

Using Experiments to Compare the Predictive Power of Models of Multilateral Negotiations*

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Abstract: We conduct unstructured negotiations in a laboratory experiment designed to empirically assess the predictive power of three approaches to modeling the multilateral negotiations observed in diverse strategic settings. For concreteness we consider two sellers negotiating with a buyer who wants to make only one trade, with the modeling approaches distinguished by whether the buyer negotiates with the sellers sequentially, simultaneously, or in a “take-it-or-leave-it” fashion. Our experiment features two scenarios within which the three approaches have observationally distinct predictions: a **differentiated** scenario with one high-surplus and one low-surplus seller, and a **homogeneous** scenario with identical high-surplus sellers. In both scenarios the buyer tends to trade with a high-surplus seller at terms indistinguishable from those in bilateral negotiations with a high-surplus seller, meaning that *introducing a competing seller does not affect the observed terms of trade*. Our findings match the predictions from the sequential approach, supporting its use in modeling multilateral negotiations.

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JEL Codes: C7 (Game Theory & Bargaining Theory), C9 (Design of Experiments), D4 (Market Structure, Pricing, and Design), L1 (Market Structure, Firm Strategy, and Market Performance)

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1. Introduction

Multilateral negotiations are an exchange mechanism frequently observed when one party wishes to trade with one of several others offering potentially different amounts of surplus to be split. For example, procurement often involves negotiations with suppliers who differ on dimensions such as quality or goodness-of-fit, such as Express Scripts' decision to include on its formulary AbbVie's hepatitis C drug Viekira Pak rather than Gilead's blockbuster drug Sovaldi.¹ Likewise, the takeover contest for Pep Boys pitted Carl Icahn against Bridgestone, with both acquirers presumably having different benefits from completing the transaction.² The NFL's Houston Texans recently outbid the Denver Broncos for quarterback Brock Osweiler, the Broncos' presumed replacement for Peyton Manning.³ Lastly, General Electric's decision to relocate its corporate headquarters to Boston concluded a lengthy battle amongst 40 varied municipalities, reportedly including ones in Connecticut, Georgia, New York, and Texas.⁴

Several theoretical models can be applied to multilateral negotiations in all manner of settings, but for concreteness we consider two sellers negotiating with a buyer who wants to make only one trade. Existing models predominantly assume players know all aspects of the environment, to simplify the analysis given the negotiations' strategic complexity. While in many situations it is unrealistic to assume players have common knowledge about environmental features such as the number of negotiating parties and the surpluses available from all trades, developing such models is an important step in developing more-realistic models. Moreover, full-

¹ "New Hep C Drug Gets Helping Hand --- As High-Cost Treatments Vie, Express Scripts Opts to Use AbbVie's Over Gilead's." *Wall Street Journal*, Dec 22, 2014, B.1.

² "Icahn Wins Pep Boys Bidding Contest." *Wall Street Journal*, Dec 31, 2015, B.3.

³ "Elway on Brock Osweiler's Exit: 'We Want Players Who Want to be Here.' *The Denver Post*, Mar 10, 2016, 8A.

⁴ "GE Decamps to Boston --- City Beats Back Fierce Competition as the Company Moves its Base from Connecticut." *Wall Street Journal*, Jan 14, 2016, B.1.

information models might offer reasonable predictions in settings with players who know each other well.

The various models can be roughly separated into three groups that differ in whether the competition faced by players on the “multi-player” side of the negotiations is sequential, simultaneous, or of the “take-it-or-leave-it” (TIOLI) variety. In our framework these distinctions correspond to whether the buyer negotiates with only one seller at a time, negotiates with both sellers simultaneously, or has the commitment power to make TIOLI offers to the sellers.

In this paper we assess those modeling approaches’ empirical relevance by comparing their predicted outcomes to the outcomes of unstructured negotiations conducted in the laboratory. Using an experiment to identify the most successful model of multilateral negotiations fits squarely within the research paradigm developed and advocated by Vernon Smith. Smith (1994, p. 113) lays out several reasons why economists run experiments; first among them is to “Test a theory, or discriminate between theories.” Smith (1976, 1982) articulates several benefits of experiments that are relevant in our setting: our experiment lets us induce players’ payoffs, control the set of possible trading partners, and observe negotiated outcomes; such control is not possible when studying naturally occurring bargaining.

We conduct unstructured negotiations rather than implement the structured protocols from bargaining models, because those models’ purpose is to make meaningful predictions about situations that lack such structure. The models impose structure on players’ behavior not to reflect actual protocols by which negotiations are conducted, but rather to enable derivation of

equilibrium strategies that lead to predicted outcomes. Consequently, empirical evidence about unstructured negotiations is necessary to assess those theoretical predictions' practical reliability.⁵

Our experiment features two scenarios for which the three modeling approaches have observationally distinct combinations of predictions: a **differentiated** scenario with one high-surplus and one low-surplus seller, and a **homogeneous** scenario with two identical high-surplus sellers. In both scenarios we find that the buyer tends to trade with a high-surplus seller at terms indistinguishable from those found in a **baseline** scenario involving bilateral negotiations between the buyer and a high-surplus seller, meaning that *introducing a competing seller does not affect the observed terms of trade*. These findings match the predictions from the sequential approach, supporting its use in modeling multilateral negotiations.

We begin our analysis in Section 2 by describing the modeling approaches evaluated in our experiment. Section 3 explains our experimental design, while Section 4 presents our experimental findings. Section 5 relates our findings to existing experimental results. Section 6 concludes briefly and suggests future research directions.

2. Modeling Background

In this section we describe three complete-information approaches to modeling multilateral negotiations in strategic environments that allow trade with different partners to yield different surpluses. Although the approaches fit varied situations in which one party wants to trade with one of several others, for concreteness we frame the models as a buyer negotiating with two sellers. The different surpluses available from trade with different sellers reflect differences in the sellers'

⁵ Imposing structure on the negotiations is another common, but distinct, experimental approach, whose purpose is to test a model's internal validity rather than its relationship to a naturally occurring phenomenon. Section 5 discusses examples of such research.

opportunity costs or the buyer's value for each seller's product. We denote the surplus (or "pie") available from trading with seller i by Π_i , and we assume $\Pi_1 \geq \Pi_2$.

