Bargaining and Reputation: Experimental Evidence on Bargaining in the Presence of Irrational Types*

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Abstract

We conduct two sets of laboratory experiments to understand what role if any, commitment and reputation play in bargaining situations. The experiments implement the *Abreu and Gul* (2000) bargaining model that demonstrates how introducing "behavioral types", which are obstinate in their demands, creates incentives for all players to build reputations for being hard bargainers. The data are qualitatively consistent with the theory, as subjects mimic induced obstinate types. Furthermore, we find evidence for the emergence of complementary types, whose initial demands instantaneously acquiesce to induced obstinate demands. However, there are important quantitative differences between the observed behavior and several of the finer predictions of the model: subjects are inclined to make aggressive demands too often, and participate in excessively long conflicts before reaching agreements. We present evidence that these deviations are in part a consequence of uncertainty over the set obstinate types. Finally, we relate our results to findings from both bilateral bargaining and reputation formation experiments in economics.

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1 Introduction

Since bargaining is the process through which many agreements are reached within the economy, it has been an active area of research in political science, industrial relations and among theoretical, empirical and experimental economists. An important aspect of many bargaining situations is that an individual will often try to improve their bargaining position by pretending they are committed and that they could not possibly accept less than a particular payoff under any circumstances. Such commitment tactics have long been recognized as not only an important factor in determining bargaining outcomes but also as a source of conflict. For example, consider the well documented behavior of union officials and management during labour negotiations. Before negotiations start, the former are often observed building up expectations of a certain wage increase. Indeed to such an extent that it would appear the union negotiators would be incompetent if they achieved anything less. For their part, management publicly claim that the firm could not afford an increase beyond a (smaller) wage; to agree to a higher wage would be to fail in their responsibilities to the shareholders. The intentions of both sides are clear: to convince the other that their hands are tied to a particular offer, from which there is no possibility of retreating. Further examples of such strategic posturing can be found in a variety of other settings: public announcements by politicians of "red lines", which they vow cannot be crossed during treaty negotiations; or salespersons claiming they could not possibly agree to a certain discount without talking to their manager, who in turn would be unlikely to consent.[1]

A number of theory papers have extended the classical non-cooperative bargaining theory of *Rubinstein* (1982) to incorporate such strategic posturing.[2] This literature has culminated in the model of bargaining and reputation by *Abreu and Gul* (2000). In their stylized game they recast the bargaining problem into two stages. In the first stage, two players choose their bargaining positions, that is the share of the pie they want. If these positions are compatible with each other the game ends. If their positions are incompatible, no further offers are made. Instead they enter a second stage in which a continuous time concession game is played, which ends when one player concedes to their opponent by accepting their division. Reputation enters

[1] The economics literature was developed in *Shelling* (1960), who documented many examples of the role of such commitment tactics. Insights from this essay were first formulated in a non-cooperative game theoretic model in *Crawford* (1982). See also *Muthoo* (1999) for a general treatment of the role of (partial) commitment in bargaining.

[2] For example, work by *Chatterjee and Samuelson* (1987, 1988) on bargaining between a buyer and a seller.

through the possibility that a player is *behavioral*. A behavioral player will never concede to any offer that does not give them at least the amount that they demanded in the first stage.[3]

With the aim of investigating the role of commitment and reputation in bargaining environments, this paper implements the above stylized bargaining model in the laboratory.[4] Understanding the extent such considerations play in bargaining not only provides a potential explanation for differences in allocations received by agents, but also for inefficiencies that result from delay or disagreement. Viewing the strategic interaction in the stylized two stage format offers a fresh perspective on the bargaining problem, one that has not previously been brought to the laboratory. Indeed this format brings to the fore the role of strategic posturing, and eliminates any proposer advantage that typically results from alternating offer protocols commonly used in the laboratory. This is theoretically emphasized by the convergence result shown in *Abreu and Gul* (2000), which connects the equilibrium outcomes of the stylized game with that of the limit of discrete time bargaining games, as the time between bargaining rounds goes to zero.[5] In this sense, the stylized game is the underlying strategic interaction in such general bargaining environments as one abstracts from the particulars of the bargaining protocol.

While the above motivates our interest in bringing the stylized game into the laboratory, it does not justify the addition of "irrationality" into the model. There are several ways in which to view the behavioral types of the model. First, these types are genuinely boundedly rational, in the sense that they are obstinate, or follow a rule of thumb or bargaining convention that has evolved outside the current model. Second, the types could result from actions taken before the bargaining process has begun that potentially commits a player to being unable to accept less than a certain outcome.[6] In both cases, there is the possibility that either player is irrevocably bound to a demand. One could imagine pre-negotiation actions that only provide partial commitment or

[3]The r-insistent types of *Myerson* (1991) is an example of the earlier use of such types.

[4]In the current context, commitment is understood to mean that an agent can only agree to a predetermined outcome or set of outcomes. Commitment does not result from the timing protocol and differs from Stackelberg leadership. Reputation in this paper refers to incomplete information over whether a player is committed to some predetermined outcome or set of outcomes. In this paper there is uncertainty about the types of both players, which differs from models (and much of the previous experimental literature) in which only one actor can build a reputation.

[5]This result allows for a very general class of bargaining protocols, including alternating offers as a special case.

[6]See *Muthoo* (1999) or *Kambe* (1999) for models that demonstrate that incomplete information over whether such actions have been taken and their availability, leads to a similar environment to that in *Abreu and Gul* (2000).

obstinate play that is more complicated than being irrevocably bound. However, this simple formulation of behavioral types permits a tractable model that highlights the role of strategic posturing and delivers delay as an equilibrium outcome.[7]

In summary the stylized bargaining model provides the framework through which an analysis of the role of strategic posturing in bargaining can be undertaken. However, conducting this analysis with field data posses a number of difficulties. First, studying the effect of taking a strategic posture requires a ceteris paribus variation of an economic relationship with and without the possibility of building up a reputation, which seems impossible with current field data. Second, the researcher must have a complete understanding of the rules of the game, the potential types of the agents and their payoff functions to distinguish between alternative motives for conflict and delay. Finally, the equilibrium predictions of the model depends on knowledge of the distribution of rational and behavioral types in the sample. While these unknowns can be estimated from demand data using the model, there is no measure by which to evaluate its performance. In the laboratory we are able to create a controlled environment where the number and strategic posture of the behavioral types is the sole difference between sessions, thereby providing a direct test of the impacts of commitment tactics on bargaining outcomes.

This experimental test of bargaining behavior includes a number of notable features, especially with regard to the related experimental bargaining literature. First, we induce certain behavioral types, which provides some control over the predictions of the model.[8] Second, bargaining in continuous time with an infinite horizon is new to the literature, as is the concession formulation of the game. This provides an opportunity to increase our perspective on how people bargain. However as a consequence, comparison with the existing literature is less clear cut. Third, estimates from a structural model are used to determine the comparative static prediction across treatments. In doing so, the predictions of the model are tested while allowing for a variety of behavioral, or norm driven, play by subjects.

The paper presents two sets of experiments. The first set places no restrictions on demands that subjects can make and only varies across treatments whether an induced behavioral type is included or not. The main interest is to see if subjects take advantage of the induced type by mimicking its initial demand. The results provide clear qualitative support that this is the case and, as such, provides evidence

[7]See *Crawford* (1982) for an exposition on the need for both uncertainty and irrevocability in a bargaining model with commitment and delay.

[8]In *Roth and Schoumaker* (1983) subjects also bargain with computers, but they are not aware of it. There are other experiments involving computer players in other strategic settings (see for instance *Grosskopf and Sarin* 2007).

that subjects recognize the role of strategic posturing in bargaining. In addition, we find evidence for the emergence of complementary types, whose initial demands instantaneously acquiesce to induced obstinate demands. However, there are important quantitative differences between the observed behavior and several of the finer details of the model, in particular with the length of delay and the pattern of concession in the second stage play. A notable exception to the latter is that concession behavior is closer to the predicted pattern in subgames in which equal split demands meet demands mimicking the induced type. This led to the conjecture that these deviations may be in part due to some uncertainty over the set of behavioral types in the subject population. A second set of experiments were conducted, in which the design was modified to ensure that the set of behavioral types is common knowledge for all subjects. This results in observed behavior closer to that predicted. However, some disparities do persist. Subjects appear to be disproportionately mimicking more aggressive types in the first stage, and delays remain longer than predicted, although to a lesser extent.

The paper is organized as follows. In the next section we provide a brief review of the related experimental literature. Section 3 outlines the theory behind a symmetric version of the bargaining and reputation model implemented in the laboratory and highlights the relevant predictions from this model. Section 4 introduces our first set of set of treatments, with the experimental design, the results and a discussion of these results contained in separate subsections. A modified experimental design, used to conduct more direct tests of several equilibrium predictions from the model, is presented in section 5. Again, the experimental design, the results and a discussion of these results are contained in separate subsections. A final section concludes.

2 Related Experimental Literature

The results presented in this paper relate to experimental studies of bargaining, reputation and war of attrition models. With regard to bargaining, a large literature has documented observations of norm driven behavior by subjects. For instance in bilateral bargaining, agents frequently agree on rather egalitarian outcomes in situations where the standard model, with purely selfish preferences, predicts rather unequal outcomes.[9] In his summary of the literature, *Roth* (1995) also notes a number of observable regularities in bargaining regarding the establishment of "focal points", what determines "credible" bargaining positions, and the roles of subjects' expecta-

[9]See *Roth* (1995) for details. Typically subjects in bargaining experiments do not choose shares that are predicted by the subgame perfect equilibrium and often propose almost equal divisions.

tions of one another as they develop during sessions.[10] These experimental findings led to the development of models incorporating other regarding preferences, initially focussing on concerns for inequality aversion (*Fehr and Schmidt* 1999, *Bolton and Ockenfels* 2000). Indeed, the other regarding preferences literature continues to be an active area of research, with the role of intentions (*Charness and Rabin* 2002) receiving increased attention.[11]

With the exception of earlier bargaining experiments, which had an unstructured format, much of the experimental literature has focused on a small number of rounds of alternating offers (in particular the ultimatum and dictator games). Consequently the format of bargaining implemented here is new to the literature. As is the focus on the role of commitment and reputation in a general bargaining context. The existing experimental literature suggests that conflicts in bargaining arise due to fairness preferences or feelings of spite, rather than strategic posturing.[12] The experiments presented here will investigate directly the role of such posturing in a one-shot bargaining environment in which delay (as well as the possibility of disagreement) is an equilibrium outcome.

The experimental literature on reputation building has focussed mainly on testing models of one-sided incomplete information in a repeated game setting. A series of experiments have tested the sequential equilibrium predictions of variants of the borrower-lender ("trust") game first implemented in the laboratory by *Camerer and Weigelt* (1988).[13] Overall, these papers observe a broad notion of reputation building by subjects in their respective environments. However, the finer details of sequential equilibrium predictions can fail to be borne out in the data. The model implemented in the experiments presented here has some important differences in theoretical structure. Most notably, two-sided incomplete information means that the incentive to build reputation is symmetric, as is the need to incorporate the other player's in-

[10]See *Roth et al.* (1981), *Roth and Murnighan* (1982), *Roth and Schoumaker* (1983). Since any combination of demands that adds up to the size of the pie is a Nash Equilibrium, in these experiments there is no obvious equilibrium focal point. The above-cited studies demonstrate that by increasing the number of norm focal points, experimental outcomes become less concentrated at 50/50 and increase the probability that the bargainers will fail to reach an agreement.

[11]It is to be the subject of a chapter in the forthcoming volume of the Handbook of Experimental Economics (*Cooper and Kagel* forthcoming).

[12]For example, *Falk et al.* (2003) examine reputation in ultimatum games defined as the recent history of acceptance/rejection of past offers. They conclude that, while it changes the outcome, the effect of reputation is to reduce the proposers' uncertainty about the responders' acceptance thresholds.

[13]See *Neral and Ochs* (1992), *Brandts and Figueras* (2003) and *Grosskopf and Sarin* (2007). *Jung et al.* (1994) uses a similar design but test the chain store game.

centive to do this into one's own strategy. An experiment by *McKelvey and Palfrey* (1995), who study a repeated hold-out game, comes closer to the strategic setting of the model implemented in this paper.[14]

Over and above the various theoretical differences in the models implemented, it is important to add that it is not obvious that evidence of reputation building in these other environments would translate to a general bargaining situation. A broad interpretation of the results from previous studies would suggest that subjects would be inclined to mimic the first stage demands of behavioral types, which corresponds to reputation building in the current context. However, reputation building in our experiments will not always align itself with adherence to some common bargaining norm (such as the 50-50 split), yet following such a norm will always be an available option for subjects. Given the documentation of strong norm driven behavior by subjects in bargaining environments, as discussed above, it is not obvious which effect will dominate.

Lastly, the stylized model is also related to a class of timing games: given incompatible demands by the bargaining parties, the second stage is a war of attrition game in which the payoffs to each party have been fixed by these demands. To the best of our knowledge, the war of attrition game has received very little attention in the experimental literature, and has not been implemented in manner in which it is here.[15] However, there is a formulation of wars of attrition that can be represented as an all pay auction (*Bulow and Klemperer* 1999), the latter being the subject of a number of experimental studies.[16] These studies generally find evidence for subjects overbidding, which would map roughly into the observation that subjects remain in the concession stage for too long. However, these results are difficult to translate more precisely to our environment, given the many differences in implementation.

[14]There is two-sided incomplete information in which agents could be either a "soft" type, which would correspond to a rational type, or a "hard" type, which would correspond to a behavioral type demanding strictly more than half the pie. This theoretical model is most closely related to the bargaining model of *Chatterjee and Samuelson* (1987).

[15]This is noted in *Brunnermeier and Morgan* (2004), who investigate a multilateral timing game with strategic incentives that are mix of those found in a pure war of attrition game and those found in a pure predation game.

[16]Readers interested in experiments of all pay auctions formulated as a war of attrition are referred to *Kirchkamp* (2006) and the references therein.

