players, which we vary across bargaining interactions such that no participant sees the same scenario more than once. In one-shot tacit bargaining games using the bargaining table layout, the arrangement of discs has been shown to influence claims (Isoni et al., 2013; Xue et al., 2021). Translated to our implementation, discs in Zone A would be more naturally associated with (and therefore claimed by) Player A, those in Zone B would be more naturally associated with Player B. However, the power of layout as a coordination device - or possibly as a source of conflict - should be tempered by the fact that a player gets continuously-updated information on the current claims of the other player.[9]

Question 3. *Will the graphical layout of the discs influence claims and outcomes?*

4.2 Individual approaches and outcomes

The interactive nature of the bargaining game, and the wide range of strategies which can be optimal against some strategy of the other player, opens the door for individual differences in approaches to bargaining to show themselves.

[9] We also note that our stranger matching protocol undercuts the possibility of the emergence of log-rolling conventions, in which a player accepts a lower share of the earnings from the current bargaining interaction in anticipation of the roles being reversed in a future interaction.

Question 4. *Are there differences in how successful different participants are at bargaining? Do some participants manage to possess discs more often than others? Do participants differ in the amount of contention that occurs in their interactions?*

Relatedly, we can ask questions about whether any observable characteristics of participants predict the outcome of the bargaining interactions they are part of. We will look at two such characteristics, gender and locus of control.

As outlined in the introduction, results across many classes of experimental games and interactions suggest there are systematic differences between genders in many environments. However, the results from different environments do not paint a clear pattern. In particular, in the case of experiments involving conflict, results on the role of gender are mixed (e.g. Eagly and Crowley, 1986; Cadsby et al., 2013; Chowdhury et al., 2016).

Question 5. *Will the efficiency and amount of contention observed in bargaining pairs differ by the gender identities of the participants in the pair?*

Previous studies on bargaining interactions (e.g. Bobbitt, 1967; Wall, 1977) have found evidence that people with an internal locus of control (LOC) behave more competitively than those with an external LOC under a cooperative bargaining environment. When the environment is more competitive, the finding is reversed, with people with an internal LOC behaving more cooperatively.

Question 6. *Do pairs in which participants both have an external locus of control incur different (higher) costs of conflict than those in which participants have an internal locus of control?*

5 Results

5.1 General patterns of bargaining

We begin with a high-level overview of earnings. For each of the 20 scenarios, we have 48 pairs, giving us 960 scenario-pairs. Figure 3 presents a histogram describing the distribution of the total earnings per scenario-pair across all 960 scenario-pair observations. Earnings in a scenario-pair could range from -3600 (conflict on all discs at all ticks) to +1800 (each disc claimed by exactly one of the two players at each tick). We observe immediately that many scenario-pairs come very close to attaining full extraction of the potential surplus. The interquartile range for total earnings by scenario-pair is $[1260, 1770]$, meaning that 25% of pairs were within 30p of full theoretical efficiency. The median scenario-pair earnings was 1674, and the mean 1398, which reflects the long tail of lower earnings; 4% of the scenario-pairs actually wound up with negative net earnings at the end of the interaction.[10]

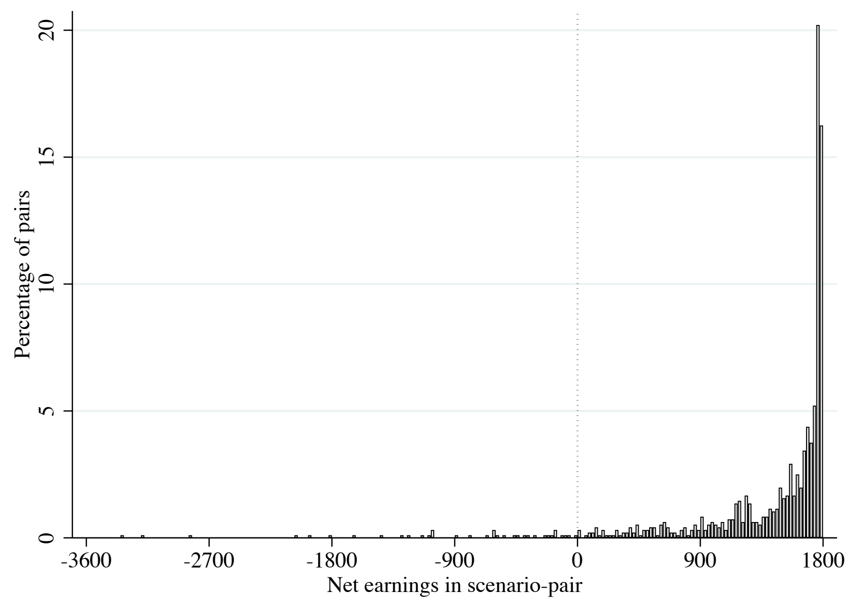


Figure 3: Distribution of total earnings per scenario-pair.