A Baseline Model of Bilateral Negotiations

We begin by describing the bilateral negotiation model from Rubinstein (1982) that forms the basis for the multilateral negotiation models considered later, following the presentation in Muthoo (1999). A buyer and seller 1 negotiate to split the surplus $\Pi_1 > 0$, and they have instantaneous rates of time preference $r_B > 0$ and $r_1 > 0$. The game's structure and parameters are common knowledge among both players.

Trade is conducted as follows, where time is measured in discrete periods $t \in \{0, 1, 2, \dots\}$ that are of length $\Delta > 0$. In even-numbered period $t \in \{0, 2, 4, \dots\}$ seller 1 makes a proposal $(s_t, \Pi_1 - s_t) \in [0, \Pi_1]^2$ to the buyer that specifies the amount s_t of the surplus Π_1 that seller 1 demands for itself, with the remainder $\Pi_1 - s_t$ that it offers to the buyer. If the buyer accepts seller 1's proposal, then the negotiations conclude. Otherwise, in odd-numbered period $t + 1 \in \{1, 3, 5, \dots\}$ the buyer makes a proposal $(b_{t+1}, \Pi_1 - b_{t+1}) \in [0, \Pi_1]^2$ to seller 1 that specifies the amount b_{t+1} of the surplus Π_1 that the buyer demands for itself, with the remainder $\Pi_1 - b_{t+1}$ that it offers to seller 1. If seller 1 accepts the buyer's proposal, then the negotiations conclude. Otherwise, play continues to the next period.

A transaction in even-numbered period t yields the buyer and seller 1 respective payoffs $(\Pi_1 - s_t)e^{-r_B t \Delta}$ and $s_t e^{-r_1 t \Delta}$, while a transaction in odd-numbered period t yields the buyer and seller 1 respective payoffs $b_t e^{-r_B t \Delta}$ and $(\Pi_1 - b_t)e^{-r_1 t \Delta}$. If no transaction occurs in any period, then each party's payoff is 0. For notational convenience define $\delta_k \equiv e^{-r_k \Delta}$, where $\delta_k \in (0, 1)$ is player k 's discount factor, for $k \in \{B, 1\}$.

This infinite-horizon game has a unique subgame-perfect Nash equilibrium (SPNE) in which the players' payoffs depend on whose turn it is to make offers. Deriving the equilibrium exploits the game's stationary structure: Each even-numbered period is the initial period of an infinite-horizon subgame that begins with seller 1 making an offer to the buyer, and every such subgame is identical. Similarly, each odd-numbered period is the initial period of an infinite-horizon subgame that begins with the buyer making an offer to seller 1, and every such subgame is identical. The players' SPNE payoffs in the "seller-offer" and "buyer-offer" subgames are

$$\begin{aligned}\pi_B^{so} &= \delta_B \left(\frac{1 - \delta_1}{1 - \delta_1 \delta_B} \right) \Pi_1 \quad \text{and} \quad \pi_1^{so} = \left(\frac{1 - \delta_B}{1 - \delta_1 \delta_B} \right) \Pi_1 \\ \pi_B^{bo} &= \left(\frac{1 - \delta_1}{1 - \delta_1 \delta_B} \right) \Pi_1 \quad \text{and} \quad \pi_1^{bo} = \delta_1 \left(\frac{1 - \delta_B}{1 - \delta_1 \delta_B} \right) \Pi_1.\end{aligned}$$

The SPNE payoffs have the feature that the party making a proposal offers just enough to induce its counterpart to accept, namely the counterpart's net present value of waiting until the next period. For example, seller 1's payoff π_1^{bo} when the buyer makes offers equals $\delta_1 \pi_1^{so}$, which is the net present value to seller 1 of rejecting the buyer's offer and moving to a "seller-offer" subgame after a delay of length Δ .

Muthoo (1999, Ch. 3.2) suggests that the appropriate case to consider is when the time between offers $\Delta \rightarrow 0$, because a party making a counteroffer has incentives to do so quickly to reduce its cost of delay. The limiting values of the payoffs as $\Delta \rightarrow 0$ also do not depend on who makes the initial proposal, so there is no first-mover advantage in the limit. As $\Delta \rightarrow 0$ the buyer's and seller 1's payoffs approach

$$\pi_B^* = \left(\frac{r_1}{r_1 + r_B} \right) \Pi_1 \quad \text{and} \quad \pi_1^* = \left(\frac{r_B}{r_1 + r_B} \right) \Pi_1.$$

Notice that the players split the surplus equally if they have identical discount rates. Otherwise the more patient player receives more than half of the surplus Π_1 .

Three Models of Multilateral Negotiations

The following three models extend Rubinstein's bilateral negotiation model to allow for more bargaining parties. While each model has an infinite horizon and uses alternating offers, the models differ in the specifics of their bargaining protocols. As a reminder, our presentation adds seller 2 who has discount rate r_2 , and trade with whom creates surplus $\Pi_2 \in (0, \Pi_1]$. In each model the buyer trades with seller 1 in equilibrium, so seller 2's payoff is 0.

Osborne and Rubinstein (1990, Ch. 9.3) consider a buyer who has the same value for each seller's product, while seller 1's cost is weakly lower than seller 2's.⁶ All players have the same discount rate. Play begins with the buyer making offers to both sellers. Seller 1 responds first and seller 2 responds second, and the buyer must trade with the first seller to accept its offer. If neither seller accepts the buyer's offer, then in the next period the sellers make simultaneous offers to the buyer. The buyer chooses which offer to accept, and play continues if the buyer rejects both offers.

One curious feature of the Osborne and Rubinstein model is that the buyer is required to demand the same payoff from both sellers, a restriction that dramatically affects the negotiated outcome. Without that restriction, when the buyer makes offers it extracts the entire surplus Π_1 from seller 1, because the buyer is required to trade if at least one seller accepts (even if the buyer would prefer not to trade). To see how the buyer achieves this feat, suppose that it offers $\epsilon \in (0, \Pi_2)$ to both sellers. Seller 2 will accept if given the chance, which forces seller 1 to accept.⁷ Letting $\epsilon \rightarrow 0$ completes the argument, which demonstrates that seller 1 is forced to accept

⁶ Osborne and Rubinstein actually present the model as a seller facing two buyers with different values for the seller's product, and the seller has the same production cost for serving either buyer. Our formulation reverses the players' labels, but is otherwise identical to the original.