3 Summary of the Theory

3.1 Setting up the Model

We begin by providing an overview of the relevant theoretic results for a symmetric version of the stylized bargaining and reputation model of *Abreu and Gul* (2000).[17] Two agents bargain over a pie of size one in two stages. In the first stage (at time 0) each player simultaneously announces a "posture" α^i (i.e. the faction of the pie they would like). If the two suggestions are compatible (i.e. $\alpha^1 + \alpha^2 \leq 1$) then the game ends immediately.[18] If the two suggestions are incompatible the game proceeds to stage two, where a continuous time concession game with an infinite horizon starts. That is for each point in time, $t \in [0, \infty)$, both players choose to accept (i.e. concede) or hold out. If player i concedes, she receive $1 - \alpha^j$, while if j concedes, player i receives α^i. Preferences of agents are risk neutral, with a common discount factor r. Thus, if an agreement is reached at time t in which an agent receives a share x, then their payoff is $e^{-rt}x$.

In addition, with some probability a player may face a behavioral type who is obstinate in their demands. Define $C := \{\alpha_1, ..., \alpha_K\}$ as the set of behavioral types, with $\alpha_K \geq \frac{1}{2}$. An α_k-type always demands α_k and only accepts an offer that gives them at least α_k. The probability that a player is an α_k-type is z_k, for $k = 1, ..., K$. The probability that a player is rational is denoted by $z_0 = 1 - \sum_{k=1}^{K} z_k$. If a specific behavioral type is incompatible with all other behavioral types in C (including themselves), we also refer to it as being an aggressive behavioral type.

3.2 Equilibrium Behavior

A key equilibrium property in such reputation situations is that a rational player would choose a posture that mimics some behavioral type (i.e. $\alpha^i \in C$ for $i = 1, 2$). To do otherwise would instantly reveal the rationality of the actor and result in their opponent appropriating any gains from trade. Consequently players can be identified by the element of C that they announced in the first stage, $\alpha_k, \alpha_l \in C$. In a symmetric equilibrium, define μ_k to be the probability that a rational player announces posture α_k to mimic the behavior of α_k. Given this symmetric equilibrium, the probability

[17] What is contained here is implicit in *Abreu and Gul* (2000). Some results for equilibrium announcements have been taken from *Abreu and Sethi* (2003), where the authors use the symmetric version of the model.

[18] If the announcements sum to strictly less than one, a sharing rule is used for the remainder. Several sharing rules can be accommodated. In the experiments we divide the remainder equally.

that a player is irrational given an announcement α_k is given by

$$\overline{\pi}_k = \frac{z_k}{z_k + z_0 \mu_k} \tag{1}$$

For a general set C, in equilibrium rational players will employ a mixed strategy over announcing different types in stage one. However, if the set C contains a type, α, such that $\alpha \leq \frac{1}{2}$, there is a possibility that this type will not be replicated in the equilibrium mixed strategy. However, if a behavioral type is replicated, then all more aggressive types are also replicated. As such, the support of the equilibrium mixing strategy, μ, will be of the form $\{R, ..., K\}$, where $1 \leq R < K$. Ensuring that rational players are indifferent between announcing any α_k (for $k = R, ..., K$), along with the μ being a probability measure (and therefore summing to one), gives the $(K - R + 2)$ equations needed to solve for μ and the expected payoff for rational players..[19]

Suppose a rational player announced α_k and faces an opponent who has announced α_l, where $\alpha_k + \alpha_l > 1$ causing the players to move on to the concession stage.[20] The unique equilibrium play in the incomplete information war of attrition game is given by a mixed strategy over the time of concession. The α_k rational player concedes with constant hazard rate, λ_{kl}, given by[21]

$$\lambda_{kl} = \frac{r(1 - \alpha_k)}{\alpha_k + \alpha_l - 1} \tag{2}$$

over the interval $[0, T_0]$, where $T_0 = \min(T_{kl}, T_{lk})$ and $T_{kl} = \frac{-\ln(\overline{\pi}_k)}{\lambda_{kl}}$ and $T_{lk} = \frac{-\ln(\overline{\pi}_l)}{\lambda_{lk}}$. Thus, equilibrium is generally characterized by inefficient delays. This entails the rational α_k player mixing over the time of concession according to the distribution function $\frac{\hat{F}^{kl}}{1-\overline{\pi}_k}$, where

$$\hat{F}^{kl}(t) = \left\{ \begin{array}{c} 1 - c_{kl} e^{-\lambda^{kl} t}, \text{ for } t \in [0, T^0] \\ 1 - \overline{\pi}_k, \text{ for } t > T^0 \end{array} \right\} \tag{3}$$

and $c_{kl} = \overline{\pi}_k e^{\lambda^{kl} T^0}$ and $(1 - c_{kl})(1 - c_{lk}) = 0$.

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[19]This is a system of non-linear equations that will, except for trivial cases, only have a numerical solution. See section A.3 for more details of the numerical solution strategy for a general set of behavioral types.

[20]Note that the player who announced α_l could be either an α_l-type or a rational player who has mimicked the α_l-type.

[21]So long as it remains possible that their opponent is a rational-type, a rational player who announced α_k is indifferent between conceding and not conceding at a time t if $r(1 - \alpha_l) = [\alpha_k - (1 - \alpha_l)] \lambda_{lk}$, where λ_{lk} is the hazard rate for concession by the opponent unconditional on knowing whether the opponent is rational or not. Equation 2 ensures this indifference holds.

Note that the distribution function is expressed in terms of $\hat{F}^{kl}$ for notational convenience: a rational player who announced α_l, when their opponent announced α_k, faces a "mixed" strategy over the time of concession given by $\hat{F}^{kl}$ (i.e. unconditional on the α_k player being rational). The value of T_{kl} is a measure of the α_k rational player's "strategic" weakness when facing an α_l player: if $T_{kl} > T_{lk}$, then the α_k rational player will have to concede at time $t = 0$ with strictly positive probability (mass), given by $q_{kl} := (1 - c_{kl})$. Such concession is referred to as *initial* concession. Concession resulting from the continuous part of the distribution function is referred to as *interior* concession. Finally, revisiting the first stage, if a type is incompatible with all the other types, *including* itself, then it is always replicated in equilibrium and is never *conceded to initially* by another player. Such a type is referred to as *aggressive*.[22]

3.3 Key Equilibrium Predictions

Although the exact nature of equilibrium play by rational players and the consequent equilibrium outcomes are dependent in a non-linear manner on the set of behavioral types and the distribution of these types, there are a number of features of equilibrium behavior that hold irrespective of such parameters. With regard to announcements made in the first stage by rational players, the following can be said:

1. Rational players will only make announcements that mimic some behavioral type.

2. If the announcement of a behavioral type is mimicked in equilibrium, then the announcements of all more demanding behavioral types are also mimicked.

With regard to second stage behavior by rational players,

3. Given announcements α_k and α_l, where $\alpha_k + \alpha_l > 1$ and $\alpha_k \geq \alpha_l$, the upper bound on the the average delay, given that agreement is eventually reached, is $\frac{1}{\lambda_{kl}}$.[23]

[22] Formally, if $\alpha_k + \alpha_l > 1$, for $l = 1, .., k$, then $\mu_k > 0$ and $T_{kl} \geq T_{lk}$, for all $l = 1, .., K$. See *Abreu and Sethi* (2003).

[23] This is a consequence of the stochastic process, which governs the time until either player concedes (given at least one eventually does), being first order stochastically dominated by the process defined as conceding (over the interval $[0, \infty)$) with a constant hazard rate λ_{kl}. Consequently the first moment of the latter provides an upper bound on expected delay, given agreement is eventually reached (i.e. at least one of these players is rational).

4. If $\alpha_k = \alpha_l$ or if both α_k and α_l are aggressive there is no initial concession by either player in this subgame.

5. If $\alpha_k < \alpha_l$, then the rational player who initially announced α_k would not concede initially in this subgame. Whether a rational α_l-announcer would initially concede depends on the full solution of the first stage equilibrium mixing strategy, but if α_k is not aggressive this will generally be the case.[24] Furthermore, $\alpha_k \geq \alpha_l$ implies that $\lambda_{kl} \leq \lambda_{lk}$. Consequently, unconditional on knowing whether or not the players are rational, the more aggressive α_k-announcer concedes at a "slower rate" than the α_l- announcer.

4 Experiment 1

4.1 Experimental Design

In order to implement the stylized game in the lab, there are three features of the model that need to be induced. Since a primary aim of the experiment is to ascertain whether agents recognize the role of reputation and replicate the demands of the behavioral types and act accordingly we introduce "computer players". Programmed to follow a fixed $\alpha-$rule (and making this rule and the probability of being matched common knowledge by including this information explicitly in the instructions), the addition of computer players to the subject pool allows for some control over the set of behavioral types and the distribution over this set.[25] Second, risk neutral preferences are induced using the lottery method (see *Roth and Malouf* 1979). During the experiment subjects bargain for probability points as opposed to monetary amounts and a binary lottery is conducted at the end of the session where the probability of winning is given by the number of probability points won during the session as a fraction of the total possible number of points.[26] The third feature that needs to be induced is the infinite horizon and common discount rate, r. This is done by "shrinking the pie" continuously over time according to the rate r. This is the continuous time ver-

[24]See Appendix A for further details.

[25]An alternative would have been to use human subjects who have a different payoff structure, namely they receive α points if and only if they get α in the bargaining and 0 otherwise. We opted not to do this as it only reduces control over the environment since it is not clear what subjects would actually do. Furthermore, we would then have to worry about what others believe subjects with these payoffs would actually do.

[26]This method induces risk neutral preferences over probability points, regardless of the subject's attitudes towards risk in monetary payoffs.

sion of discretely discounting payoffs as typically seen in bargaining experiments with alternating offers.

The experiments were conducted at NYU using undergraduate students recruited through e-mails from all majors. Instructions were read to students aloud and they interacted solely through computer terminals.[27] Subjects were randomly matched in pairs, then simultaneously placed a demand (between 0 and 30). If the demands they made were compatible with the person they were matched with (that is, summed to 30 or less), then the round ended and each subject earned their demand plus half of any remainder. If the demands were incompatible, then that match moved on to a second stage. This stage proceeded in continuous time, with subjects having the option to choose to concede. If either they or the person they were matched with conceded then the round ended. The subject that conceded earned 30 minus the demand of the player they were matched with, multiplied by the discount factor for the amount of time taken to reach an agreement ($e^{-0.01t}$, where t is the time in seconds at which one of the two subjects conceded). The subject that was conceded to earned their demand multiplied by the discount factor. Throughout the second stage, subjects were shown a 2×2 matrix displaying the real time discounted payoffs to themselves and the person they were matched in both the case that they conceded at that moment or that they were conceded to.[28] During each session we randomly rematched subjects fifteen times thereby providing subjects an opportunity to gain experience with the game. Sessions lasted about one and a half hours.

To examine the question of whether subjects understand the role of reputation two treatments were initially conducted. The first treatment, a control treatment did not contain any computer players.[29] In the second treatment, referred to as the *20-Comp* treatment, two computer players, whose bargaining posture was 20, were included in each session. The probability that a student was matched with a computer is $\frac{2}{15}$. Table 1 provides a summary of the sessions that were conducted for the control and *20-Comp* treatments.

As indicated in Section 3, the exact predictions of the model are dependent on the set of behavioral types and their distribution. However, given the prior experimental evidence of norm driven behavior in bargaining environments, one must consider the possibility that not all subjects that enter the laboratory will correspond to a

[27]See appendix B for sample instructions.

[28]See appendix C for screen shots.

[29]Note that when there are no behavioral types in the model, there exists a continuum of equilibria. Consequently the outcome of this treatment must be interpreted in conjunction with later treatments, where there are equilibrium predictions irrespective of whether the computer players are the only behavioral types.

	Session			
Control	1	2	3	Overall
Number of Subjects	12	12	10	
Number of Computers	0	0	0	
Computer Types				
Number of Matches per Round	6	6	5	
Number of Rounds	15	15	15	
Av Points Payoff	216.0	214.6	198.2	210.2
20-Comp				
Number of Subjects	14	14	14	
Number of Computers	2	2	2	
Computer Types	20	20	20	
Number of Matches per Round	8	8	8	
Number of Rounds	15	15	15	
Av Points Payoff	189.6	204.8	174.5	189.6

Table 1: Session Characteristics by Treatment

rational-type player in the model. Consequently, the set of potential behavioral types (and their distribution) amongst the population of subjects that are brought into the laboratory must be considered, along with any induced types (using computer players). Overall the treatments were designed so that, for many assumptions over the set of these behavioral types, going from the *Control* to the *20-Comp* treatment would imply an increase in the number 20 demands. To see this, a number of simple cases are considered, followed by the most general case. As a starting point, the simplest comparative static assumes that all subjects do indeed correspond to a rational-type. In this case there is no longer a unique symmetric sequential equilibrium in the control treatment (since there is no longer any behavioral types). However, there is a precise prediction for the 20−comp treatment: only 20 announcements should be made in the first stage. While this scenario is silent on what would be expected in the control treatment, it would be observed in conjunction with *only* 20 announcements in the 20−comp treatment.

The analysis differs should there be behavioral types in the population of subjects. For example consider the case where, with some probability, a subject could be a 15−type (and that is the only behavioral type). In this case, 15 should be announced by all players (rational or behavioral) in the control treatment, whereas in the *20-Comp* treatment rational subjects should announce both 15 and 20. Consequently, in the second treatment 20 announcements should be observed when previously (in the control) they were not. This case is indicative of the comparative static for the more general scenario where 20 is *not* an element of the behavioral types in the population. If 20 is not part of that set, then 20 announcements should be observed in the 20−comp treatment where they previously were not in the control.

However, when the set of behavioral types contains any combination of aggressive and concessionary types (including a 20−type), it is no longer possible to know *ex ante* the direction of the comparative static predictions across treatments. Testing this in such a setting requires knowledge of both the set of behavioral types and the distribution of behavioral types in the population of subjects in the control treatment. While one cannot control for these elements in the control session, it is possible to estimate the distribution of behavioral types with data from the control sessions via maximum likelihood methods. Using these estimates one can predict the implied probability of demands of 20 in the *20-Comp* treatment and determine the direction of the comparative static prediction.