Because the interaction is so open-ended and so many approaches to bargaining are consistent with best-responding, we expect that participants might learn and adjust with experience on how to achieve concord and avoid contention. In Figure 4, we show how the cumulative distribution of costs of contention evolves over time. In the graph, the bottom region, shaded the lightest, is the

[10]Recall that we paid one randomly-selected period, and that participants were given a participation payment of £9, which was used to offset any losses realised in the selected period. Therefore losses up to £9 by a participant in the selected period would be realised in their final earnings, while losses above that would not drive down total experiment earnings further. These earnings distribution shows that the participants' limited liability in the event of massive contention is not an important factor.

proportion of pairs which had exactly zero contention. Each successive contour line represents the proportion of pairs with costs up to 25, up to 50, and so on in steps of 25. The top region, shaded in black, are pairs with costs above 350. What is particularly remarkable is the observation that in the first period, 50% of pairs had *exactly zero costs of contention*. This proportion drops rapidly in the second period, and further generally declines throughout the experiment. Meanwhile, the proportion of pairs with costs above zero but below 25 increases; above a cost of 25, the proportions do not change much across the experiment. Taken together, we observe that participants are initially reluctant to engage in contention, but quickly recognise that effective bargaining requires a willingness to incur small costs.[11] However, participants in general do not learn how to resolve large amounts of contention, as high-contention-cost pairs continue to occur throughout all periods.

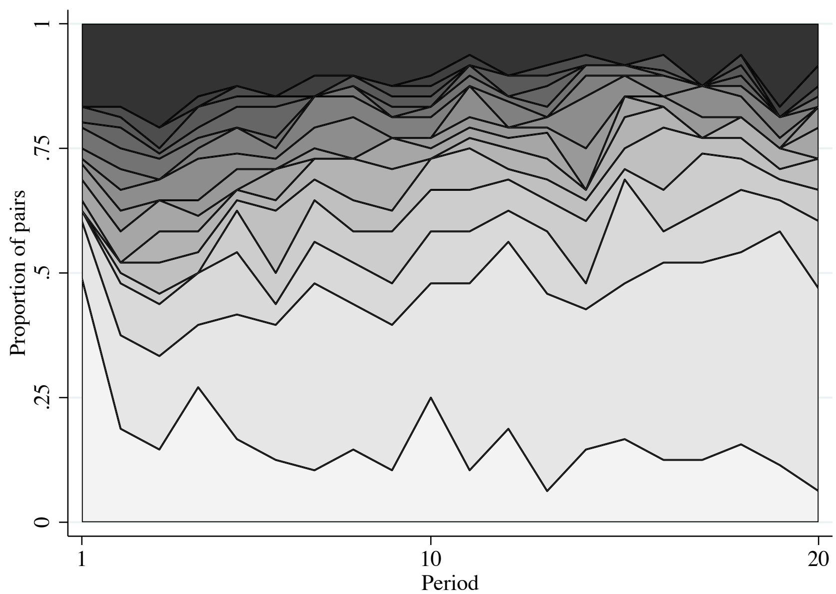


Figure 4: Cumulative distribution of costs of contention, by period. The lowest region are pairs with exactly zero contention. Each successive region plots the proportion of pairs in increments of 25p of costs. The top region represents pairs with costs above 350.

Result 1. *Approximately one-third of pairs overall achieve high efficiency outcomes. Participants learn quickly to use small amounts of contention to drive bargaining without suffering much inef-*

[11]This "convergence from below" is likely influenced in part by our choice of initial condition that guaranteed interactions started in a situation of no contention; this alone however would not explain the large movement from period 1 to period 2.

ficiency, while high-contention pairs occur throughout the experiment.

The size of the efficiency losses would appear to be consistent with sustained contention, rather than leaving discs idle to avoid contention. This is indeed the case. Figure 5 plots the number of discs left idle as a function of the tick number, aggregated across all scenario-pairs. From this we can see it takes up to 2 to 3 seconds for participants to complete selecting their initial claims. After that initial selection, the number of idle discs is negligible. From this we see that some of the inefficiency in those scenario-pairs who attained joint earnings close to 1800 did arise simply because of the time required to carry out the mechanics of setting up initial claims. However, idle discs are not a substantial contributor to inefficiency during the bulk of the interactions, and "demilitarised zone" techniques were at most rarely used to forestall potential contention. We therefore focus the remainder of the analysis on efficiency, and how it is affected by the structure of contention.