⁷ Our earlier parenthetical statement, about the buyer possibly preferring not to trade if its offer is accepted, comes into play if $\Pi_2 - \epsilon$ is strictly less than the net present value of the buyer's payoff from letting play proceed to the next period. This condition will hold for low values of Π_2 .

extremely unfavorable offers. Finally, in the limit as the time between offers $\Delta \rightarrow 0$, the buyer obtains the entire surplus Π_1 in every subgame, regardless of who is making offers. This result holds even if Π_2 is strictly positive yet arbitrarily small.

While assumptions need not match the protocols employed in practice for a model to be useful, one must be wary of such assumptions if they harm the party on whose behavior they are imposed. Ironically, this point is made strongly in Binmore (1985), who introduces a model that forms the basis for the Osborne and Rubinstein model:

(p. 270): Of course, if a particular bargaining model imposes constraints on a player's behavior that he would prefer to violate and no mechanism exists in the situation one is trying to model that would prevent such violations, then little insight can be expected from the model.

(p. 283): The only firm principle would seem to be that one cannot expect players to submit to constraints that limit their payoffs unless there is some mechanism that forces the constraints on them.

Given the preceding points, we view the modified version of the Osborne and Rubinstein model, without the restriction that the buyer make identical price offers to both sellers, as reflecting a distinct approach to modeling multilateral negotiations. After all, in multilateral negotiations it is not apparent that the buyer's offers would be restricted. In the modified model, as $\Delta \rightarrow 0$ the buyer's and seller 1's payoffs approach

$$\pi_B^* = \Pi_1 \quad \text{and} \quad \pi_1^* = 0.$$

Seller 2's presence dramatically affects the negotiated outcome, regardless of the size of $\Pi_2 > 0$.

Ray (2007) provides an overview of research considering coalition formation in multi-party negotiations, in which a range of diverse coalitional structures all can create value. While the emphasis is to generalize multilateral bargaining settings in which multiple parties bargain to split one joint surplus, as in Krishna and Serrano (1996), this approach can accommodate one buyer that wishes to trade with exactly one of two sellers.

In Ray's bargaining protocol the buyer can make only one offer in a period in which it makes offers, and it can receive only one offer in a period in which sellers make offers. All players have the same discount rate. Example 7.6 in Ray (2007) shows that a buyer facing two identical sellers receives only the portion of the surplus it would get in bilateral negotiations with one seller.⁸ That is, the second seller has no impact on the negotiated outcome. More generally, for arbitrary Π_1 and $\Pi_2 \leq \Pi_1$, as $\Delta \rightarrow 0$ the buyer's and seller 1's payoffs approach

$$\pi_B^* = \frac{\Pi_1}{2} \quad \text{and} \quad \pi_1^* = \frac{\Pi_1}{2}.$$

Seller 2's presence does not affect the negotiated outcome, regardless of how close Π_2 is to Π_1 .

Thomas (2016) introduces a multilateral negotiation model in which one party wishes to trade with exactly one of several others. The parties can have arbitrary discount rates. Applying Thomas' model to our setting, play begins with both sellers making simultaneous offers to the buyer. If the buyer accepts an offer, then the negotiations conclude. If the buyer rejects both offers, then after a delay of length Δ the buyer makes simultaneous offers to both sellers, who respond simultaneously. The buyer chooses whether to trade with a seller that accepted its offer, but the buyer also can choose to retract an accepted offer.

Thomas' analysis highlights a tension between allowing the buyer to retract accepted offers and requiring the buyer to trade if at least one seller accepts an offer. Requiring trade enables the same sort of surplus-extraction that emerges in the modified version of the Osborne and Rubinstein (1990, Ch. 9.3) model. Allowing offer-retraction might enable any split of Π_1 to be a SPNE,

⁸ This solution is only approximate, but one can get the same solution exactly by using Ray's algorithm for solving the game. Doing so exploits the fact that once one trade occurs, the next trade is worth nothing.

including inefficient outcomes with arbitrarily long delays to reach an agreement.⁹ Thomas avoids this problem by analyzing SPNE with a particular stationary structure.

When all players have the same discount rate, as $\Delta \rightarrow 0$ the buyer's and seller 1's payoffs approach

$$\pi_B^* = \max \left[\frac{\Pi_1}{2}, \Pi_2 \right] \quad \text{and} \quad \pi_1^* = \min \left[\frac{\Pi_1}{2}, \Pi_1 - \Pi_2 \right].$$

Seller 2's presence affects the negotiated outcome if and only if the surplus Π_2 from trading with seller 2 exceeds the buyer's payoff $\frac{\Pi_1}{2}$ from bilateral negotiations with seller 1.

Categorizing Models of Multilateral Negotiations

The preceding models embody three approaches distinguished by the type of competition the sellers face. We categorize that competition as being take-it-or-leave-it, sequential, or simultaneous.

Models like the modified version of Osborne and Rubinstein (1990, Ch. 9.3) reflect take-it-or-leave-it competition, in which the buyer can make TIOLI offers to the sellers. Such bargaining power enables the buyer to extract the entire surplus from seller 1, regardless of how small is the surplus available to be split with seller 2. This extreme bargaining power is familiar from the Ultimatum game first analyzed by Guth, Schmittberger, and Schwarze (1982), and from bilateral bargaining models in which one party makes all of the offers.¹⁰

Models like Ray (2007) reflect sequential competition, in which the buyer can negotiate with only one seller at a time. The necessity of switching sellers has an enormous strategic impact, because the buyer's negotiation with seller 1 proceeds as if seller 2 is not present. Other models

⁹ This possibility follows from the analysis in Muthoo (1999, Ch. 7.3), which found such results after adding offer-retraction to Rubinstein's bilateral negotiation model.