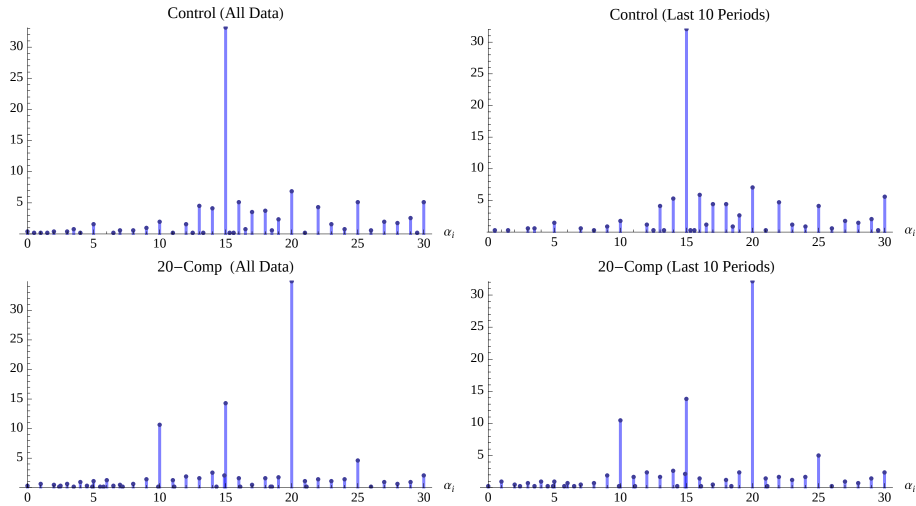

Figure 1: Subject Announcements in the First Stage (%)

4.2 Results

Figure 1 presents the first stage announcement data from the control sessions (top row) and the *20-comp* sessions (bottom row), excluding announcements by computers. The left panel displays data from the complete session. The right hand excludes data from the first five rounds, where subjects may have been unfamiliar with the game. A broad span of demands were made in the first stage, ranging from quite concessionary demands to those that are extremely aggressive. Moving from the control to the *20-comp* treatment noticeably impacts the frequency of demands for $10, 15$ and 20. In the control treatment, as one might expect, announcements of 15 dominate all others. In the *20-comp* treatment, 20 becomes the most popular announcement, along with significant numbers of 15 demands and also 10 demands. Table 2 reports the figures for these announcements in each treatment (the top panel using all the data; the bottom panel using the last 10 rounds), and includes a significance test of the treatment effect using the estimates from a regression model with clustered errors by subject. As the table illustrates, the changes in the proportion of announcements for $10, 15$ and 20 are statistically significant.

While a significant increase in the proportion of 20 announcements is observed, this is not necessarily consistent with the predictions of the model. As figure 1 demonstrates, many demands are observed in both the control and *20-Comp* treatments, including demands for strictly less than 15. Consequently the comparative static

			Announcement		
			10	15	20
All Data	Control	%	*2.0*	*33.1*	*6.9*
		(freq)	(10)	(169)	(35)
	20-comp	%	*10.6*	*14.3*	*34.9*
		(freq)	(67)	(90)	(220)
	Treatment $p-$value		0.00	0.01	0.00
Last 10 Rounds	Control	%	*2.1*	*32.1*	*7.0*
		(freq)	(8)	(120)	(26)
	20-comp	%	*10.6*	*13.4*	*32.9*
		(freq)	(49)	(62)	(152)
	Treatment $p-$value		0.00	0.02	0.00

Table 2: Summary of Key Announcements by Treatment

must be established empirically. The estimates of the mixing probability by rational-types in the control and the implied mixing probability in the *20-Comp* treatment are reported in table 3.[30] Due to the relatively high probability of being matched to a type that demands less than 15, the estimated equilibrium mixing strategy is to only mimic demands of 25 or higher. That is, 20 is not mimicked by rational players in the control even though there are 20−types. 20 is, however, predicted to be mimicked in the *20-Comp* treatment. Consequently, more announcements of 20 are predicted for this treatment (even excluding robot announcements). In other words, the comparative static prediction going from the Control to the *20-Comp* treatment is for an increase in the announcements of 20.

Turning attention to second stage play, the probability of conflict is 62% for the control treatment and 67% for the *20-Comp* treatment. Unfortunately, due to the large span of first stage announcements, few of the individual "subgames" (i.e. combination of first stage demands) contain many observations. Lack of observations, along with dependence on the unobserved distribution of behavioral types, makes testing the finer details of predicted second stage behavior infeasible. However, as discussed

[30]For further details on the estimation procedure see appendix A.

	Estimated from Control			Predicted for *20-Comp*		
Announcement	μ	95% C.I.		μ	95% C.I.	
Estimated Rational Demands in the Control						
24	0.03	(0.00	0.18)	0.03	(0.00	0.12)
25	0.30	(0.00	0.40)	0.14	(0.07	0.27)
26	0.05	(0.00	0.25)	0.02	(0.00	0.13)
27	0.22	(0.07	0.41)	0.06	(0.02	0.15)
28	0.13	(0.05	0.41)	0.03	(0.01	0.15)
29	0.15	(0.04	0.37)	0.04	(0.01	0.09)
29.5	0.11	(0.00	0.11)	0.03	(0.00	0.02)
Prediction for 20						
20	0.00	(0.00	0.00)	0.27	(0.14	0.42)

Table 3: Summary of Estimated Comparative Static

in section 3, there are restrictions on expected delay and probability of concession that abstract from the precise distribution of behavioral types. Tables 4 and 5 report summary information on observed delay and concession behavior by "subgame", restricting attention to combinations of announcements for which there are at least five observations.

Irrespective of the distribution of behavioral types, the expected delay following incompatible announcements, conditional on there eventually being agreement, should be strictly less than $\frac{1}{\lambda_{HL}}$ (α_H is larger than α_L). The results presented in table 4 show that, for the majority of the observed data, the average is more than double the corresponding upper bound. In fact, only the $15-25$ "subgame" has an average delay statistic that is significantly below the bound. This pattern is further illustrated by the reported upper bounds on z. The largest observed time to agreement in the second stage has implications for distribution of the two behavioral types involved in that "subgame".[31] As the last two columns of table 4 show, for all "subgames" the observed delays imply that the probability that there exists such a behavioral type is close to zero. In particular, the bound on the probability of being matched to a 20 type in the *20-Comp* treatment is less than the probability of being

[31] See Appendix A.5 for more details on these bounds.

matched to a computer player. This either indicates that the subjects are engaging in excessively costly delays or are not disagreeing enough with respect to the theoretical prediction.[32]

The model imposes a great deal of structure on concession behavior by both rational and behavioral subjects. The latter are exogenously assumed never to concede to an incompatible offer. The demands of equilibrium impose that rational subjects will either concede instantly, if the demand made by the other player is *not* mimicked by rational players in the first stage,[33] or employ a mixed strategy over time of concession. In the latter case, the mixed strategy, outside the possibility of initial concession, has the form of arriving with a constant hazard rate with the player making the *less* aggressive demand actually conceding with a *greater* hazard rate.[34] That is, in such cases, it is the player making the lower demand that is more likely to concede. Contrary to this, table 5 reveals that in the vast majority of "subgames", it is the player that made the larger demand that is more likely to concede outside of the first 2 seconds of the second stage.[35] There is an exception to this: the 20−comp treatment "subgames" involving 15 and 20 announcements appear to follow the predicted pattern. Furthermore, this is the only "subgame", with differing demands that proceed to a second stage, that has a significant number of observations.[36] Finally, overall there is little evidence of any initial concession by players making the higher demand.

4.3 Discussion

The results support the main qualitative prediction of the model, namely the introduction of the 20 computer results in a significant increase in these demands,

[32]A possible conjecture to explain this result is that the "shrinking pie" implementation of an infinite horizon adopted in the experimental design makes disagreement difficult. To test this, "adjusted" delays were also considered, where observations with time to agreement in excess of 1000 seconds are treated as disagreement points. The results from this exercise did not differ significantly from the unadjusted delay results and are thus not included.

[33]That is in equilibrium, with probability one the other player is irrational. Consequently there is no benefit to holding out for any length of time as the other player will never concede.

[34]These probabilities of conceding are unconditional on the player being rational or not.

[35]Dropping the first 2 seconds is an arbitrary cutoff meant to eliminate initial concession. Results are not sensitive to small changes in the specific cutoff.

[36]This pattern is only regarding "subgames" that go on to a second stage in which one of the announcements is strictly larger than the other. For "subgames" with the same demand that move to the second stage, neither player should concede initially and both players should concede at the same hazard rate.

Subgame		Obs		Delay	Upper bounds		
α_L	α_H	Freq	%	Av.	Av.	z_L	z_H
Control Treatment							
13	15	6	2.4	.	.	.	.
14	15	5	2.0	.	.	.	.
15	15	38	14.9	.	.	.	.
15	16	5	2.0	45.2	7.1	0.00	0.00
15	17	8	3.1	44.3	15.4	0.00	0.00
15	18	6	2.4	82.2	25.0	0.00	0.00
15	19	8	3.1	133.6	36.4	0.00	0.00
15	20	5	2.0	108.8	50.0	0.00	0.00
15	22	5	2.0	188.0	87.5	0.00	0.00
15	25	7	2.7	44.1 §	200.0	0.00	0.00
15	29	6	2.4	415.5	1400.0	0.00	0.00
15	30	7	2.7	52.4	.	.	.
20-Comp Treatment							
10	15	14	5.1	.	.	.	.
10	20	21	7.7	.	.	.	.
14	20	6	2.2	44.7	40.0	0.00	0.00
15	15	5	1.8	.	.	.	.
15	20	29	10.6	120.0	50.0	0.00	0.00
20	20	44	16.1	348.2	100.0	0.00	0.00
20	25	7	2.6	248.0	300.0	0.00	0.00
20	30	5	1.8	558.6	.	.	.

Table 4: Delay in seconds by Treatment

§ Indicates that the average delay is significantly less than the theoretical upper bound at the 10% (§), 5% (§§) or 1% (§§§) level (one-sided sign test).

Subgame		Obs		Prob. of *initial* concession ($t < 2$)		Prob. of *interior* concession ($t \geq 2$)		
α_L	α_H	Freq	%	α_L	α_H	α_L	α_H	
Control Treatment								
13	15	6	2.4	.	.	.	.	
14	15	5	2.0	.	.	.	.	
15	15	38	14.9	.	.	.	.	
15	16	5	2.0	0.00	0.00	0.40	0.60	
15	17	8	3.1	0.00	0.00	0.00	1.00	
15	18	6	2.4	0.00	0.00	0.17	0.83	
15	19	8	3.1	0.00	0.00	0.00	1.00	
15	20	5	2.0	0.00	0.00	0.40	0.60	
15	22	5	2.0	0.00	0.00	0.20	0.80	
15	25	7	2.7	0.00	0.14	0.14	0.71	
15	29	6	2.4	0.00	0.00	0.50	0.50	
15	30	7	2.7	0.00	0.00	0.00	1.00	
20-Comp Treatment								
10	15	14	5.1	.	.	.	.	
10	20	21	7.7	.	.	.	.	
14	20	6	2.2	0.00	0.00	0.50	0.50	
15	15	5	1.8	.	.	.	.	
15	20	29	10.6	0.00	0.03	0.76	0.21	***
20	20	44	16.1	0.00	.	1.00	.	
20	25	7	2.6	0.00	0.00	0.00	1.00	
20	30	5	1.8	0.00	0.00	0.00	1.00	

Table 5: Probability of Concession by Treatment

§ For all subgames in both treatments, the probability of initial concession by the higher announcer is *not* significantly higher than by the lower announcer at the 10% (§), 5% (§§) or 1% (§§§) level (one-sided sign test).
* Probability of interior concession by the lower announcer is significantly higher than by the higher announcer at the 10% (*), 5% (**) or 1% (***) level (one-sided sign test).

providing evidence of subjects replicating behavioral types. However, quantitatively there are some respects in which the model does not perform well. In particular the large increase in 20 announcements is at odds with the small change predicted by the structural model. At the very least this suggests that, if subjects are recognizing the role of reputation, they are inclined to go after the aggressive 20 announcement more than they should.

Furthermore, there are a number of disparities between the observed concession behavior and that predicted by the model. Unfortunately, the wide variety in first stage announcements results in less data for any particular subgame of the second stage. While this makes it difficult to analyze second stage behavior with this data set, the limited evidence available suggest that subjects are not conceding in the second stage in the manner that the model predicts. Notably, subjects announcing more aggressive demands are a) not conceding initially, and b) then conceding too often (during the *interior* of the second stage). Finally, subjects appear to take a much longer time to reach agreement or do not disagree enough.

While there is evidence of a disparity between observed concession behavior and the implication of equilibrium behavior, there is a notable exception: the subgame following announcements of 15 and 20 in the *20-comp* treatment. An assumption of the model is that the set of behavioral types is common knowledge. While, *ex-ante*, it is not unreasonable to expect some behavioral types in the population, it seems implausible that all of the wide variety of announcements observed in both the control and $20-comp$ treatments could have been known to subjects. Between 15 being the fair $50-50$ offer (as well as the Nash bargaining solution) and 20 being the demand of the computer players, it could be argued that this is the only subgame in which there is some certainty that the two announcements correspond to genuine behavioral types.[37] This observation leads to the conjecture that these failures of the model are a consequence of lack of common knowledge of the set of behavioral type. The subsequent section introduces a change to the experimental design aimed at testing this conjecture.

[37] The same could be argued for the subgames $15-15$ (in both the control and *20-comp* treatments) and $20-20$ (in only the *20-comp* treatment). However, neither subgame is relevant for the testable prediction on second stage concession behavior: the first does not even reach a second stage, while the second predicts rational players should follow the same concession rule since they made the same first stage demand.