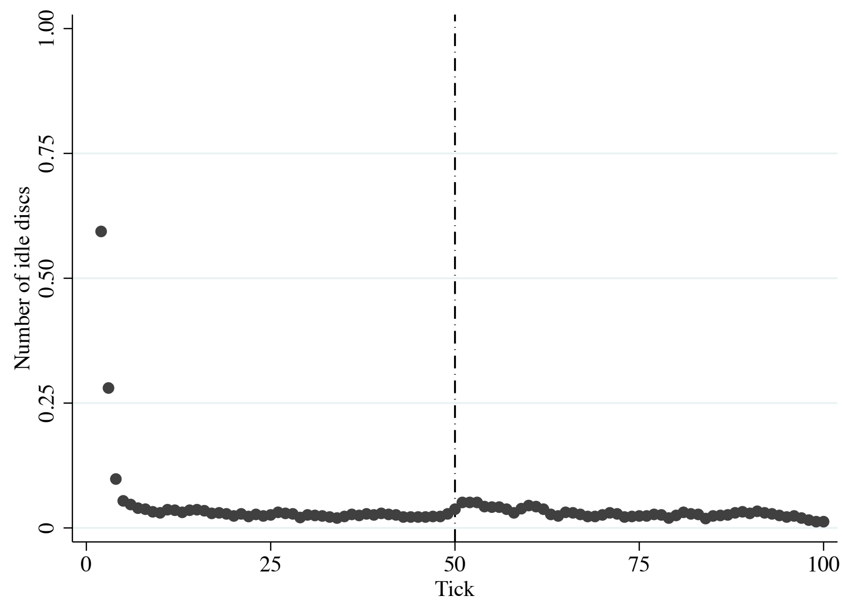


Figure 5: Number of discs left idle, by tick, aggregating across all scenario-pairs.

To get a sense of the broad patterns of efficiency and distribution of earnings, and how that may be influenced by the graphical representation of the scenario, we report per-scenario scatterplots in Figure 6. We represent the payoff outcomes as a pair $(u_A + u_B, u_A - u_B)$, in which the first coordinate captures the (in)efficiency of the outcome, and the second the distribution of payoffs between the players. The feasible outcomes form a triangle, with the efficient outcomes along the edge at the top, and the worst outcome (contention on all discs at all ticks) corresponding to the vertex at the bottom. To each triangle we add two reference lines: a vertical line which is the locus of outcomes in which both participants earn the same amount, and a horizontal line which is the local at which the total net payoff is zero. The outcome of each pair is plotted as a point.

This representation shows at a glance the general patterns of bargaining outcomes. From this we can make some general qualitative observations. In all scenarios, pairs do cluster near the efficient and equal outcome. However, the distribution of points does not appear to differ systematically across scenarios as a function of D_C or $D_A - D_B$. In scenarios with $D_A > D_B$, outcomes are roughly equally likely to fall to the left of the equal-earnings reference line (meaning player A earned more), or to the right (meaning player B earned more). This suggests that whatever influence the graphical layout of the discs might have on bargaining is at most a minor consideration relative to the approaches to bargaining the participants take.

We next look at how the size of contention changes throughout the progress of a given bargaining pair. At each tick t, we tabulate the proportion of pairs who, at t, have contention on zero discs (i.e., concord), one disc, or two or more discs. Figure 7 plots these proportions. This figure reveals two interesting observations. First, the proportion of pairs in concord increases over time, with one important exception, which occurs around tick 50. Just after tick 50, there is a drop in the proportion of pairs in concord, with a corresponding rise in the proportion of pairs in contention over exactly one disc. After this jump, the proportion of pairs in concord resumes its rise, but from this new lower base level. Second, the trajectory of the lines for contention on zero discs and one disc closely mirror one another. The trajectory for the proportion of pairs with contention on multiple discs is generally flat after the the first few ticks. Taken together, these observations suggest that initial contention over a single disc is resolvable roughly half of the time, while contention over two or more discs is much more intractable.

The increase in contention after tick 50 is driven principally by pairs in which the player who