¹⁰ Osborne and Rubinstein (1990, Ch. 3.10.3) briefly discuss bilateral negotiations with one-sided offers

requiring switching find similar results, including Osborne and Rubinstein (1990, Ch. 9.4.1) and Houba and Bennett (1997).¹¹

Finally, models like Thomas (2016) reflect simultaneous competition, in which the buyer can negotiate with multiple sellers at the same time. The buyer's ability to hold multiple offers and to hold an offer while seeking improvements provides no advantage when seller 2 is a distant competitor to seller 1 (unlike in the TIOLI approach), but enables the buyer to leverage a closely competing seller 2's presence (unlike in the sequential approach). Similar results emerge in the unmodified version of the Osborne and Rubinstein (1990, Ch. 9.3) model and in models of bilateral negotiations with exogenously-specified outside options, such as Binmore, et al. (1989), Shaked (1994), and Muthoo (1999, Ch. 5.6).¹²

The experiment we describe in the next section discriminates amongst the three approaches' predictions by having subjects negotiate in two multilateral scenarios, with the surpluses specified so that the three modeling approaches have distinct combinations of predictions. Such separation is possible because of the structure of the buyer's equilibrium payoffs as the time between offers $\Delta \rightarrow 0$: Π_1 in the TIOLI approach, $\frac{\Pi_1}{2}$ in the sequential approach, and $\max\left[\Pi_2, \frac{\Pi_1}{2}\right]$ in the simultaneous approach. Simply speaking, we compare predicted and actual outcomes when rival sellers are either very similar or very different.

¹¹ Shaked and Sutton (1984) find that introducing an identical seller affects outcomes even though the buyer must switch. This difference from other models with switching arises from their assumption that the buyer can switch only upon receiving an offer, and makes an offer to the other seller in that period. Hence, there is occasionally a "simultaneous" element to their model's negotiation protocol.

¹² Other models with simultaneous competition introduce identical sellers, such as Corominas-Bosch (2004).

3. Experimental Design

We conducted 10 laboratory sessions at the University of Alaska-Anchorage, each consisting of nine human subjects drawn from a standing economic participant pool. Three randomly selected subjects in each session were permanently assigned to be buyers, with the other six permanently assigned to be sellers. None of our 90 unique subjects had previously participated in any related studies. The average subject earned \$9.29 plus a \$5 participation payment for the one-hour experiment.¹³

Subjects read instructions informing them they would engage in a sequence of two or three distinct interactions involving buyers and sellers trying to agree on a price at which to trade.¹⁴ This buyer/seller framing is commonly used in market experiments to facilitate subjects' understanding, by using the familiar notion of price as a means to allocate surplus.¹⁵ Subjects had no information about the nature of the actual or possible interactions they would encounter, in terms of available surpluses and the number of buyers or sellers.

Within a session each subject participated in each of the following three scenarios at most once. In the **baseline** scenario a buyer negotiates with a *high-surplus seller* whose cost is \$0 to produce a good the buyer values at \$10. In the **homogeneous** scenario a buyer negotiates to trade with one of two high-surplus sellers. In the **differentiated** scenario a buyer negotiates to trade

¹³ Participants were recruited for one hour due to the untimed negotiations, but most sessions finished in approximately 30 minutes including directions and payment.

¹⁴ The appendix contains a copy of the instructions.

¹⁵ Market frames have been studied in ultimatum games, where they appear to (weakly) promote self-interested behavior. Hoffman, et al. (1994) report that market framing led to more self-interested behavior than did abstract framing, while Cox and Deck (2005) found no effect of market framing on outcomes. These findings suggest market framing should not lead subjects toward altruistic behavior.

with one of a high-surplus seller and a *low-surplus seller*; the latter's cost is \$0 to produce a good the buyer values at \$2.¹⁶

Table 1 reports the limiting values of the predicted prices for each modeling approach and negotiation scenario, under the assumption of identical discount rates. For readers wary of the assumption that the time between offers $\Delta \rightarrow 0$, suppose subjects have a discount rate of 100% per year (which is extremely high), and suppose the length of a period is 1 hour (which is extremely long, given that the experiments all concluded in less than an hour). In this case, $\Delta = \frac{1}{24*365}$, and applying the associated discount factor of 0.999886 to the different approaches' non-limiting payoffs yields the separation we need amongst the predictions.

Table 1. Predicted Prices by Modeling Approach and Negotiation Scenario

	Baseline	Homogeneous	Differentiated
TIOLI	\$5	\$0	\$0
Sequential	\$5	\$5	\$5
Simultaneous	\$5	\$0	\$5

We specified the scenarios' costs and values to let us distinguish among the modeling approaches by exploiting their distinct combinations of predictions in the homogeneous and differentiated scenarios. Although each approach predicts a price of \$5 in the baseline scenario, we had subjects negotiate bilaterally to calibrate observed behavior.

It is worth reiterating what drives the predictions. The TIOLI approach predicts the buyer trades with a high-surplus seller at a price of \$0 in both the homogeneous and differentiated scenarios, because the model's built-in commitment effectively allows the buyer to make take-it-

¹⁶ Three subjects in the seller role necessarily are inactive when the buyers are engaging in bilateral negotiations with other sellers. To balance expected payments, the sellers who are inactive during the baseline are put in the favorable position of being the high-surplus seller in the differentiated scenario.

or-leave-it offers. The sequential approach predicts the buyer trades with a high-surplus seller at a price of \$5 in both the homogeneous and differentiated scenarios, because the buyer can negotiate with only one seller at a time. The simultaneous approach predicts the buyer trades with a high-surplus seller at a price of \$0 in the homogeneous scenario, because of the severe competition between the two identical sellers; it predicts the buyer trades with the high-surplus seller at a price of \$5 in the differentiated scenario, because the buyer cannot credibly threaten to trade with the low-surplus seller to extract more surplus from the high-surplus seller.

Each session was temporally divided into three phases, and within a phase subjects were matched into groups and participated in one of the three scenarios.¹⁷ We matched subjects so that no two interacted more than once, a “perfect-strangers protocol” that replicates the modeling approaches’ one-shot strategic nature by preventing reputation-building or reciprocity.

Table 2 depicts one sequence of subject-matchings; in it, Subject 1 is a buyer who interacts with Subjects 4 and 5 in the homogeneous scenario in phase 1, with Subjects 7 and 8 in the differentiated scenario in phase 2, and with Subject 9 in the baseline scenario in phase 3. Other matchings are denoted similarly. Across sessions we varied the order in which each scenario occurred, to control for learning effects or other behavioral spillovers.