5 Experiment 2

5.1 Experimental Design

We modified the design for the second set of experiments in an effort to see if play by subjects would converge closer to the equilibrium predictions if the set C was clearly made common knowledge. These experiments are identical to those described in section 4.1, with two exceptions:

- Subjects are only permitted to announce a demand from a restricted set of possible announcements. The finite set from which announcements can be made is displayed in the subject instructions and announced during their reading to ensure this set is common knowledge amongst all participants.[38]

- For each announcement included in the restricted treatment there will be a single computer player included in the experiment for whom this demand is their strategic posture. Thus for each demand we induce a strictly positive probability of being matched with a behavioral player of this type. From an experimental design perspective, this has the advantage of not creating any asymmetry between the behavioral types, as would be the case if computers player only played a strict subset of the announcements in the restricted set.

We consider two treatments using this modified design. In the first, referred to as *restricted A*, only announcements from the set $\{8, 15, 18, 20\}$ are permitted. The second, *restricted B*, only permits announcements $\{15, 18, 20\}$. The characteristics of each treatment are summarized in table 6.

Demands of 15 and 20 are included in both sets to capture key aspects of the control and the $20-$comp treatment. These demands were respectively the most common choice in each treatment. Furthermore, the demand of 15, being the equal split, is *ex-ante* the most natural candidate for a potential behavioral type in the underlying subject population. The 20 demand replicates induced behavioral type from the $20-$comp treatment.

18 is included to gain some insight regarding the conjecture that subjects will mimic 20 too often. This is particularly the case in the *restricted B* treatment, where all demands are aggressive (if only weakly so for the case of 15). In this treatment, an

[38] Restricting the choice of first stage announcements that subjects can make, gives the experimenter greater control over the set of behavioral types. By increasing our control of behavioral types, there will be far fewer combinations of second stage subgames for a similar number of observations permitting a more detailed analysis.

	Session			
Restricted A	1	2	3	Overall
Number of Subjects	12	12	12	
Number of Computers	4	4	4	
Computer Types	8,15,18,20	8,15,18,20	8,15,18,20	
Number of Matches per Round	8	8	8	
Number of Rounds	15	15	15	
Av Points Payoff	210.9	209.7	210.7	210.4
Restricted B				
Number of Subjects	13	13	13	
Number of Computers	3	3	3	
Computer Types	15, 18, 20	15, 18, 20	15, 18, 20	
Number of Matches per Round	8	8	8	
Number of Rounds	15	15	15	
Av Points Payoff	198.1	198.1	209.5	201.9

Table 6: Session Characteristics by Treatment

observation of significantly more 20 announcements than 18 announcements can only be rationalized by the model if subjects are significantly more likely to be a 20−type than an 18−type.[39] In this sense, this treatment will provide for a finer test of whether subjects fully understand the role of reputation and how to act accordingly.

By additionally allowing demands of 8 in the *restricted A* treatment we introduce a demand that is compatible with all types (including the most aggressive type 20). In both the control and 20−comp treatments we observed subjects making concessionary offers. However, in equilibrium the model predict that demands of 8 should *not* be mimicked by rational types.[40] Including a concessionary demand allows us to gain a handle on the magnitudes of any potential demand induced effect resulting from including a particular computer type. Furthermore, the presence of a demand for strictly less than half the pie has implications for second stage concession behavior. In particular, rational players making aggressive demands should concede initially with strictly positive probability to any announcement that is strictly less then their demand. This differs from the prediction in the *restricted B* treatment, where there should be *no* initial concession in equilibrium.

5.2 Results

Figure 2 and table 7 display the results for first stage announcements in both treatments (using data from all the periods and the last 10 periods). In the restricted A treatment, 20 is the most popular announcement, followed by 15. Demands of 18 are only made about 12% of the time, significantly less then either 20 or 15. Demands of 8 by subjects are observed, but only about 5% of the time. In the restricted B treatment, demands of 15 and 20 are equally popular ($45 - 46\%$), while again demands of 18 are significantly less popular (less than 10%). Moving from the restricted A to the restricted B treatment, the frequency of 15 demands increases to be at same level as the 20 demands, which remains at the $45 - 50\%$ level. Since demands of 18 remain unpopular, at under 10%, at the treatment level it appears that 8 demands are moving to 15 demands in the restricted B treatment.[41] There does not appear

[39] This is a consequence of there being no initial concession by rational subjects when all behavioral types are aggressive. See A.6 for further details.

[40] This strategy is strictly dominated by making the most aggressive announcement and, therefore, cannot be a member of the support of the equilibrium mixing strategy.

[41] When restricting attention to the last 10 rounds, the increase in frequency of 15 announcements in the restricted B treatment compared to the restricted A treatment is also resulting from a reduction in the frequency of announcing 20. This is a reduction of a similar magnitude as the frequency of 8 demands in the restricted A treatment.

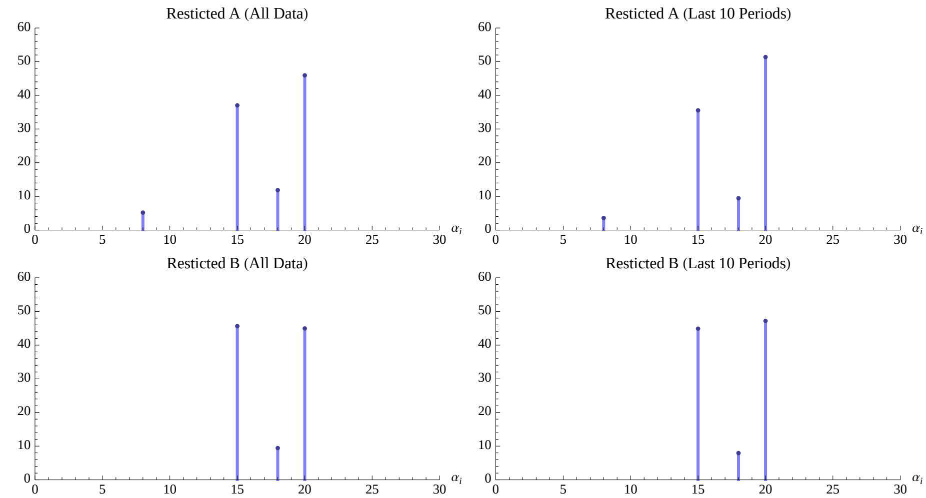

Figure 2: Subject Announcements in the First Stage (%)

			Announcement			
			8	15	18	20
All Data	*Restricted A*	%	*5.2*	*37.0*	*11.9*	*45.9*
		(freq)	(28)	(200)	(64)	(248)
	Restricted B	%	.	*45.6*	*9.4*	*45.0*
		(freq)		(267)	(55)	(263)
Last 10 Rounds	*Restricted A*	%	*4.3*	*34.8*	*9.6*	*51.3*
		(freq)	(17)	(138)	(38)	(203)
	Restricted B	%	.	*45.6*	*9.4*	*45.0*
		(freq)		(267)	(55)	(263)

Table 7: Summary of Announcements by Treatment

to be any systematic time varying patterns in these demands even when focusing on only the last 5 periods.

The observed announcement behavior in the restricted A treatment is reminiscent of that in the unconstrained 20−comp treatment in that 20 and 15 are by far the most frequent announcements, while there is a small but significant percentage of concessionary demands made.[42] As the restricted designs enforce a smaller type of demands, a more parsimonious specification can be used to estimate the unknown structural parameters including the probability distribution over the set of behavioral types, z. These estimates of z are used to gauge the extent to which subject behavior is consistent with quantitative predictions of the model.

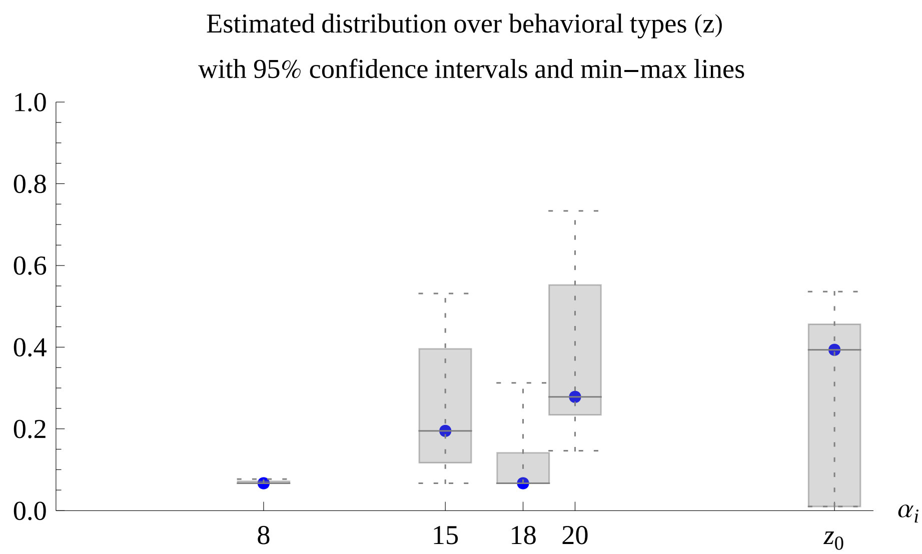

Figure 3: Summary of Estimates for Restricted A

Figures 3 and 4 graph the estimates of z for the restricted A and restricted B treatments respectively. In the restricted A treatment the point estimate for z_0 is 0.39, suggesting that the model is able to explain a significant part of the observed announcement behavior without relying mostly on behavioral types. However, the lower bound of the 95% bootstrap confidence interval is very small (just above 0.01). With regard to the restricted B treatment, the point estimate suggests that the model

[42]Although the exact frequencies of these specific demands differ, it is apparent that restricting the set of demands has not made the announcement behavior unrecognizable from the first set of experiments.

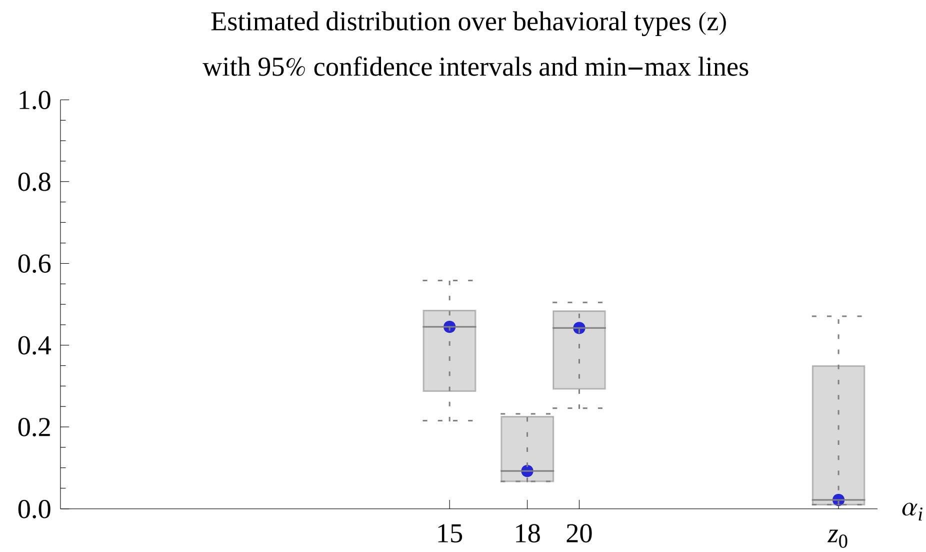

Figure 4: Summary of Estimates for Restricted B

struggles to explain the observed announcement behavior. The point estimate for z_0 is just above 0.02, with the 95% bootstrap confidence interval ranging from just above 0.01 to 0.35.[43]

A striking feature of the announcement behavior is that few demands of 18 are made in both treatments. Consequently the estimated probability of being a behavioral 20−type is estimated to be significantly higher than being a behavioral 18−type. This effect is illustrated most clearly in the restricted B treatment. Being an only aggressive types treatment, the equilibrium prediction is that the ratio of rational players announcing 18 to those announcing 20 should be strictly smaller than the ratio of behavioral types announcing 18 to those announcing 20. Thus, irrespective of the true probabilities of being each behavioral type, observing significantly more 20 announcements than 18 announcements is only consistent with the probability of being a behavioral 20−type being strictly larger than a behavioral 18−type.

Finally, with respect to announcement behavior, the estimated probability of being a behavioral 8−type in the restricted A treatment is very low. It is essentially the probability of being matched with the one computer player of this type added to the subject pool. This result is of interest with regard to gauging the extent of any "demand induced" effects resulting from the addition of computer players. This low

[43]As computer players are included, the estimate of z_0 cannot be larger than 0.8.

Subgame		Obs		Delay		Upper bounds		
α_L	α_H	Freq	%	Av.		Av.	z_L	z_H
Restricted A Treatment								
8	15	8	.	.		.	.	.
8	18	2	1.0	.		.	.	.
8	20	11	5.7	.		.	.	.
15	15	28	14.5	.		.	.	.
15	18	15	7.8	19.6	§§	25.0	0.00	0.00
15	20	63	32.6	23.1	§§§	50.0	0.00	0.00
18	18	5	2.6	48.0		50.0	0.00	.
18	20	18	9.3	77.2	§§	80.0	0.00	0.00
20	20	43	22.3	102.7		100.0	0.00	.
Restricted B Treatment								
15	15	49	21.0	.		.	.	.
15	18	15	6.4	55.1		25.0	0.00	0.00
15	20	104	44.6	60.1	§§§	50.0	0.00	0.00
18	18	2	0.9	23.1		50.0	0.01	.
18	20	20	8.6	133.4		80.0	0.00	0.00
20	20	43	18.5	106.6		100.0	0.00	.

Table 8: Delay in Seconds by Treatment

§ Indicates that the average delay is significantly less than the theoretical upper bound at the 10% (§), 5% (§§) or 1% (§§§) level (one-sided sign test).

estimate and the observation that the 8 announcement is made very infrequently (about 5% of the time) suggest any such effects to be of second order.[44]

Tables 8 and 9 repeat the analysis on observed second stage behavior of section 4.2 for the *Restricted A* and *Restricted B* treatments. With regard to average delay, moving to the restricted design has resulted in average delay statistics that are much closer to the upper bound dictated by the model. Furthermore, the $15-20$ "subgame", in both treatments, and the $15-18$ and $18-20$ "subgames", in the *Restricted A* treatment, are significantly less than the bound. However, the last two columns of table 8 show that the observed supports over concession times continue to imply that almost all subjects should be rational. Given that in the restricted design there is a computer player added for each permitted announcement, these bounds should be no less than the probability of being matched with a computer. Overall, the observation that subjects remain in the second stage for too long or do not disagree enough carries over to the restricted design.