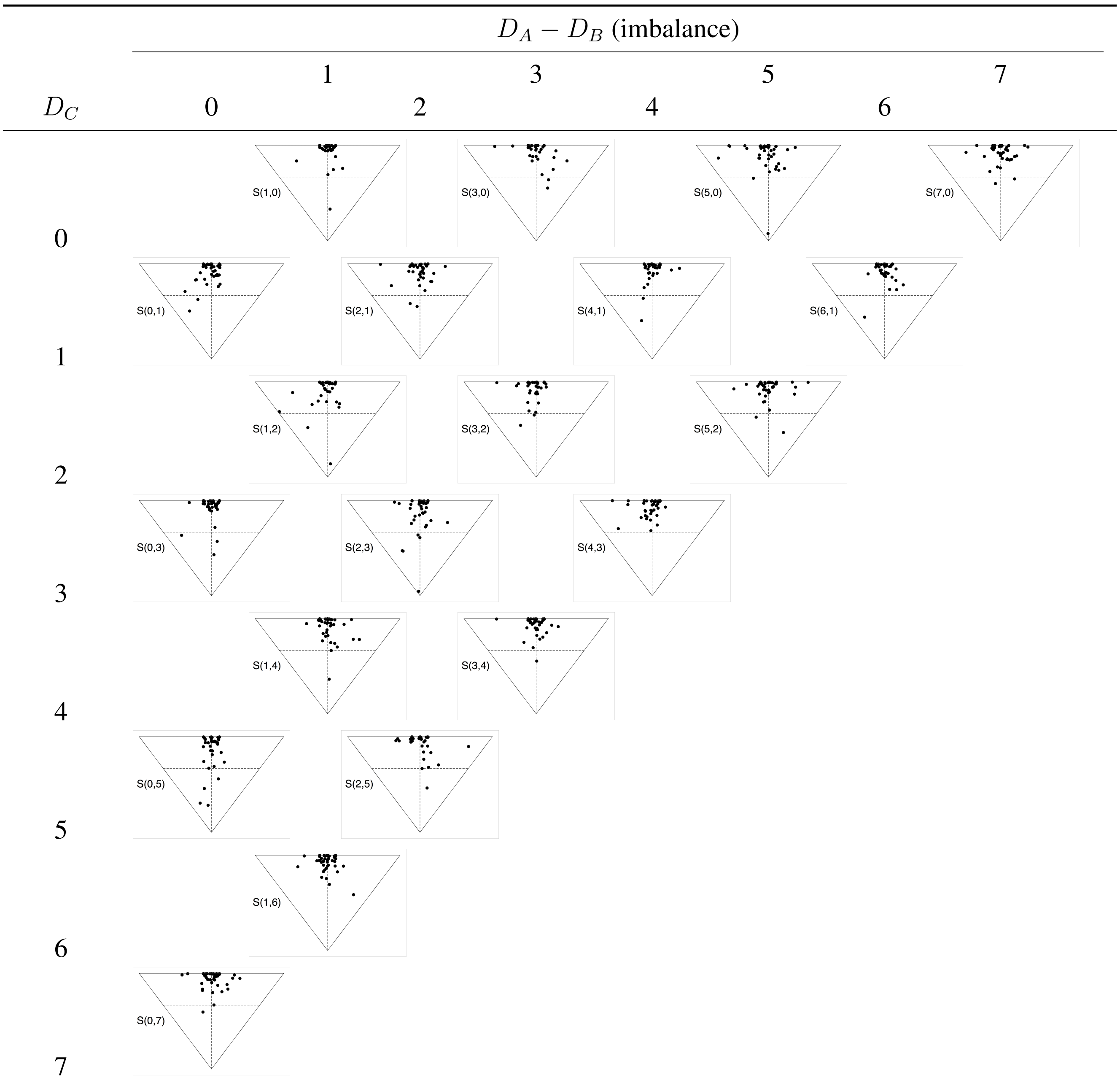


Figure 6: Pairwise earnings outcomes, by scenario. Each triangle represents the set of feasible earnings distributions in the labeled scenario, and each dot the outcome of one pair in that scenario.

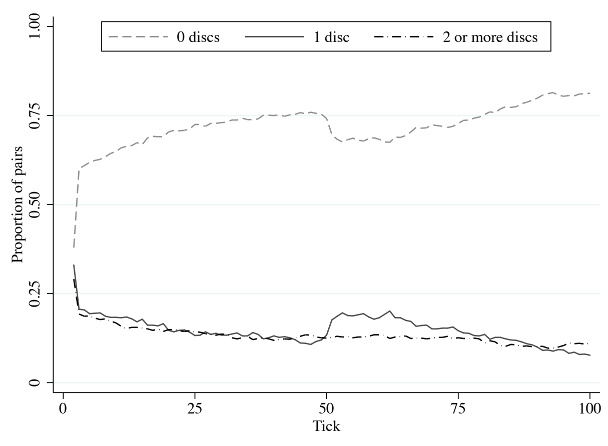


Figure 7: Proportion of pairs by amount of contention, by tick number.

has been unfavoured in the first half of the game negotiating an implementation of a turn-taking strategy. To look for evidence of turn-taking approaches, for each pair, we compute the proportion of ticks at which $\#a_A > \#a_B$, and the proportion of ticks at which $\#a_B > \#a_A$. A strategy profile which exhibits perfect turn-taking these proportions would both be exactly one-half.