Table 2. Sample Subject Matching

Buyers	Sellers					
	Subject 4	Subject 5	Subject 6	Subject 7	Subject 8	Subject 9
Subject 1	H – 1	H – 1	–	L – 2	H – 2	H – 3
Subject 2	H – 2	H – 3	H – 1	H – 1	–	L – 2
Subject 3	–	L – 2	H – 2	H – 3	H – 1	H – 1

Table entries S – P indicate the *surplus* of the seller (H or L) when interacting with a buyer and the *phase* (1, 2 or 3) in which they interacted.

¹⁷ In the experiment we referred to the phases as periods. Here we use “phase” to avoid confusion with our use of “period” to denote a point at which a party can make an offer in the bargaining models presented in Section 2.

A matched buyer and seller could communicate both formally and informally. Formal communication consisted of a numeric price offer from the buyer or seller, acceptance of which constituted an agreement and ended the phase for that group of matched subjects. No structure was imposed on the making of price offers. For example, one party could replace its old offer with a new offer, without waiting for a counteroffer by the other party; an offer could be withdrawn at any point before it was accepted; and a new offer did not have to improve upon a previous offer. Informal communication consisted of unstructured, non-binding, real-time text-messaging whose content was unrestricted, except that messages could not contain personally identifying information or offensive language. We anticipated subjects would use this informal channel to discuss possible price offers and offers from rivals.

Matched sellers in the homogeneous and differentiated scenarios could not communicate with each other, and a seller could not observe price offers or text messages exchanged between its matched buyer and the other seller. A seller who did not trade was informed only that the buyer traded with the other seller.

Unmatched subjects could not communicate with each other. Likewise, no subject received information about trading outcomes for other groups of subjects.

At the start of each phase, matched subjects learned the number of sellers and the surplus from trade with each seller. There was no time limit on negotiations, nor any mechanism by which a party could terminate the process without trading. Figure 1 shows a sample seller screen in the homogeneous scenario, with a formal price offer of \$2.34 from the buyer.

Figure 1. Sample Seller's Screen in the Homogeneous Scenario



4. Experimental Results

Our data consist of 90 outcomes from subject-matchings in our three scenarios: 30 baseline, 30 homogeneous, and 30 differentiated. We report our results as a series of three findings, beginning with behavior in the baseline scenario.

Finding 1: *Negotiated prices in the baseline scenario of bilateral negotiations are statistically indistinguishable from the predicted price of \$5.*

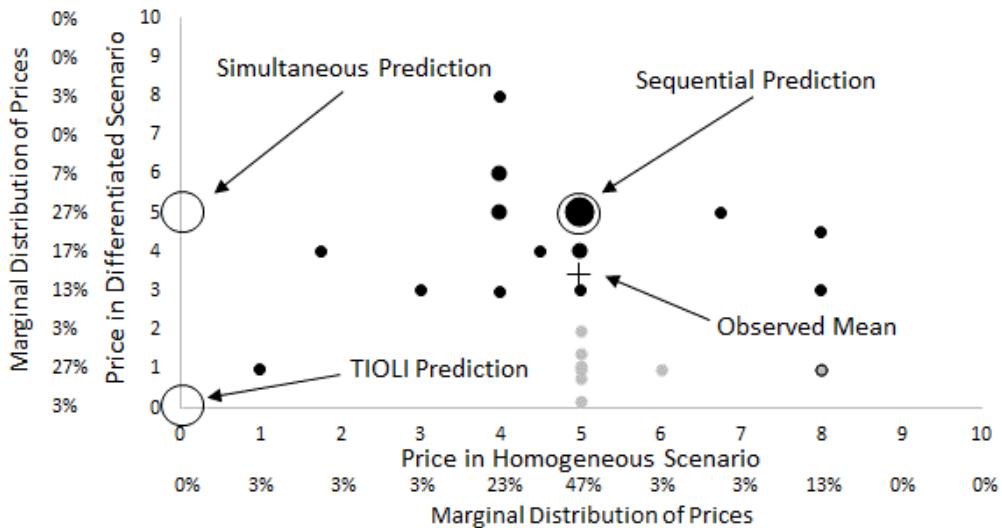
Evidence: In the 30 outcomes in the baseline scenario, the average transaction price is \$5.23 ($\hat{\sigma} = 1.48$), which is not statistically different from \$5 (t-statistic = 0.85, p-value = 0.401). ■

The similarity between the observed and predicted prices in bilateral negotiations implies there is no need to use observed outcomes to normalize behavior in the other scenarios.¹⁸ This result also supports our use of the modeling assumptions that subjects have identical discount rates and that the time between offers $\Delta \rightarrow 0$.

¹⁸ For example, if the price were \$8 in the baseline scenario, then observing prices of \$8 in the homogeneous and differentiated scenarios could be considered evidence in favor of the sequential model; that model predicts that adding a second seller does not affect price.

Turning to our primary goal of discriminating among the TIOLI, sequential, and simultaneous approaches, Figure 2 plots as ordered pairs each buyer's negotiated prices in the homogeneous and differentiated scenarios. We focus on buyers rather than sellers because each buyer trades in both scenarios, while each seller does not. Each marker's size indicates the frequency of a particular price-pair, the large open circles denote the predicted price-pairs for each modeling approach, and the cross hairs denote the observed means. Figure 2 also provides the marginal distribution of prices.¹⁹ The experimental data visually match best the sequential approach, a finding that we next establish statistically.

Figure 2. Observed Prices in Homogeneous and Differentiated Scenarios



Finding 2: *Negotiated prices in the homogeneous and differentiated scenarios are generally consistent with the sequential approach, but they are inconsistent with the TIOLI and simultaneous*

¹⁹ Prices could be negotiated in cents and subjects were paid to the penny. The marginal distributions presented in Figure 2 are constructed by rounding a price to the nearest whole dollar amount.

approaches. We conclude that the sequential approach has greater predictive power than do the TIOLI or simultaneous approaches.

Evidence: In the 30 outcomes in the homogeneous scenario, the average transaction price is \$4.97 ($\hat{\sigma} = 1.63$). Table 3 reports the results of hypothesis tests comparing observed prices in the homogeneous scenario to both a price of \$0 and a price of \$5. The average price is highly statistically different from \$0 (p-value < 0.001), but it is not statistically different from \$5 (p-value = 0.911).²⁰ Further, the observed data are 4.52×10^{15} times more likely to have been generated by a distribution with a mean of \$5 than with a mean of \$0.²¹ This pattern is consistent with the sequential approach, but it is inconsistent with the TIOLI or simultaneous approaches.