While the results for concession behavior remain mixed, the move to a restricted design has also resulted in behavior that is closer to the predictions of the model. In the case of *initial* concessions in the $15-20$ "subgame" (which accounts for the majority of the relevant observations), there is significantly more concessions by the more demanding announcer in the *Restricted A* treatment and no significant difference between the two in the *Restricted B* treatment. This is as is predicted in the model. Furthermore, the *interior* concessions in the *Restricted B* treatment is significantly higher by the less demanding announcer, again in accordance with the model. However, this is the only occurrence across both treatments of the pattern of *interior* concession matching the predicted direction.

5.3 Discussion

The restricted design was introduced to give greater control over the set of behavioral types and ensure common knowledge of this set. This provided the opportunity to test in more detail subject announcement behavior. The inclusion of a concessionary demand (8) in the *Restricted A* treatment, which is not predicted to be replicated by rational types, provides a marker for the size of any potential demand induced effects (of the order of 5%). Given that rates of announcing demands larger than 15 are larger than this marker, both treatments provide evidence of subjects mimicking behavioral types. However, there is strong support for the conjecture that subjects mimic the

[44] We also conducted two sessions of unrestricted design where subjects could be matched with computers having demands of 20 and 12 (data available upon request). Here again, we found the rate at which subjects mimiced the conciliatory computer 12 was less than 5%.

Subgame		Obs		Prob. of *initial* concession ($t < 2$)			Prob. of *interior* concession ($t \geq 2$)		
α_L	α_H	Freq	%	α_L	α_H		α_L	α_H	
Restricted A Treatment									
8	15	8	4.1	.	.		.	.	
8	18	2	1.0	.	.		.	.	
8	20	11	5.7	.	.		.	.	
15	15	28	14.5	.	.		.	.	
15	18	15	7.8	0.07	0.00		0.47	0.47	
15	20	63	32.6	0.02	0.22	§§§	0.32	0.44	
18	18	5	2.6	0.00	.		1.00	.	
18	20	18	9.3	0.00	0.06		0.67	0.28	*
20	20	43	22.3	0.05	.		0.95	.	
Restricted B Treatment									
15	15	49	21.	.	.		.	.	
15	18	15	6.4	0.07	0.00		0.47	0.47	
15	20	104	44.6	0.11	0.03		0.53	0.34	**
18	18	2	0.9	0.00	.		1.00	.	
18	20	20	8.6	0.00	0.00		0.55	0.45	
20	20	43	18.5	0.00	.		1.00	.	

Table 9: Probability of Concession by Treatment

§ Probability of initial concession by the higher announcer is significantly higher than by the lower announcer at the 10% (§), 5% (§§) or 1% (§§§) level (one-sided sign test).
* Probability of interior concession by the lower announcer is significantly higher than by the higher announcer at the 10% (*), 5% (**) or 1% (***) level (one-sided sign test).

most aggressive demand too much. This feature of subject behavior is highlighted in the *Restricted B* treatment. Since this is an aggressive types only treatment, observing more 20 announcements than 18 announcements is only consistent with there being more 20−types in the population than 18−types. While *ex-ante* one might have expected more 15−types in the population than either 18− or 20−types (since it is both the "fair" outcome as well as the Nash bargaining solution), there does not appear to be any reason to expect more 20−types than 18−types.

Restricting first stage announcements also provided better data to investigate second stage concession behavior. With more control over the set of behavioral types, the observed pattern of concessions comes closer to that predicted by the model. This is particularly the case for the pattern of *initial* concessions. For *interior* concessions, most of the observed data in the *Restricted B* treatment has the less demanding player conceding more. However, in the *Restricted A* treatment this is no longer the case. Furthermore, although average delay statistics are closer to their predicted upper bound, the observation that subjects concede too slowly or do not disagree enough persists, albeit to a lesser extent than was the case in the first set of experiments.

6 Conclusions

In implementing the stylized model of *Abreu and Gul* (2000), the experiments presented in this paper investigate behavior in a setting that underlies a general class of bargaining environments. In particular, the behavior predicted by this model should persist as one abstracts from the details of the bargaining protocol. One of the main features of this prediction is mimicking the demands of obstinate players: to do otherwise would reveal rationality and lead to a weak bargaining position. The first set of experiments provide clear evidence of subjects recognizing this and mimicking the induced obstinate type.

This observation is reminiscent of results from earlier unstructured bargaining experiments. In experiments with bargaining over lottery points, *Roth et al.* (1981) found that, when one player has a lower prize in the final lottery than the other (and this is common knowledge to both parties), subjects would tend to negotiate over an equal expected value allocation or an equal lottery points allocation. The former allocation requires giving more lottery points to the disadvantaged player to equate expected payoffs, while the latter implies a higher expected value for the advantaged player. Furthermore, the player with the higher lottery payoff was more likely to suggest the equal lottery points allocation, thus using an available notion of fairness in a strategic manner. This result is also in line with a number of experiments that test the role of intentions in other regarding preferences. In particular studies that investigate the extent to which subjects will behave in a more self-interested manner when they are given a means by which to hide their intentions (for example *Dana et al.* (2006) and *Dana et al.* (2007) with dictator games and *Tadelis* (2008) with trust games). Finally, a contrast can be drawn to the observations of *Grosskopf and Sarin* (2007) in their study of one-sided reputation. In their generalization of the trust game, their results suggest that the theoretical predictions of reputation effects are more likely to be borne out when such effects are aligned with the prevalent other regarding preferences of the environment. Namely, when the reputation effect requires an honest action (good reputation) rather than a dishonest one (bad reputation). In our experiments, we observe subjects building reputation as a type demanding strictly more than the 50-50 split (the prevalent norm), despite the 50-50 split always being an available alternative to subjects.

A further result coming out of the unrestricted design is the emergence of a type that demands 10 following the introduction of a 20−type. While the model used in this paper does not predict an increase in such a type, the coexistence of complementary pairs, such as 10 and 20, is an outcome of the evolutionary stability analysis of *Abreu and Sethi* (2003). Consequently the data supports the prediction that, when agents find themselves in a settled bargaining environment, some will acquiesce to credibly obstinate demands, rather than go through the negotiation process to reach an agreement.

While the qualitative predictions of the model are borne out in the results, some of the finer details of the sequential equilibrium predictions are not: most notably the inclination of subjects to make more demanding announcements too often, and to remain in the concession stage for too long. However, it is worth stressing that the quantitative details of the sequential equilibrium predictions are quite complicated. Subjects are required to employ not only a mixed strategy over first stage announcement, but also a mixed a strategy over concession time, all calibrated to ensure their (rational-type) opponent is indifferent over their respective choices. A number of experimental studies have noted that subjects find mixed strategies difficult to implement (for example *Walker and Wooders* 2001, *Shachat* 2002). Furthermore, with regard to the second stage, delaying concession for too long has been observed in all pay auctions, a setting with arguably a simpler strategy for subjects to implement (rather than mixing over concession times, they play a pure strategy following the random draw of their cost function).

Finally, the improved performance of the model under the restricted design points to the importance of having an explicit set of behavioral types (for observed behavior, as well as theoretically). To the extent that the results from the restricted design are aligned to the predicted behavior, the model is a good predictor of behavior in situations where the causes and possibilities for obstinate play are well understood by the bargaining parties. Should this not be the case, the results from second stage play in the unrestricted design (along with the wide variety of first stage announcements observed) suggest that the process by which such behavioral play becomes credible needs to be modeled more directly. Hence, in environments where the bargaining parties are experienced, and thus more likely to share a common understanding of the posturing possibilities, it provides a useful model of bargaining behavior.

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A Further Details of the Theory

A.1 Setting up the System of Equations

Consider a general set of behavioral types $C = \{\alpha_1, ..., \alpha_K\}$. Denote by the index p the smallest aggressive demand. [45] As discussed in section 3, for such a general set C the equilibrium first stage announcement strategy by rational players will be to employ a mixed strategy over a set $\{\alpha_R, ..., \alpha_p, ..., \alpha_K\}$, where $1 \leq R \leq p \leq K$. For $(\mu_R, ..., \mu_K)$ to be an equilibrium, rational players need to be indifferent between announcing demands $\alpha_R, ..., \alpha_K$ and have no incentive to announce a demand $\alpha_1, ..., \alpha_{R-1}$, given their opponent employs the mixed strategy $(\mu_R, ..., \mu_K)$.

The expected payoff to a rational player for making an announcement α_i when their opponent announces α_j is as follows:

$$EP[\alpha_i|\alpha_j] = \begin{cases} \frac{1}{2} + \frac{\alpha_i - \alpha_j}{2} & \text{, if } \alpha_i + \alpha_k \leq 1 \\ (1 - \alpha_j) & \text{, if } \alpha_i + \alpha_k > 1, T_{ij} \geq T_{ji} \\ (1 - \alpha_j) + (1 - c_{ji})(\alpha_i + \alpha_j - 1) & \text{, if } \alpha_i + \alpha_k > 1, T_{ij} < T_{ji} \end{cases}$$

The above can be used to calculate the expected payoff of announcing a demand α_i in stage 1, and to build a system of equations that need to be satisfied in order for the mixed strategy $(\mu_R, ..., \mu_K)$ to form an equilibrium, in which the ex-ante expected value to a rational player is v:[46]

$$\begin{bmatrix} EP[\alpha_R] - v \\ \vdots \\ EP[\alpha_K] - v \\ \left(\sum_{i=R}^{K} \mu_i\right) - 1 \end{bmatrix} = \begin{bmatrix} \sum_{j=1}^{K} \left(z_j + z_0\mu_j\right) EP[\alpha_R|\alpha_j] - v \\ \vdots \\ \sum_{j=1}^{K} \left(z_j + z_0\mu_j\right) EP[\alpha_K|\alpha_j] - v \\ \left(\sum_{i=R}^{K} \mu_i\right) - 1 \end{bmatrix} = \begin{bmatrix} 0 \\ \vdots \\ 0 \\ 0 \end{bmatrix}$$

When there are more than two aggressive types, i.e. $p < K$, the size of the system of equations can be reduced. This can be done by taking advantage of the fact that an aggressive type is never conceded to initially by another behavioral type (and being aggressive means that all other types are incompatible and consequently result in a second stage). If there are at least two such types, enforcing that neither type is ever conceded to initially guarantees that a rational player is indifferent between choosing

[45] If $\alpha_1 + \alpha_K < 1$, that is there are no aggressive types in the set C, set $p = K$.

[46] Note that μ_i and μ_j enter c_{ji} in a non-linear fashion. Further note that there are $K - R + 2$ equations, including the condition that the probabilities sum to one, and $K - R + 2$ unknowns, including the unknown value v.

either demand in stage 1; the expected payoff in any subgame following announcing either demand is always $1-\alpha_j$, where α_j is the announcement made by the other player. Let α_p and α_k, with $k>p$, be two aggressive types. In any subgame in which an α_p- announcer and an α_k-announcer meet, the equilibrium mixing strategy over behavioral types must be such that μ_p and μ_k imply $T_{pk}=T_{kp}$:

$$
\begin{aligned}
-\frac{\ln \overline{\pi}_p}{\lambda_{pk}} &= -\frac{\ln \overline{\pi}_k}{\lambda_{kp}} \\
&\Longrightarrow \\
\overline{\pi}_k &= \overline{\pi}_p^{\frac{1-\alpha_k}{1-\alpha_p}} \\
&\Longrightarrow \\
\mu_k &= \left(\frac{z_k}{z_0}\right)\left[\left(\frac{z_p+z_0\mu_p}{z_p}\right)^{\frac{1-\alpha_k}{1-\alpha_p}}-1\right]
\end{aligned}
$$

That is, we have $\mu_k = g\left(\mu_p, z_p, z_k, z_0\right)$, for $k=p+1,...,K$, which guarantees the expected payoff to announcing α_k equals that to announcing α_p. Using this, the system of equations can be simplified to a system of $p-R+2$ equations in $p-R+2$ unknowns (these are $\mu_R,...,\mu_p$ and v):

$$
\begin{bmatrix}
\sum_{j=1}^{K}\left(z_j+z_0\mu_j\right)EP\left[\alpha_R|\alpha_j\right]-v \\
\vdots \\
\sum_{j=1}^{K}\left(z_j+z_0\mu_j\right)EP\left[\alpha_p|\alpha_j\right]-v \\
\left(\sum_{i=R}^{p}\mu_i\right)+\left(\sum_{p+1}^{K} g\left(\mu_p, z_p, z_k, z_0\right)\right)-1
\end{bmatrix}
=
\begin{bmatrix}
0 \\ \vdots \\ 0 \\ 0
\end{bmatrix}
$$

replacing μ_k with $g\left(\mu_p, z_p, z_k, z_0\right)$, for $k=p+1,...,K$, where ever it appears in the expressions $\{EP[\alpha_i|\alpha_k]\}_{i=R,..,p}$.

A.2 Initial Concession

The first point to note is that, considering only the implications of second stage equilibrium play, initial concession in the second stage between a player that announced α_i and a player that announced α_j is governed by which is the smaller of $\overline{\pi}_i^{\frac{1}{1-\alpha_i}}$ and $\overline{\pi}_j^{\frac{1}{1-\alpha_j}}$. This follows from the expression for T_0, the time by which rational players who announced either α_i or α_j must have conceded by: Suppose $T_{j,i}<T_{i,j}$, i.e. the α_i announcer must initially concede to the α_j announcer with strictly positive probability.