In Figure 8 we look at the sample of 443 scenario-pairs in which there was no contention for more than 90% of the ticks; in this bubbleplot the size of the bubble at a coordinate is proportional to the number of pairs represented. This plot shows that pairs achieve concord overwhelmingly by one of two routes. The more common arrangement is that either Player A or Player B claims a majority of the discs at almost all ticks. In 12.7% of the 960 scenario-pairs, Player A claims a majority in over 95% of the ticks, while in a further 9.0%, Player B claims a majority in over 95% of the ticks. Turn-taking strategies are represented in the region in which both of the proportions are close to one-half. We define a turn-taking strategy profile as one in which both Player A and Player B each claim a majority of the discs in at least 43% of the (no-contention) ticks. 13.2% of scenario-pairs qualify as turn-takers under this criterion. Recall that around tick 50, the proportion of pairs with no contention drops by about 10%. This increase in contention is the result of pairs adopting turn-taking strategy profiles negotiating a swap-over at the halfway point.[12]

[12] We looked by hand for more complex turn-taking arrangements. We found just a handful of instances in which a pair successfully swapped over after each 25 ticks. The simplicity and focality of swapping over halfway outweighs the strategic uncertainty faced by the player who is unfavoured by the claims agreed in the first half.

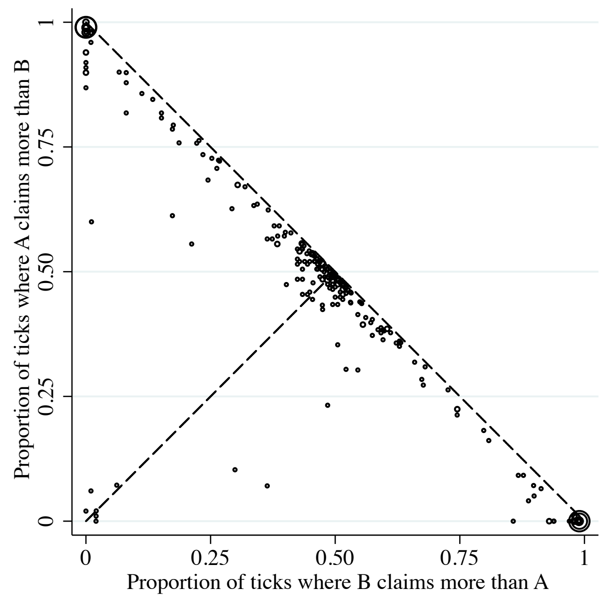


Figure 8: Patterns of action claims across a bargaining pair. Each pair is located on the graph by the proportion of ticks at which A claimed more discs than B (vertical axis), and the proportion of ticks at which B claimed more discs than A (horizontal axis). The size of the bubble at each coordinate is the number of pairs at that coordinate.

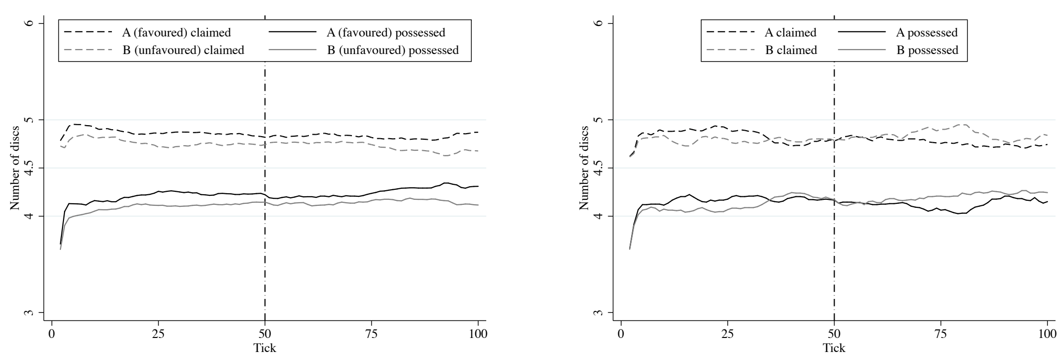
Result 2. *Concord is achieved by a mix of turn-taking approaches and pairs who agree to let one player claim a majority of the discs throughout. Discs are very rarely left idle for extended periods of time.*

We look next at whether the layout of the discs affects the amount of contention. Table 1 reports the mean cost of conflict over each of the 48 pairs in each scenario. There are no clear patterns in these costs as a function either of D_C or of $D_A - D_B$, suggesting that the layout of discs is not an important source of contention, and, combined with the earnings distributions in Figure 6, does not drive outcomes.

Drilling down, we look also at the progress of bargaining in symmetric and asymmetric scenarios. Recall that in a symmetric scenario where $D_A = D_B$, the choice of which player is player A is arbitrary. In Figure 9 we look at how the number of discs claimed and possessed by players A and B, respectively, evolve over time, separately for symmetric and asymmetric scenarios. We observe that in symmetric scenarios, the number of discs claimed and possessed by both players

	$D_A - D_B$ (imbalance)							
D_C	0	1	2	3	4	5	6	7
0		87.6		100.9		150.9		122.6
1	126.5		130.3		96.8		119.6	
2		142.1		108.7		113.5		
3	104.5		201.7		113.1			
4		145.1		111.5				
5	185.6		103.1					
6		122.0						
7	102.4							

Table 1: Mean cost of contention, by scenario.