In the 30 outcomes in the differentiated scenario, the average transaction price is \$3.42, but this includes eight instances in which the buyer purchased from the low-surplus seller.²² These eight observations are shown in Figure 2 with light gray markers.²³ In the 22 outcomes in which the buyer traded with the high-surplus seller, the average transaction price is \$4.30 ($\hat{\sigma} = 1.58$). Table 3 reports the results of hypothesis tests comparing observed prices in the differentiated scenario to both a price of \$0 and a price of \$5. The average price is highly statistically different from \$0 (p-value < 0.001), but it is also statistically different from \$5 (p-value = 0.049). However, the observed data are 2.08×10^9 times more likely to have been generated by a distribution with a

²⁰ The power of both tests is close to 1 given the small sample-standard deviation under the assumption that the alternative hypothesis is that the mean price equals X when the null hypothesis is a mean price of 5-X. The same is true for the differentiated scenario.

²¹ This calculation is based on application of Baye's Law to the appropriate p-values.

²² Four of the eight buyers who purchased from the low-surplus seller in the differentiated scenario first participated in the homogeneous scenario. This pattern suggests it is unlikely that buyers purchased from the low-surplus seller due to a mistaken belief they could make two purchases in the differentiated scenario.

²³ The gray marker with a black border at (8,1) in Figure 2 reflects the fact that this outcome was observed once for a buyer who purchased from the low-surplus seller in the differentiated scenario and once by a buyer who purchased from the high-surplus seller in the differentiated scenario.

mean of \$5 than with a mean of \$0.²⁴ This pattern is somewhat consistent with the sequential and simultaneous approaches, but it is inconsistent with the TIOLI approach.

From the preceding results, we conclude that the sequential approach has greater predictive power than do the TIOLI or simultaneous approaches. ■

Table 3. Statistical Analysis of Prices in Homogeneous and Differentiated Scenarios

	Homogeneous Scenario	Differentiated Scenario
Average Observed Price	\$4.97	\$4.30
Standard Deviation of Observed Price	1.63	1.58
Number of Observations	30	22
t-test of H_0 : Average Price = \$5	p-value = 0.911	p-value = 0.049
t-test of H_0 : Average Price = \$0	p-value < 0.001	p-value < 0.001
Relative chance price is \$5 rather than \$0	4.52×10^{15}	2.08×10^9

The reported p-values are based on the two-sided test, and the relative chance is the ratio of the p-values. The results reported for the differentiated scenario exclude observations in which the buyer purchased from the low-surplus seller, but the results are qualitatively unchanged if all data are used; the relative chance that all observed data are generated by a distribution with a mean of \$5 rather than a mean of \$0 is 6.79×10^5 .

Our preceding analyses of each scenario's average transaction price ignores that buyers might vary substantially in their negotiating ability or in their degree of altruism or "fair-mindedness." We expect such personal characteristics to change the level of a particular buyer's negotiated prices, but not the difference in that buyer's negotiated prices across scenarios.

To control for price variation stemming from buyer-specific attributes, we leverage our experimental design's within-subject nature by assessing the difference in price that each buyer paid across scenarios. For example, if a buyer paid \$4.25 in the differentiated scenario and \$4.00 in the homogeneous scenario, then the price difference is \$0.25.

²⁴ This analysis ignores that negative prices were not allowed. Thus, errors could only be one-sided under the null hypothesis that the mean was \$0. However, the qualitative results would hold even if one makes allowances for this. For example, the data from the homogeneous and differentiated scenarios are 1.32×10^{10} and 1.72×10^7 times more likely to have been generated by a distribution with a mean of \$5 than with a mean of \$1.

Finding 3: *A particular buyer's negotiated price does not differ across scenarios, which implies its payoff is unaffected by a second seller's presence or type. This result is consistent with the sequential approach, but it is inconsistent with the TIOLI and simultaneous approaches.*

Evidence: Table 4 reports the observed and predicted price differences. It also reports the results of statistical comparisons based on paired sample t-tests, using the difference in price that a buyer paid in two scenarios as the unit of observation.

The average price change for a buyer going from the baseline scenario to the homogeneous scenario is \$0.264, from the baseline scenario to the differentiated scenario is \$0.728, and from the differentiated scenario to the homogeneous scenario is -\$0.477. Each change in price is not statistically different from \$0 (p-values = 0.422, 0.168, 0.365), but it is highly statistically different from \$5 (with each p-value < 0.001).

All three comparisons show no statistical evidence that a buyer's negotiated price changed based on the presence or type of a second seller. This result is predicted by the sequential approach, but it is not predicted by the TIOLI or simultaneous approaches. ■

Table 4. Within-Buyer Price Differences Across Scenarios: Observed and Predicted

	Baseline Price – Homogeneous Price	Baseline Price – Differentiated Price	Differentiated Price – Homogeneous Price
Observed Price Difference			
Average	\$0.264	\$0.728	-\$0.477
Standard Deviation	1.77	2.39	2.42
t-test of $H_0: \Delta\text{Price} = \0	p-value = 0.422	p-value = 0.168	p-value = 0.365
t-test of $H_0: \Delta\text{Price} = \5	p-value < 0.001	p-value < 0.001	p-value < 0.001
Predicted Price Difference			
TIOLI	\$5	\$5	\$0
Sequential	\$0	\$0	\$0
Simultaneous	\$5	\$0	\$5

The reported p-values are for paired t-tests of the null hypotheses based on a two-sided alternative. Comparisons involving the differentiated scenario only include buyers who purchased from the high-surplus seller.

5. Relationship to Existing Experimental Literature

A vast experimental literature explores many aspects of bargaining, and in what follows we compare our results to those from two sets of other experiments that assess the impact of introducing competition to bilateral settings.^{25,26} The first considers bilateral negotiations in which the buyer has an exogenously-specified outside option that might be viewed as the negotiated outcome with an un-modeled seller; the second considers multi-party negotiations involving identical sellers.