Then,

$$
\begin{aligned}
T_0 &= -\frac{\ln\left(\overline{\pi}_j\right)}{\lambda_{j,i}} \\
&= -\frac{\ln\left(\frac{\overline{\pi}_i}{c_{i,j}}\right)}{\lambda_{i,j}} \\
&\Longleftrightarrow \\
c_{i,j} &= \frac{\overline{\pi}_i}{\overline{\pi}_j^{\left(\frac{1-\alpha_i}{1-\alpha_j}\right)}}
\end{aligned}
$$

Since in this case we have $c_{i,j} < 1$, the above implies that

$$
\overline{\pi}_i^{\frac{1}{1-\alpha_i}} < \overline{\pi}_j^{\frac{1}{1-\alpha_j}}
$$

Note that the above inequality only considers the restrictions imposed by second stage equilibrium play. Adding the restriction that the symmetric equilibrium is in mixed strategies, and therefore all choices in the mixed strategy must give the same expected payoff, gives a stronger result. Namely,

Claim 1 *Suppose $\alpha_i + \alpha_j > 1$. If $\alpha_i < \alpha_j$, then $\overline{\pi}_i^{\frac{1}{1-\alpha_i}} \geq \overline{\pi}_j^{\frac{1}{1-\alpha_j}}$.*

Proof. Suppose the contrary. That is there exits $\alpha_i, \alpha_j \in C$ such that $\alpha_i + \alpha_j > 1$, $\alpha_i < \alpha_j$ and $\overline{\pi}_i^{\frac{1}{1-\alpha_i}} < \overline{\pi}_j^{\frac{1}{1-\alpha_j}}$. The proof contains two steps. The first is to show that for any announcement, α_k-announcement that concedes initially to an α_i-announcement with strictly positive probability, this α_k- announcer will concede initially to an α_j-announcer with even greater probability. The second step is to step through all possible subgames an α_i-announcer could face and show that the expected payoff is strictly less than that which could be obtained by announcing α_j. This provides a contradiction to both α_i and α_j being part of the same mixed equilibrium strategy.

Step 1: The aim is to show that for any $\alpha_k \in \{\alpha \in C | \alpha + \alpha_i > 1\}$ such that $\overline{\pi}_k^{\frac{1}{1-\alpha_k}} < \overline{\pi}_i^{\frac{1}{1-\alpha_i}}$, it is the case that $c_{k,j} < c_{k,i}$. Since, $\overline{\pi}_k^{\frac{1}{1-\alpha_k}} < \overline{\pi}_i^{\frac{1}{1-\alpha_i}} < \overline{\pi}_j^{\frac{1}{1-\alpha_j}}$, both

$c_{k,j} < 1$ and $c_{k,i} < 1$. Using the expression for c derived above gives

$$c_{k,i} = \frac{\overline{\pi}_k}{\overline{\pi}_i^{\left(\frac{1-\alpha_k}{1-\alpha_i}\right)}} = \left(\frac{\overline{\pi}_k^{\left(\frac{1}{1-\alpha_k}\right)}}{\overline{\pi}_i^{\left(\frac{1}{1-\alpha_i}\right)}}\right)^{1-\alpha_k}$$

$$c_{k,j} = \frac{\overline{\pi}_k}{\overline{\pi}_j^{\left(\frac{1-\alpha_k}{1-\alpha_j}\right)}} = \left(\frac{\overline{\pi}_k^{\left(\frac{1}{1-\alpha_k}\right)}}{\overline{\pi}_j^{\left(\frac{1}{1-\alpha_j}\right)}}\right)^{1-\alpha_k}$$

By assumption $\overline{\pi}_i^{\frac{1}{1-\alpha_i}} < \overline{\pi}_j^{\frac{1}{1-\alpha_j}}$, thus $c_{k,j} < c_{k,i}$ and $(1 - c_{k,j}) > (1 - c_{k,i})$; the latter inequality being the probability of α_k-announcer initially conceding to an α_j- announcer is strictly larger than the probability of an α_k- announcer initially conceding to an α_i-announcer.

Step 2: For each of the following cases, the expected payoff of announcing α_i when facing an α_k-announcer, denoted by $EP\left[\alpha_i|\alpha_k\right]$, is compared to the expected payoff to announcing α_j, $EP\left[\alpha_i|\alpha_k\right]$:

- for $\alpha_k \in C$ such that $\alpha_k + \alpha_j \leq 1$:

$$\begin{aligned} EP\left[\alpha_i|\alpha_k\right] &= \frac{1}{2} + \frac{\alpha_i - \alpha_k}{2} \\ EP\left[\alpha_j|\alpha_k\right] &= \frac{1}{2} + \frac{\alpha_j - \alpha_k}{2} \end{aligned}$$

  Since, $\alpha_i < \alpha_j$, this implies $EP\left[\alpha_i|\alpha_k\right] \leq EP\left[\alpha_j|\alpha_k\right]$.

- for $\alpha_k \in C$ such that $\alpha_k + \alpha_j > 1$ and $\alpha_k + \alpha_i \leq 1$:

$$\begin{aligned} EP\left[\alpha_i|\alpha_k\right] &= \frac{1}{2} + \frac{\alpha_i - \alpha_k}{2} \\ EP\left[\alpha_j|\alpha_k\right] &= 1 - \alpha_k \end{aligned}$$

  Since $\alpha_k + \alpha_i \leq 1$ implies $\alpha_i \leq 1 - \alpha_k$, it is the case that $EP\left[\alpha_i|\alpha_k\right] \leq 1 - \alpha_k = EP\left[\alpha_j|\alpha_k\right]$.

- for $\alpha_k \in C$ such that $\alpha_k + \alpha_i > 1$ and $\overline{\pi}_k^{\frac{1}{1-\alpha_k}} \geq \overline{\pi}_i^{\frac{1}{1-\alpha_i}}$: In this case, the α_k-announcer will *not* concede initially to the α_i-announcer (this could or could not be the case for the α_j-announcer). Consequently,

$$\begin{aligned} EP\left[\alpha_i|\alpha_k\right] &= 1-\alpha_k \\ EP\left[\alpha_j|\alpha_k\right] &\geq 1-\alpha_k \end{aligned}$$

which again implies that $EP\left[\alpha_i|\alpha_k\right] \leq EP\left[\alpha_j|\alpha_k\right]$.

- for $\alpha_k \in C$ such that $\alpha_k + \alpha_i > 1$ and $\overline{\pi}_k^{\frac{1}{1-\alpha_k}} < \overline{\pi}_i^{\frac{1}{1-\alpha_i}}$: In this case, the α_k-announcer will concede initially to both the α_i- and the α_j-announcers with strictly positive probability. Consequently the payoffs are

$$\begin{aligned} EP\left[\alpha_i|\alpha_k\right] &= (1-\alpha_k) + (1-c_{k,i})\,\alpha_i \\ EP\left[\alpha_j|\alpha_k\right] &= (1-\alpha_k) + (1-c_{k,j})\,\alpha_j \end{aligned}$$

  Since $\alpha_i < \alpha_j$ and, by step one, $(1-c_{k,i}) < (1-c_{k,j})$, again it is the case that $EP\left[\alpha_i|\alpha_k\right] \leq EP\left[\alpha_j|\alpha_k\right]$.

Consequently, for all possible announcements by the opposing player, the expected payoff from announcing α_j is at least as larger as from announcing α_i. Given that there is a strictly positive probability of the other player being rational and announcing α_i themselves, and the expected payoffs in this case being

$$\begin{aligned} EP\left[\alpha_i|\alpha_i\right] &= (1-\alpha_i) \\ EP\left[\alpha_j|\alpha_i\right] &= (1-\alpha_i) + (1-c_{i,j})\,\alpha_j \end{aligned}$$

announcing α_j gives a strictly higher payoff than announcing α_i. This is a contradiction to α_i and α_j being a part of the same mixing strategy. ■

The above claim enables a simplification in setting up the system of equations used to solve numerically for the equilibrium mixing strategy of rational players. Now the ordering of $\left\{\overline{\pi}_k^{\frac{1}{1-\alpha_k}}\right\}_{k=1}^{K}$ is known in advance (i.e. before solving for μ), which means knowing which rational announcers need to concede initially in any given second stage subgame in advance.

A.3 Numerical Solution for a General Set of Behavioral Types

For a given support for the equilibrium mixed strategy in first stage announcements, $\{\alpha_R, ..., \alpha_p, ..., \alpha_K\}$, using the system of equations defined in A.1, including the simplifications contained in A.2, it is possible to obtain a numerical solution for the μ.

However, for a general set of behavioral types C that include types that are non-aggressive, it is not possible to know in advance what the support of the mixing strategy will be.

The following features of the equilibrium are used to develop an algorithm to find a full solution for μ:

- Aggressive types are always replicated in equilibrium.
- If a type α is replicated in equilibrium, then all larger types are also replicated.
- If a type α is compatible with all other types in C, i.e. $\alpha + \alpha_k \leq 1$ for all $k = 1, ..., K$, then this demand is *never* replicated by rational players.

For step $s = 0, ..., (p - m + 1)$:

1. Assume the support of μ is $S = \{\alpha_{p-s}, ..., \alpha_p, ..., \alpha_K\}$;
2. Using the assumption on the support, set up and solve the system equations;
3. For each $\alpha \in \{\alpha_m, ..., \alpha_{p-s-1}\}$, calculate expected value to a rational player from deviating to choosing α, assuming other rational players continue to mix according to α;
4. If there is no incentive to deviate to an α outside of the assumed set S, end the algorithm. Otherwise, continue to the next step, which will add the largest demand outside of S to the set S and repeat the process.

A.4 Estimating z from First Stage Announcement Data

Using the numerical solution algorithm described above, for any distribution, z, over a given set of behavioral types, C, can be mapped into an equilibrium announcement strategy, $\mu(z)$. Consequently, for a series of n observed announcement pairs, $\{\alpha_i\}_{i=1}^{2n}$, the likelihood of z (given a C) is given by

$$L\left(z, C; \{\alpha_i\}_{i=1}^{2n}\right) = \prod_{i=1}^{2n} \mathbb{I}(\alpha_i \in C)(z_i + z_0\mu_i(z))$$

where $\mathbb{I}(\alpha_i \in C) = 1$ if $\alpha_i \in C$ and 0 otherwise, and z_i and $\mu_i(z)$ are the elements of the vectors z and $\mu(z)$ that correspond to the type α_i . Note that $(z_i + z_0\mu_i(z))$ is the probability of observing an announcement α_i without knowledge of the rationality of the announcer.

Since choosing an estimate of the set C such that there exists an observed that is *not* an element of C results in a zero likelihood for any z over C, the estimated set of behavioral types is taken to be the union of all observed announcements, $\hat{C} := \cup \{\alpha_i | i = 1, ..., 2n\}$.[47] Given this choice of $\hat{C}$, the log likelihood is given by

$$LogL\left(z; \{\alpha_i\}_{i=1}^{2n}\right) = \sum_{i=1}^{2n} \ln\left(z_i + z_0\mu_i\left(z\right)\right)$$

The estimated z is given by $\hat{z} := \arg\max\left\{\sum_{i=1}^{2n} \ln\left(z_i + z_0\mu_i\left(z\right)\right) | z \in \Delta^{|\hat{C}|}\right\}$, where $\Delta^{|\hat{C}|}$ is the unit simplex in $\mathbb{R}^{|\hat{C}|}$.

A.5 Bounds on z Derived from Second Stage Play

Consider the subgame following the announcement of α_k and α_l where $\alpha_k + \alpha_l > 1$ for which there has been at least one observed concession (by either player). Denote by α_k the, weakly, larger of the two announcements (i.e. $\alpha_k \geq \alpha_l$). Let t_{max}^{kl} be the largest such concession time for this subgame. Since only rational players concede, and rational players concede over the support $[0, T_0]$, it must be the case that $t_{max}^{kl} \leq T_0$. Putting t_{max}^{kl} into the expression for second stage behavior by rational players gives:

$$\begin{aligned}
1 - c_{k,l}e^{-\lambda_{kl}t_{kl}^{max}} &\leq 1 - \overline{\pi}_k \\
1 - e^{-\lambda_{lk}t_{kl}^{max}} &\leq 1 - \overline{\pi}_l \\
&\Longrightarrow \\
\overline{\pi}_k &\leq e^{-\lambda_{kl}t_{k,l}^{m}ax} \\
\overline{\pi}_l &\leq e^{-\lambda_{lk}t_{k,l}^{m}ax}
\end{aligned}$$

Since $\overline{\pi}_i = \frac{z_i}{z_i + z_0\mu_i}$ is bounded below by z_i, for all $i = 1, ..., K$ (the denominator is bounded from above by $z_k + (1 - z_k) \times 1 = 1$), this gives the following bounds on z_k and z_l:

$$\begin{aligned}
z_k &\leq e^{-\lambda_{kl}t_{max}^{kl}} \\
z_l &\leq e^{-\lambda_{lk}t_{max}^{kl}}
\end{aligned}$$

[47]Note that adding elements to $\hat{C}$ that are not observed would result in these announcements having strictly positive probability of being observed, and some of the other elements of $\hat{C}$ having strictly smaller probability of being observed.

A.6 Special Case: Only Aggressive Types

Assume the set C is such that $\alpha_1 + \alpha_K \geq 1$. Since all types are aggressive, we know that all behavioral types are replicated by rational players with positive probability, $\mu_k > 0$ for all k, and that no player concede initially in any subgame (that is $T_{kl} = T_{lk}$, for all k, l). In this special case, the system of equations that are used to solve for μ can be simplified to finding the root of the following equation:

$$\left(\sum_{k=1}^{K} g\left(\mu_1, z_1, z_k, z_0\right)\right) - 1 = 0$$

where

$$\mu_k = g\left(\mu_1, z_1, z_k, z_0\right) = \tilde{z}_k \left[\left(1 + \frac{\mu_1}{\tilde{z}_1}\right)^{\frac{1-\alpha_k}{1-\alpha_1}} - 1\right]$$

and

$$\tilde{z}_k := \frac{z_k}{z_0}$$

See subsection A.1 for details.