(a) Asymmetric scenarios

(b) Symmetric scenarios

Figure 9: Discs claimed and possessed by players A and B, by tick, averaged over all pairs.

	Data				Permutation test on SD		
Measure	N	Median	Mean	SD	Expected	Interquartile	CDF
Income	96	822.2	824.4	39.9	36.3	(34.6,38.0)	.923
Contention	96	102.6	125.6	92.3	49.3	(47.2,51.3)	$>$.999
Payoff	96	730.5	698.8	100.2	78.3	(75.0,81.6)	$>$.999

Table 2: Individual participant performance measures. The first group of columns are summary statistics across the 96 participants. The second group are data for test of whether the standard deviation of the measure is greater than would be expected by chance, based on a Monte Carlo permutation test.

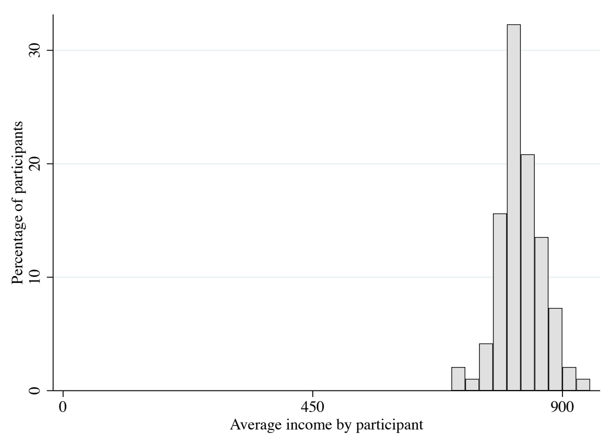
is comparable throughout the interaction. However, in asymmetric scenarios, there is a small but persistent bias, in that players A both claim and possess slightly more discs.

Result 3. *The graphical layout of discs does lead to player A claiming and possessing slightly more discs on average, but the overall effect of this on levels of contention and bargaining outcomes is negligible.*

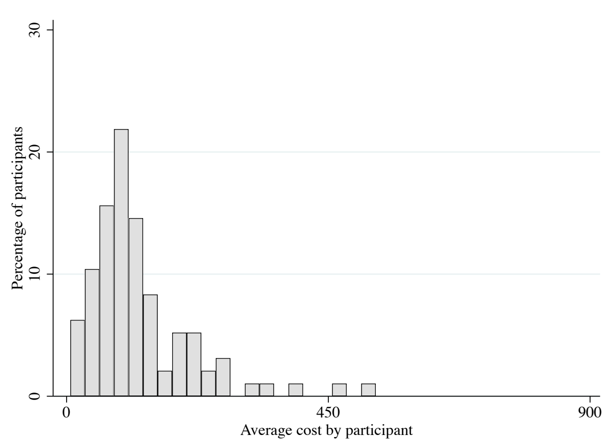
5.2 Individual approaches and outcomes

As a starting point, we compute three overall performance metrics for each participant, averaged over the 20 scenarios: their average income from discs controlled, their average cost of contention, and their average earnings. We present summary statistics on the distribution of these in Table 2, and plot histograms of their distributions in Figure 10. The distribution of payoffs across participants is skewed; this skewness comes principally from the shape of the distribution of costs of contention. From a visual inspection, it appears that participants do vary in their ability to earn money from bargaining, and this variation is explained by their (in)ability to avoid contention, rather than their ability to claim and hold larger numbers of discs over time.

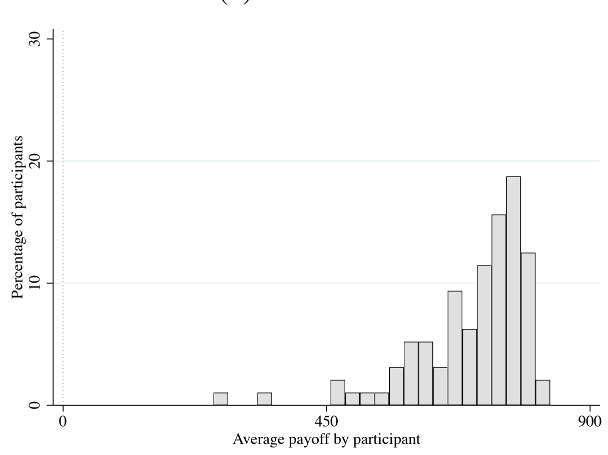
To make this observation more precise, we conduct hypothesis tests on the standard deviation of these measures. Within an experimental cohort, there is nothing that can be measured independently, as participants start receiving feedback about their interactions from the first tick of the first scenario. Although different cohorts can be treated as independent observations in principle,



(a) Income



(b) Contention



(c) Payoffs

Figure 10: Distributions of participant performance measures, averaged across the 20 scenarios.