Our descriptions of these experiments emphasize the elements most relevant to ours, but at the outset it is worth mentioning two ways their designs differ from ours: each imposes rigidly structured negotiation protocols, and each imposes explicit discounting that shrinks the available surpluses across periods. Within these highly structured negotiating environments, the goal is to test whether subjects' behavior matches the equilibrium predictions associated with the experimental design. This approach contrasts with our use of unstructured negotiations to assess the predictive power of different approaches to modeling multilateral negotiations in practice. On a lesser note, the experiments use different naming conventions for the subjects' roles; to facilitate comparison with our results, we use "buyer" and "seller" to refer to subjects on what correspond to the "single-player" and "multi-player" sides of the negotiations.

²⁵ We would be remiss if we did not mention Thomas and Wilson (2002), who provided the first experimental analysis of multilateral negotiations. Like us they analyzed unstructured negotiations, but in settings in which sellers had private information about their costs. In a series of papers they compared the performance of multilateral negotiations and auctions, so their findings do not relate closely to ours.

²⁶ There also is experimental research that introduces additional proposers or responders to standard ultimatum games. Such papers tend to examine the extent to which subjects' concerns for fairness are affected by competition, and consequently their findings do not relate closely to ours. For example, see Roth, et al. (1991), Grosskopf (2003), Fischbacher, et al. (2009), and Cox (2013).

Bilateral Negotiations with Outside Options

Binmore, et al. (1989), Binmore, et al. (1991), and Kahn and Murnighan (1993) analyze infinite-horizon, alternating-offers bilateral negotiations in which the buyer can take up an exogenously-specified outside option. The size of the outside option is a treatment variable that is one of three types. Outside options of zero or well below half the surplus correspond respectively to our baseline and differentiated scenarios. Larger outside options strictly between half the surplus and the entire surplus correspond to what in our setting might be called a **mildly differentiated scenario**, in which a *medium-surplus seller* competes with a high-surplus seller.

Binmore, et al. (1989) compare the performance of two predictions in bilateral negotiations to split £7, in which the buyer can take up its outside option of £0, £2, or £4 only when responding to an offer. The first prediction is that the buyer obtains the greater of £3.5 and its outside option, which corresponds to the SPNE of the structured bargaining protocol from the authors' experiment. The second is that the players "split-the-difference" by equally sharing the surplus in excess of the buyer's outside option, which corresponds to the Nash bargaining solution that uses the outside options as the "disagreement point." The results support the SPNE prediction and strongly reject the Nash-bargaining prediction.

Binmore, et al. (1991) analyze bilateral negotiations to split £5, in which the buyer can voluntarily take up an outside option of £1.80 or £3.20.²⁷ The small outside option does not seem to affect the negotiated outcome: the buyer obtains half the surplus in $\sim\frac{1}{3}$ of the observations, and obtains varying amounts between half the surplus and the split-the-difference amount in the bulk of the remaining observations. However, the large outside option does affect the negotiated outcome: the buyer obtains an amount equal to its outside option in $\sim\frac{1}{3}$ of the observations, and

²⁷ The seller has an outside option of £0.20, but it is not varied and seems too small to noticeably impact the negotiated outcomes.

obtains varying amounts between its outside option and the split-the-difference amount in the bulk of the remaining observations.

Kahn and Murnighan (1993) analyze bilateral negotiations to split \$10, in which the buyer's outside option is \$1 or \$9 and other structural features are varied systematically. In the setting most relevant to ours,²⁸ the average buyer's payoff is ~\$4.25 when the outside option is \$1, and it is ~\$8.25 when the outside option is \$9. Thus, they find that the outside option does not matter when it is small, but does matter when it is large. While the buyer earns less than predicted, its observed payoff increases with its predicted payoff.

Our results are partially consistent with those in the preceding papers. The findings that small outside options do not affect outcomes are comparable to our finding that outcomes are the same in the baseline and differentiated scenarios. However, the findings that large outside options affect outcomes differ from our finding that outcomes are the same in the baseline and homogeneous scenarios.

The earlier papers' results align better with the predictions from the simultaneous approach than from the sequential approach, and the difference from our results might reflect the impact of how those experiments' design elements differ from ours: rigidly structured negotiations; explicit discounting; outside options that are exogenously-specified rather than determined by negotiating with another person; lack of communication between subjects; or having subjects switch roles or repeat the same negotiation situation. For example, compared to a fixed outside option, the buyers in our experiment might be unwilling or unable to fully extract the surplus available from trading with another person due to subjective costs of negotiating or concern for that person's welfare. Alternatively, the need to actively determine the outside option in our experiment might lead

²⁸ For the interested reader, that setting features a probability of termination of 0.05, a discount factor of 1, and the buyer's ability to voluntarily opt out.

subjects to view the multilateral negotiations in a piecemeal fashion, as a sequential process rather than a simultaneous one.

Structured Multilateral Negotiations with Identical Sellers

Charness, et al. (2007) and Dogan, et al. (2013) analyze finite-horizon, alternating-offers negotiations involving one or more identical buyers facing one or more identical sellers. Each considers a setting corresponding to our homogeneous scenario, with one buyer facing two identical sellers.

Charness, et al. (2007) analyze how negotiated outcomes vary in buyer/seller networks with different structures, in which each possible trade initially is worth 2500 and each player has an outside option worth 200. In multilateral negotiations with one buyer and two sellers, the buyer earns ~1500 but is predicted to earn 2300.

Dogan, et al. (2013) analyze 3-period bilateral and multilateral negotiations to split 240. Negotiations are preceded by each buyer/seller pair simultaneously deciding to form a costly communication-link, so the buyer might face one or both sellers. The cost of the links affects observed behavior, even though those costs are sunk when negotiations begin: a buyer facing one seller initially offers to pay ~100 with either costless or costly links, versus the predicted offer of 80; a buyer facing both sellers initially offers to pay ~80 with costless links and ~55 with costly links, versus the predicted offer of 0. The buyer offers to pay more than predicted when facing one or both sellers, and the effect is more pronounced when facing two sellers.