The result that $T_{kl} = T_{lk}$, for all k, l, gives the following simple observation: For any $\alpha_k, \alpha_l \in C$,

$$\overline{\pi}_k = \overline{\pi}_l^{\frac{\lambda_k}{\lambda_l}} = \overline{\pi}_l^{\frac{1-\alpha_k}{1-\alpha_l}}$$

Adding the definition of $\lambda_{kl} = \frac{r(1-\alpha_k)}{\alpha_k+\alpha_l-1}$ and the definition of $\overline{\pi}_k = \frac{z_k}{z_k+z_0\mu_k} = \frac{1}{1+z_0\frac{\mu_k}{z_k}}$ to the above, gives the following useful observation on equilibrium play in the first stage

Observation 1 *In equilibrium, given announcement pair α_k and α_l, the following are equivalent*

$$\alpha_k > \alpha_l \iff \lambda_{kl} < \lambda_{lk} \iff \overline{\pi}_k > \overline{\pi}_l \iff \frac{\mu_k}{\mu_l} < \frac{z_k}{z_l}$$

That is the ratio of "rational" players mimicking the more aggressive type to those mimicking the less aggressive type is smaller than the ratio of more aggressive behavioral types in the population to less aggressive types in the population.

The fact that the equilibrium mixing strategy, μ, is such that there is no time zero concession with strictly positive probability mass for any subgame allows following analysis of concession behavior (irrespective of the particulars of the numerical solution of μ:

The probability that a player, which has announced α_k and faces an opponent who has announced α_l, will concede in the second stage is given by

$$\begin{aligned} & p\left(\alpha_k - \text{ announcer conceding}\right) \\ = \quad & \left(\tfrac{\lambda_{kl}}{\lambda_{kl}+\lambda_{lk}}\right)\left[1-e^{-(\lambda_{kl}+\lambda_{lk})T_0}\right] \end{aligned}$$

Note that this probability is unconditional on knowing that the α_k-announcer is rational. This leads to the following observation

Observation 2 *In equilibrium, for any announcements pair $\alpha_k, \alpha_l \in C$,*

$$\begin{aligned} & p\left(\alpha_l - \textit{announcer conceding}\right) > p\left(\alpha_k - \textit{announcer conceding}\right) \\ \Longleftrightarrow & \\ & \alpha_l < \alpha_k \end{aligned}$$

Observations 1 and 2 permit a little interpretation of the equilibrium behavior of rational actors: whilst for the most part they restrain themselves in the behavioral type that they replicate (i.e. not going for the "greedier" types so often), when they are aggressive in the initial stage, they remain aggressive (in probabilistic terms) in the concession stage.[48]

[48]It should be noted that observation 2 also holds for a general set C (i.e. when not all types are aggressive) if the probabilities are conditional on there being no initial concession.

B Sample instructions

Welcome (Control treatment)

You are about to participate in a session on decision-making, and you will be paid for your participation in cash, privately at the end of the session. What you earn depends partly on your decisions, partly on the decisions of others, and partly on chance.

Please turn off pagers and cellular phones now. Please close any programs you may have open on the computer. The entire session will take place through computer terminals, and all interaction between you and other session participants will take place through the computers. Please do not talk directly to or attempt to communicate with other participants during the session.

We will start with a brief instruction period. During the instruction period you will be given a description of the main features of the session and will be shown how to use the computers. If you have any questions during this period, raise your hand and your question will be answered so everyone can hear.

Instructions

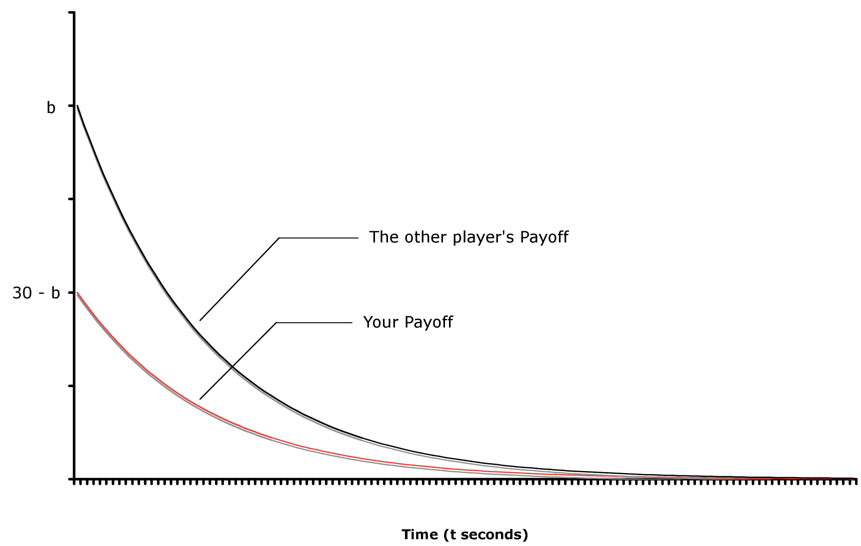
In this experiment you will be asked to make decisions in 15 periods. At the beginning of each period you will be matched at random to another player. In the room there are 16 players. During the period your task is to divide 30 points between yourself and the other player you are matched with.

Each period has up to two stages:

- First Stage: You place an announcement for the number of points that you want for yourself out of the 30 (denote this by a). Simultaneously, the other player will make an announcement for the number of points they want for themselves (denote this by b).
  - If the two announcements sum to 30 or less, then you will receive your announcement plus half of what is left over (30 minus the sum of the two announcements) and the period will end. In other words, you will receive $a + \frac{(30-a-b)}{2}$ points and the other player receives $b + \frac{(30-a-b)}{2}$.
  - If the two announcements sum to more than 30, then you move on to the second stage.

- Second Stage: You can now either accept the other player's announcement or wait until they accept your announcement. Accepting their announcement immediately means that you receive $30 - b$ points for that period. However, the longer you wait the less your points are worth. Approximately, points decrease at a rate of 1% per second. More precisely, if you accept the other player's announcement after t seconds, you will receive $(30 - b) \times (0.99)^t$ and the other player will receive $b \times (0.99)^t$. Figure 1 illustrates this. If on the other hand, the

Figure 1

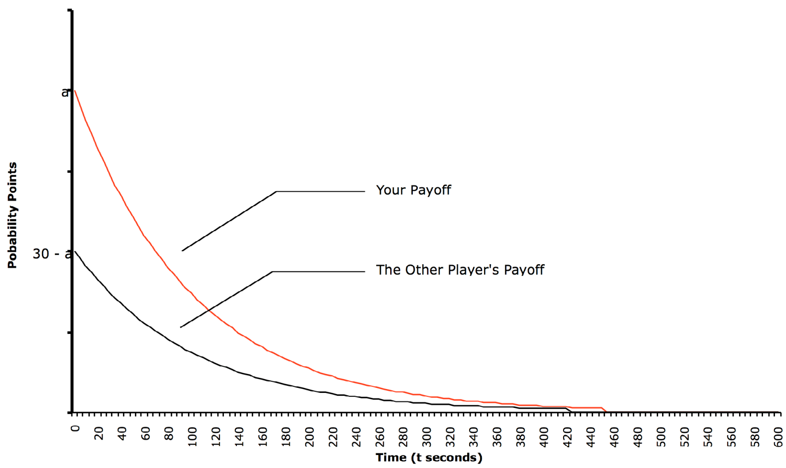


other player accepts your offer after t seconds, you will receive $a \times (0.99)^t$ and the other player will receive $(30 - a) \times (0.99)^t$. Figure 2 illustrates this. Your computer screen will display the points you and the other player would receive if you were to accept, or if they were to accept your announcement at different points in time. Once either you or the other player has accepted, or the value of the points have reached zero, the period is over.

A few examples might help your understanding. These are not meant to be realistic:

1. In the first stage, you announce 1.5 and the other player announces 3.5. Since $1.5 + 3.5 = 5$, which is smaller than 30, the period ends and you receive $1.5 +$

Figure 2



$(30-5)/2 = 14$ points. If instead the other player had announced 23.5, then you would have received $1.5 + (30-25)/2 = 4$ points.

2. In the first stage, you announce 15 and the other player announces 23. Since $15 + 23 = 38$, which is greater than 30, you go to the second stage. In the second stage, the other accepts your announcement after 1 second. You get $15 \times (0.99)^1 = 14.85$ points. If instead, the other player does not accept immediately and you accept after 10 seconds, then you obtain $(30-23) \times (0.99)^{10} = 6.33$ points.

3. In the first stage, you announce 25 and the other player announces 5. Since $25 + 5 = 30$, the period ends and you obtain 25 points.

As you can see there are many possibilities.

When every pair has finished this task, the next period begins. You will be randomly re-assigned to a player in the next period. The task in the next period is exactly the same as the one just described (but with the randomly re-matched player). The session consists of 15 such periods.

Once the 15 periods have been completed, the total number of points you have earned will be displayed (denote this by P). This determines the odds of winning a prize in your lottery. Your lottery has the following structure:

- The odds of winning are given by the number of points you earned throughout the experiment divided by the total number of points available. Since there are 15 periods and there are 30 points available in each period, the total number of points available is given by $15 \times 30 = 450$. Thus the odds of winning are $\frac{P}{450}$.
- The prize is \$20.
- That is, you have $\frac{P}{450}$ chance of winning the prize and $1 - \frac{P}{450}$ chance of receiving \$0.

In summary, your earning from this session is comprised of a \$15 participation fee and the outcome of your lottery. The probabilities associated with your lottery depend on the number of points you have earned throughout the session. You can earn either \$0 or \$20 from the lottery.

Are there any questions?

Summary

Before we start, let me remind you that:

- After a period is finished, you will be randomly re-matched to a player for the next period.
- In each period, you and another player will make announcements to divide 30 points between both of you. If the sum of your two announcements is less than 30 the period ends. If the sum of the two announcements is 30 or more you move to a second stage. In the second stage, the points decrease in value until either you or the other player accepts the announcement made by the other party, at which point the period ends.
- At the end of the session, your earnings are determined by a lottery with probabilities that depend on the number of points you have earned throughout the experiment. You can earn either \$0 or \$20 from the lottery. In addition you will receive a \$15 show-up fee.

Good Luck.

Welcome (*20-Comp* treatment)

You are about to participate in a session on decision-making, and you will be paid for your participation in cash, privately at the end of the session. What you earn depends partly on your decisions, partly on the decisions of others, and partly on chance.

Please turn off pagers and cellular phones now. Please close any programs you may have open on the computer. The entire session will take place through computer terminals, and all interaction between you and other session participants will take place through the computers. Please do not talk directly to or attempt to communicate with other participants during the session.

We will start with a brief instruction period. During the instruction period you will be given a description of the main features of the session and will be shown how to use the computers. If you have any questions during this period, raise your hand and your question will be answered so everyone can hear.

Instructions

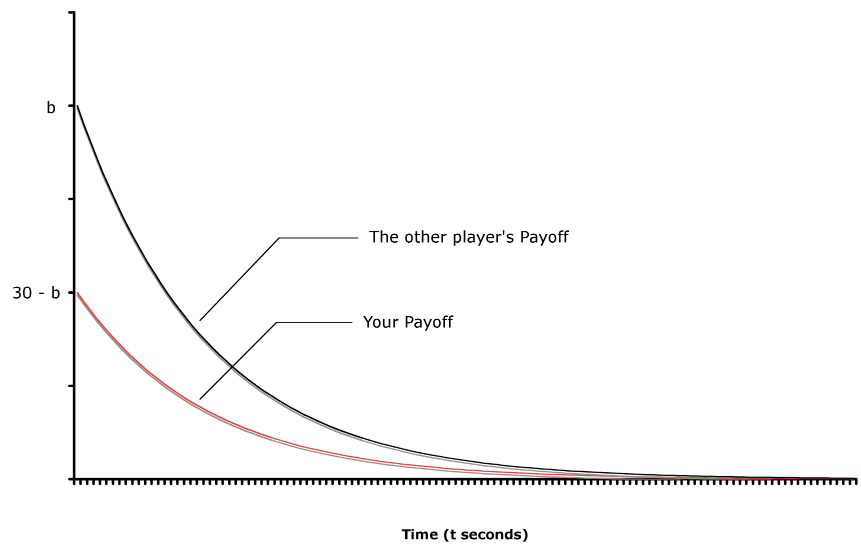
In this experiment you will be asked to make decisions in 15 periods. At the beginning of each period you will be matched at random to another player. That player will be either another subject in the room or a computer player (more on this later). In the room there are 14 human players and 2 computer players. During the period your task is to divide 30 points between yourself and the other player you are matched with.

Each period has up to two stages:

- First Stage: You place an announcement for the number of points that you want for yourself out of the 30 (denote this by a). Simultaneously, the other player will make an announcement for the number of points they want for themselves (denote this by b).
  - If the two announcements sum to 30 or less, then you will receive your announcement plus half of what is left over (30 minus the sum of the two announcements) and the period will end. In other words, you will receive $a + \frac{(30-a-b)}{2}$ points and the other player receives $b + \frac{(30-a-b)}{2}$.
  - If the two announcements sum to more than 30, then you move on to the second stage.

- Second Stage: You can now either accept the other player's announcement or wait until they accept your announcement. Accepting their announcement immediately means that you receive $30 - b$ points for that period. However, the longer you wait the less your points are worth. Approximately, points decrease at a rate of 1% per second. More precisely, if you accept the other player's announcement after t seconds, you will receive $(30 - b) \times (0.99)^t$ and the other player will receive $b \times (0.99)^t$. Figure 1 illustrates this. If on the other hand, the

Figure 1

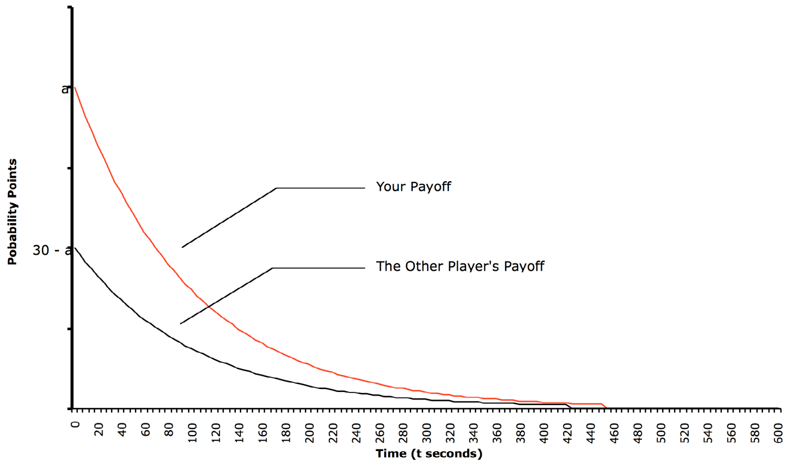


  other player accepts your offer after t seconds, you will receive $a \times (0.99)^t$ and the other player will receive $(30 - a) \times (0.99)^t$. Figure 2 illustrates this. Your computer screen will display the points you and the other player would receive if you were to accept, or if they were to accept your announcement at different points in time. Once either you or the other player has accepted, or the value of the points have reached zero, the period is over.