our design aims to minimise the chances of conventions emerging across the cohort from repeated interaction by implementing stranger-matching, and so our cohorts are large relative to the sample size. So, standard workhorses like the Mann-Whitney-Wilcoxon (MWW) test are not suited to our data. Instead, we maintain the spirit of such tests by carrying out permutation tests. Specifically for the tests on the participant performance measures, for each measure we create 10000 copies of the dataset, in which, in each cohort and period, we shuffle randomly the participant identifiers, and compute the standard deviation of the participant performance measure for each copy of the dataset. We then compare our observed standard deviation against this distribution. The data for carrying out these tests is summarised in the second group of columns in Table 2. We find that the standard deviation we observe for costs of contention and overall payoff are far larger than would be expected by random chance,[13] which allows us to reject a null hypothesis of no variability in bargaining approaches across the participants at any standard level of significance. The standard deviation of income from discs controlled is likewise above what is expected, but not far enough into the tail to reject a null hypothesis of no individual variation against the two-sided alternative at standard levels.

Result 4. *Participants do vary significantly in their success in bargaining, as measured by their average earnings across scenarios. This occurs principally because participants vary in the costs of contention they incur.*

Table 3 breaks out the distributions of earnings and costs of contention by the two demographics of interest: gender and locus of control. The outcomes of females are more dispersed than those of males, by both measures; females were both more likely to have very low and very high costs of contention. Nevertheless, the distribution of relative rankings by both measures are not different (MWW test on earnings, $p = 0.97$; on contention, $p = 0.58$).[14] For locus of control, there are no clear differences in either level (MWW test on earnings, $p = 0.42$; on contention, $p = 0.49$) or dispersion, except for the casual observation that the participants who were farthest out in the tail

[13]Indeed, our observed values are greater than *any* value in our simulated datasets.

[14]The sample for gender consists of 94 participants as two declined to disclose their gender on the demographics survey.

Group	N	Mean	SD	Five-number summary				
				Min	25th	Median	75th	Max
Male	46	708.8	86.8	458.0	677.9	726.2	765.3	797.0
Female	48	690.1	118.9	256.8	627.7	737.0	769.4	821.3
Internal LOC	45	707.9	92.1	458.0	678.5	730.1	770.7	821.3
External LOC	51	690.8	107.1	256.8	626.9	730.9	787.8	804.7

(a) Earnings

Group	N	Mean	SD	Five-number summary				
				Min	25th	Median	75th	Max
Male	46	117.9	66.8	31.6	69.5	105.9	135.5	337.9
Female	48	131.7	112.7	6.5	57.7	91.7	188.7	516.8
Internal LOC	45	126.6	85.4	6.5	81.8	98.1	147.0	401.7
External LOC	51	124.7	98.9	15.4	61.4	102.9	176.0	516.8

(b) Contention

Table 3: Distribution of bargaining performance per scenario, by demographic group

on earnings and contention did report an external LOC.

		Player B	
		Female	Male
Player A	Female	.620	.697
	Male	.599	.530

(a) Asymmetric scenarios

		Player B	
		Female	Male
Player A	Female	.781	.679
	Male	.683	.468

(b) Symmetric scenarios

Table 4: Average number of discs in contention per tick by gender composition of pair.

We can also look for potential interaction effects by the type of the pair on the amount of contention. We first look at gender in Table 4, which breaks out the average number of discs in contention per tick by the genders of the two players in the pair. In both symmetric and asymmetric scenarios, we observe that the point values of contention are higher in pairs consisting of two females than those with two males. However, these differences are not statistically significant at standard levels. We perform a permutation test in which we create 10000 simulated datasets in which we randomly re-shuffle the genders of the participants, and re-compute the discs in contention measure for pairs using the simulated genders. We cannot reject the null hypothesis of no difference between female-female and male-male pairs in symmetric ($p = 0.26$) nor asymmetric ($p = 0.63$) scenarios, against the two-sided alternative.

Result 5. *Females engage in slightly more contention than males, but the difference does not approach significance at standard levels. The dispersion of contention and earnings amounts is slightly larger for females than males.*

		Player B	
		Internal	External
Player A	Internal	.677	.653
	External	.567	.598

(a) Asymmetric scenarios

		Player B	
		Internal	External
Player A	Internal	.711	.595
	External	.410	.868

(b) Symmetric scenarios

Table 5: Average number of discs in contention per tick by locus of control composition of pair.

Looking at locus of control, Table 5 reports discs in contention per tick by pair type in asymmetric and in symmetric scenarios. Here we observe a pattern in which pairs of opposite LOC types tend to have higher amounts of contention. In symmetric scenarios, same-type pairs average .799 discs per tick against .500 for opposite-type pairs, while in asymmetric scenarios same type-pairs average .633 discs per tick against .610 for opposite-type pairs. Using the same permutation test method as for gender, we find neither the differences in symmetric scenarios ($p = 0.07$) nor the difference in asymmetric scenarios ($p = 0.75$) are significant.