Once again our results are partially consistent with those in the preceding papers. Their findings that the buyer does not fully extract the surplus in multilateral negotiations are comparable to our finding in the homogeneous scenario. However, Dogan, et al. (2013) find that the buyer

does better in multilateral negotiations than in bilateral negotiations, while we find that the buyer's payoff does not differ across the homogeneous and baseline scenarios.²⁹

Differences in experimental design might explain why the results in Charness, et al. (2007) and Dogan, et al. (2013) fall somewhere between the predictions from the simultaneous and sequential approaches, while ours fit the sequential approach and the results in Binmore, et al. (1989), Binmore, et al. (1991), and Kahn and Murnighan (1993) align better with the simultaneous approach. For example, a rigid structure and a fixed outside option might push behavior toward outcomes predicted by the simultaneous approach, as observed by Binmore, et al. (1989), Binmore, et al. (1991), and Kahn and Murnighan (1993). Charness, et al. (2007) and Dogan, et al. (2013) retain the rigid structure but require actively determining the outside option by negotiating with another person. Their results fall between the simultaneous and sequential approaches. Finally, our experiment dispenses with the structured negotiations and requires the buyer to negotiate with a person to determine its outside option, with outcomes that match the predictions from the sequential approach.

6. Conclusion

We report the results of unstructured negotiations conducted in a laboratory experiment that lets us run a horse-race to assess the predictive power of three approaches to structurally modeling the multilateral negotiations observed in strategic settings such as procurement, takeover contests, high-end job markets, and large-scale investment. For concreteness we consider two sellers negotiating with a buyer who wants to make only one trade. Trade with each seller can yield either a high or a low surplus, and we specify the surplus amounts in different negotiating

²⁹ We cannot make this comparison with Charness, et al. (2007), because they do not examine bilateral negotiations.

scenarios so that the three modeling approaches have distinct combinations of predictions. At an intuitive level, we analyze negotiated outcomes when the two sellers are either very similar or very different, in terms of the surplus available from trading with each.

We find that introducing a competing seller does not affect the observed terms of trade, relative to a baseline scenario in which a buyer negotiates with a single high-surplus seller. This finding and the observed transaction prices are consistent with the sequential modeling approach associated with Ray (2007) and others, in which the buyer can negotiate with only one seller at a time. Our results are inconsistent with the approach in which the sellers compete simultaneously for the buyer's business, and with the approach that effectively lets the buyer make take-it-or-leave-it offers to the sellers. Consequently, this experiment supports using the sequential approach to model multilateral negotiations.

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8. Appendix: Experiment Materials

Instructions (read by subjects)

You are participating in a study on economic decision making. You will be paid based on your decisions, so it is important that you understand these directions completely. Please do not talk to or disrupt other participants during the study. If you have a question at any point, please raise your hand and someone will assist you.

What am I doing in this study?

There are 9 people in your session. Each person is permanently assigned the role of either a **Buyer** or a **Seller**. Your role appears in the middle of your screen and will not change during the study.

The study will last three periods. In each period each person will be assigned to one of multiple markets consisting of 1, 2, or 3 people. 2-person markets have one **Buyer** and one **Seller**. 3-person markets have two people in one role and one person in the other role. The matching of **Buyers** and **Sellers** into markets is done so *that no one is ever in a market with anyone twice*. That is, once you interact with someone, you will never interact with them again.

Each 2-person and 3-person market is a trading opportunity between people in different roles. Sellers' costs for their product are always \$0.00, but a Buyer's value for a product can differ from market to market and can differ between two sellers in the same market. Similarly, different Buyers can have different values for a particular Seller's product from market to market, or within a market. In each market, a Buyer's value for each Seller's product is shown on everyone's screen, so it is common information.

If you are assigned to a 1-person market, then in that period you have no trading opportunities.

There can be at most one trade in a market.

Once a Buyer trades with a Seller, the market ends **and no other trades can occur**. Once all markets in a period end, the study proceeds to the next period: Buyers and Sellers will be assigned to new markets, and Buyers' values for Sellers' products will be specified.

The price at which you trade affects your earnings from participating in this study.

If a Buyer and a Seller make a trade, then

$$\text{Seller's Profit} = \text{Price}$$

$$\text{Buyer's Profit} = \text{Value of Seller's Product} - \text{Price}$$

If a person **does not make a trade**, then that person's **Profit = 0**.

Your payment for the experiment is the sum of your earnings in the markets in which you participate. All values, costs, prices, and profits are in dollar amounts.

How is the price determined?

There is a negotiation area for each Buyer and Seller in a market, in which you can **chat** with other players with a different role than yours, **make** price offers to them, and **accept** price offers from them.

CHATTING: A Seller in a market can use the **Chat** feature to send a text message to a Buyer in their market, and vice versa. Messages cannot be sent between two people in the same role, nor can anyone view any message for which they were not the sender or the intended recipient. For example, a Seller cannot chat with another Seller, and a Seller cannot see a message a Buyer sent to another Seller.

Chat messages should not contain offensive language or personally identifying information. Anyone sending such messages will be dismissed from the experiment without payment.

MAKING A PRICE OFFER: You can propose a price by typing it into the box beside the **Offer** button in the appropriate negotiation area. Your offer must be between the Seller's cost of \$0.00 and the Buyer's value for that

Seller's product. The computer rejects offers outside this range or with more than 2 decimal places. If you make an offer that is accepted, then trade takes place at the offered price.

If you make an offer, the profit you will earn if it is accepted is displayed next to it. You can make a new offer at any time by typing it into the box beside the **Offer** button. Your new offer is not restricted by the amount of any earlier offer(s) you made. If you wish to withdraw an offer you already made, you can do so by pressing the **Withdraw** button. Note that if your current offer is accepted before you change it or withdraw it, then you are committed to trading at your current offer. Also, you do not have to withdraw your current offer before making a new offer; simply enter a new offer in the Offer box.

ACCEPTING A PRICE OFFER: If someone makes you a price offer, an **Accept** button appears next to it along with your profit from accepting the offer. Pressing **Accept** means that you agree to trade at the price the other person offered. Doing so causes the trade to occur, ends the market, and lets everyone's profit for the period be calculated.

Your screen will show you the number of Buyers and Sellers in your market (including yourself). If there is someone else in the same role as you, you cannot see the offers made between that person and the person in the other role, so “????” will be shown on your screen instead of that information.

Once you are done reading these directions, please press **Finished with Directions**.

Summary Announcements (read aloud by experimenter)

1. You will never be in a market with someone more than once.
2. Once one trade occurs in your market, there can be no other trades in your market.
3. All chat messages and offers are only observed by the person sending them and the one person on the other side of the market to whom they are sent.
4. Your payment will be the sum of your earnings from the up to three markets in which you will participate.