A few examples might help your understanding. These are not meant to be realistic:

1. In the first stage, you announce 1.5 and the other player announces 3.5. Since $1.5 + 3.5 = 5$, which is smaller than 30, the period ends and you receive $1.5 +$

Figure 2



$(30-5)/2 = 14$ points. If instead the other player had announced 23.5, then you would have received $1.5 + (30-25)/2 = 4$ points.

2. In the first stage, you announce 15 and the other player announces 23. Since $15 + 23 = 38$, which is greater than 30, you go to the second stage. In the second stage, the other accepts your announcement after 1 second. You get $15 \times (0.99)^1 = 14.85$ points. If instead, the other player does not accept immediately and you accept after 10 seconds, then you obtain $(30-23) \times (0.99)^{10} = 6.33$ points.

3. In the first stage, you announce 25 and the other player announces 5. Since $25 + 5 = 30$, the period ends and you obtain 25 points.

As you can see there are many possibilities.

When every pair has finished this task, the next period begins. You will be randomly re-assigned to a player in the next period. The task in the next period is exactly the same as the one just described (but with the randomly re-matched player). The session consists of 15 such periods.

Computer players do the same thing every period. In the first stage, the computer player will always announce that they want 20 points. If the period goes to the second stage (that is the announcements are incompatible), the computer player will never accept your offer. At the beginning of each period, you have a 2/15 chance of being matched to a computer player.

Once the 15 periods have been completed, the total number of points you have earned will be displayed (denote this by P). This determines the odds of winning a prize in your lottery. Your lottery has the following structure:

- The odds of winning are given by the number of points you earned throughout the experiment divided by the total number of points available. Since there are 15 periods and there are 30 points available in each period, the total number of points available is given by $15 \times 30 = 450$. Thus the odds of winning are $\frac{P}{450}$.
- The prize is \$20.
- That is, you have $\frac{P}{450}$ chance of winning the prize and $1 - \frac{P}{450}$ chance of receiving \$0.

In summary, your earning from this session is comprised of a \$15 participation fee and the outcome of your lottery. The probabilities associated with your lottery depend on the number of points you have earned throughout the session. You can earn either \$0 or \$20 from the lottery.

Are there any questions?

Summary

Before we start, let me remind you that:

- After a period is finished, you will be randomly re-matched to a player for the next period.
- In each period, you and another player will make announcements to divide 30 points between both of you. If the sum of your two announcements is less than 30 the period ends. If the sum of the two announcements is 30 or more you move to a second stage. In the second stage, the points decrease in value until either you or the other player accepts the announcement made by the other party, at which point the period ends.

- At the end of the session, your earnings are determined by a lottery with probabilities that depend on the number of points you have earned throughout the experiment. You can earn either \$0 or \$20 from the lottery. In addition you will receive a \$15 show-up fee.

Good Luck.

Welcome (***Restricted B*** treatment)

You are about to participate in a session on decision-making, and you will be paid for your participation in cash, privately at the end of the session. What you earn depends partly on your decisions, partly on the decisions of others, and partly on chance.

Please turn off pagers and cellular phones now. Please close any programs you may have open on the computer. The entire session will take place through computer terminals, and all interaction between you and other session participants will take place through the computers. Please do not talk directly to or attempt to communicate with other participants during the session.

We will start with a brief instruction period. During the instruction period you will be given a description of the main features of the session and will be shown how to use the computers. If you have any questions during this period, raise your hand and your question will be answered so everyone can hear.

Instructions

In this experiment you will be asked to make decisions in 15 periods. At the beginning of each period you will be matched at random to another player. That player will be either another subject in the room or a computer player (more on this later). In the room there are 13 human players and 3 computer players. During the period your task is to divide 30 points between yourself and the other player you are matched with.

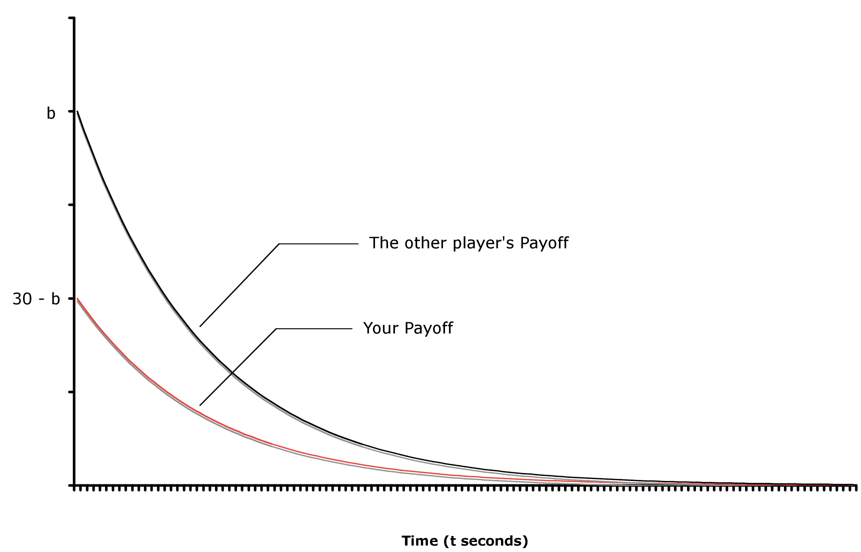
Each period has up to two stages:

- First Stage: You place an announcement for the number of points that you want for yourself out of the 30 (denote this by a). This announcement can either be $15, 18$, or 20. These are the only three options that are available to you. Simultaneously, the other player will make an announcement for the number of points they want for themselves (denote this by b). He too can only ask for $15, 18$, or 20.

- If the two announcements sum to 30 or less, then you will receive your announcement and the period will end.
- If the two announcements sum to more than 30, then you move on to the second stage.

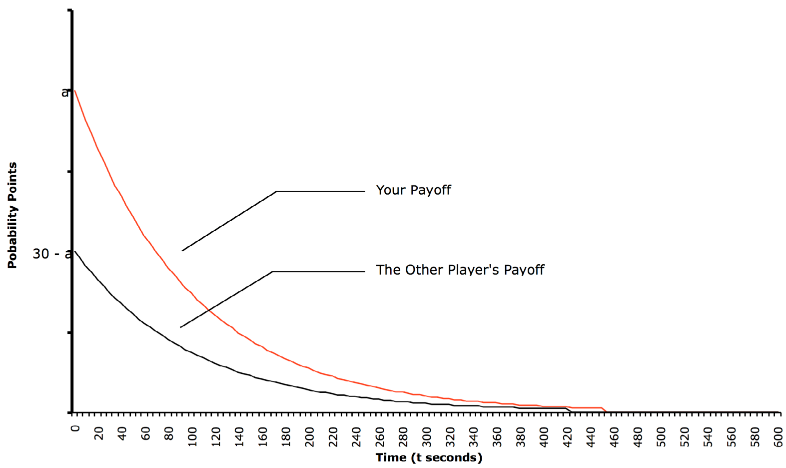
- Second Stage: You can now either accept the other player's announcement or wait until they accept your announcement. Accepting their announcement immediately means that you receive $30 - b$ points for that period. However, the longer you wait the less your points are worth. Points decrease at a rate of approximately 1% per second. More precisely, if you accept the other player's announcement after t seconds, you will receive $(30 - b) \times (0.99)^t$ and the other player will receive $b \times (0.99)^t$. Figure 1 illustrates this. If on the other hand, the

Figure 1



other player accepts your offer after t seconds, you will receive $a \times (0.99)^t$ and the other player will receive $(30 - a) \times (0.99)^t$. Figure 2 illustrates this. Your computer screen will display the points you and the other player would receive if you were to accept, or if they were to accept your announcement at different points in time. Once either you or the other player has accepted, or the value of the points have reached zero, the period is over.

Figure 2



A few examples might help your understanding. These are not meant to be realistic:

1. In the first stage, you announce 15 and the other player announces 15. Since $15 + 15 = 30$ the period ends and you receive 15 points.

2. In the first stage, you announce 15 and the other player announces 20. Since $15 + 20 = 35$, which is greater than 30, you go to the second stage. In the second stage, the other accepts your announcement after 1 second. You get $15 \times (0.99)^1 = 14.85$ points. If instead, the other player does not accept immediately and you accept after 10 seconds, then you obtain $(30 - 20) \times (0.99)^{10} = 9.04$ points.

3. In the first stage, you announce 20 and the other player announces 18. Since $20 + 18 = 38$, you would move on to the second stage...

As you can see there are many possibilities.

When every pair has finished this task, the next period begins. You will be randomly re-assigned to a player in the next period. The task in the next period is exactly the same as the one just described (but with the randomly re-matched player). The session consists of 15 such periods.

Computer players do the same thing every period. The first computer player, "Computer I", acts as follows: In the first stage, the "Computer I" will always announce that they want 20 points. If the period goes to the second stage (that is the announcements are incompatible), "Computer I" will never accept your offer. The second computer player, "Computer II", acts as follows: In the first stage, "Computer II" will always announce that they want 18 points. If the period goes to the second stage (that is the announcements are incompatible), "Computer II" will never accept your offer. The third computer player, "Computer III", acts as follows: In the first stage, "Computer III" will always announce that they want 15 points. If the period goes to the second stage (that is the announcements are incompatible), "Computer III" will never accept your offer. At the beginning of each period, you have a $\frac{1}{15}$ chance of being matched to "Computer I", a $\frac{1}{15}$ chance of being matched to "Computer II", and a $\frac{1}{15}$ chance of being matched to "Computer III".

Once the 15 periods have been completed, the total number of points you have earned will be displayed (denote this by P). This determines the odds of winning a prize in your lottery. Your lottery has the following structure:

- The odds of winning are given by the number of points you earned throughout the experiment divided by the total number of points available. Since there are 15 periods and there are 30 points available in each period, the total number of points available is given by $15 \times 30 = 450$. Thus the odds of winning are $\frac{P}{450}$.
- The prize is \$20.
- That is, you have $\frac{P}{450}$ chance of winning the prize and $1 - \frac{P}{450}$ chance of receiving \$0.

In summary, your earning from this session is comprised of a \$15 participation fee and the outcome of your lottery. The probabilities associated with your lottery depend on the number of points you have earned throughout the session. You can earn either \$0 or \$20 from the lottery.

Are there any questions?

Summary

Before we start, let me remind you that:

- After a period is finished, you will be randomly re-matched to a player for the next period.

- In each period, you and another player will make announcements to divide 30 points between both of you. If the sum of your two announcements is less than 30 the period ends. If the sum of the two announcements is 30 or more you move to a second stage. In the second stage, the points decrease in value until either you or the other player accepts the announcement made by the other party, at which point the period ends.
- You can make one of three possible announcements: $15, 18$, and 20.
- At the end of the session, your earnings are determined by a lottery with probabilities that depend on the number of points you have earned throughout the experiment. You can earn either \$0 or \$20 from the lottery. In addition you will receive a \$15 show-up fee.

Good Luck.

C Screenshots

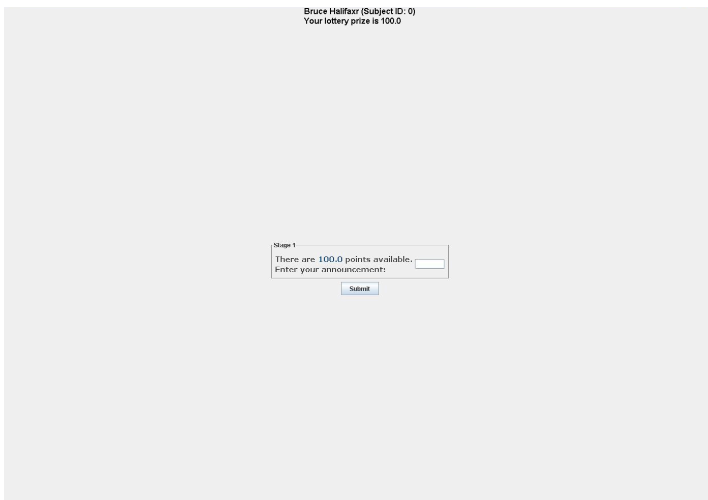


Figure 5: Stage 1

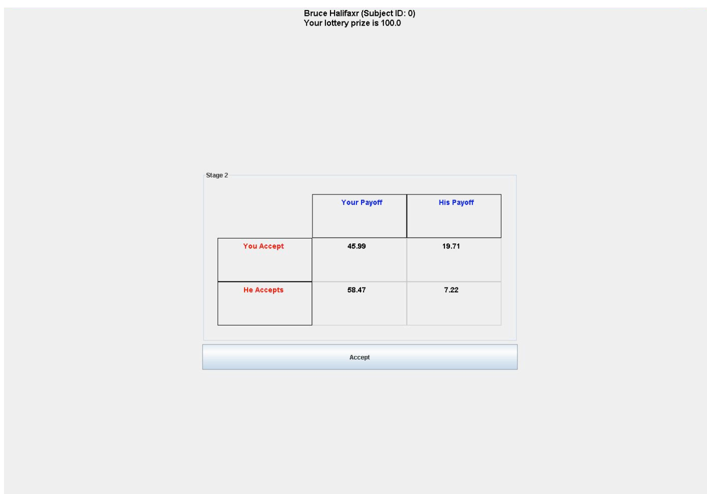


Figure 6: Stage 2