Result 6. *The bargaining performance of participants with internal and with external LOC are similar in aggregate. The average pair with the same locus of control exhibits more contention than the average pair with opposite locus of control, but the differences are not significant at standard levels.*

6 Conclusion

We report the results of an experiment in which participants bargain over valuable assets which yield streams of income while the negotiations take place. The environment is sufficiently open-ended that most bargaining behaviours are consistent in principle with best responses to some conjectured strategy of the other player. The rich interaction that is possible in this environment leaves it up to the participants what they will make of the interaction: they can get mired in intractable conflicts that last throughout the interaction, or they can find a way to extract the available surplus efficiently. Rather than imposing a rigid extensive game form on the interaction, the experimental design reveals something of the process through which concord is or is not achieved.

We find that concord and contention co-exist throughout the experiment. Interestingly, even participants who are inclined towards finding a cooperative solution to extract most of the surplus learn quickly the usefulness of small amounts of contention. This low-level contention is frequently associated with the negotiation of turn-taking strategies that allow pairs to approximate efficient and equal outcomes.

A challenge of games such as ours which have rich interaction between the participants is that independence is impossible: participants are constantly learning both within a period and across the experiment. The establishment of social conventions over the course of the experiment would require participants to have some amount of shared experience. Our stranger matching protocol strongly impedes the formation of such conventions, allowing us to focus on the individual negotiations between participants.

We do find that participants differ systematically in their approaches to the game. In particular, participants differ in the amount of contention they enter into; however, a greater willingness to engage in contention does not in general lead to generating more income from possessing assets. Gender does not significantly explain variation across participants. The interactions in our experiment are anonymous, so participants are not primed by knowing the gender of their co-player. Meanwhile, gender effects reported in the literature are varied across different contexts; given that our interactions can endogenously become either cooperative or competitive in nature, any gender effects are likely to be subtle and dependent on the path of play.

Our results on locus of control, while somewhat consistent with previous studies, are weaker than we might have expected. There is some weak evidence that bargaining works best with a pair with opposite LOC orientations. This does make some intuitive sense: same-LOC pairs could fall into contention traps, but for different reasons. A pair in which both players have external LOC could have contention because both of them feel that "that's just the way it is", while a pair in which both have internal LOC might have contention because both players try to force their will on the other. We think a potentially promising direction for future experiments would be to investigate this in more detail. In our design, we do not observe anything in the bargaining process that allows us to distinguish clearly between these passive or active modes of contention; it would be interesting to adapt our dynamic game framework to be able to generate process evidence that could distinguish not just the observed paths of play, but the strategic intentions of the players.

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A Locus of Control inventory questions

Question 1

- ⊙ Many of the unhappy things in people's lives are partly due to bad luck.
- ⊙ People's misfortunes result from the mistakes they make.

Question 2

- ⊙ One of the major reasons why we have wars is because people don't take enough interest in politics.
- ⊙ There will always be wars, no matter how hard people try to prevent them.

Question 3

- ⊙ In the long run, people get the respect they deserve in this world.
- ⊙ Unfortunately, an individual's worth often passes unrecognized no matter how hard he tries.

Question 4

- ⊙ The idea that teachers are unfair to students is nonsense.
- ⊙ Most students don't realize the extent to which their grades are influenced by accidental happenings.

Question 5

- ⊙ Without the right breaks, one cannot be an effective leader.
- ⊙ Capable people who fail to became leaders have not taken advantage of their opportunities.

Question 6

- ⊙ No matter how hard you try, some people just don't like you.
- ⊙ People who can't get others to like them don't understand how to get along with others.

Question 7

- ⊙ I have often found that what is going to happen will happen.
- ⊙ Trusting to fate has never turned out as well for me as making a decision to take a definite course of action.

Question 8

- ⊙ In the case of the well prepared student, there is rarely, if ever, such a thing as an unfair test.
- ⊙ Many times exam questions tend to be so unrelated to course work that studying is really useless.

Question 9

- ⊙ Becoming a success is a matter of hard work; luck has little or nothing to do with it.
- ⊙ Getting a good job depends mainly on being in the right place at the right time.

Question 10

- ⊙ The average citizen can have an influence in government decisions.
- ⊙ This world is run by the few people in power, and there is not much the little guy can do about it.

Question 11

- ⊙ When I make plans, I am almost certain that I can make them work.
- ⊙ It is not always wise to plan too far ahead because many things turn out to be a matter of luck anyway.

Question 12

- ⊙ In my case, getting what I want has little or nothing to do with luck.
- ⊙ Many times we might just as well decide what to do by flipping a coin.

Question 13

- ⊙ What happens to me is my own doing.
- ⊙ Sometimes I feel that I don't have enough control over the direction my life is taking.