A Laboratory Study of Duopoly Price Competition with Patient Buyers

Timothy N. Cason
Department of Economics
Krannert School of Management
Purdue University
West Lafayette, IN  47907

and

Shakun D. Mago
Department of Economics
Robins School of Business
University of Richmond
Richmond, VA 23173

August 2011

Abstract: This paper reports a duopoly experiment in which sellers compete to sell to a potentially patient buyer. Each period sellers simultaneously post prices and the buyer costlessly observes either one or both prices. The buyer can then either accept an observed price or reject all offers. Following a rejection, sellers may have an opportunity to post prices again in another round. We study how the duopolists’ pricing behavior responds to changes in the likelihood of the buyer observing multiple prices, \( \gamma \), and the probability of continuing to another round, \( \delta \). The unique stationary equilibrium features mixed strategies. Consistent with the equilibrium, observed prices are decreasing in \( \gamma \) and \( \delta \). Contrary to the equilibrium, however, buyers sometimes reject profitable price offers, and average prices are lower than predicted when only one round of offers is possible and higher than predicted in the multiple-round game.

JEL Classification: D43, D83, L13

Keywords: posted offer, experiment, price dispersion, buyer behavior, durable goods

Acknowledgements: We thank University of Richmond for providing subject payments to conduct this experiment, and two anonymous referees and audiences at ESA and SEA conferences for valuable feedback. Justin Krieg and Jingjing Zhang provided excellent research assistance.
1. Introduction

Two extreme forms of pricing behavior – sometimes called the Bertrand Paradox and the Diamond Paradox – emerge from a single distinguishing assumption. Bertrand (1883) assumes that a buyer knows *ex ante* the prices of all sellers, and notes that with homogeneous goods a single competitive price emerges even amongst a small number of sellers because at any slightly higher price at least one seller can increase his profit by engaging in undercutting. In Diamond’s (1971) model, on the other hand, a buyer first chooses a seller and then receives the price quote *ex post*. Even with infinitesimal search cost, in equilibrium a buyer searches only one seller and all sellers charge the monopoly price. The only difference between the two formulations is whether sellers price *ex ante* or *ex post*.\(^1\) Intuitively however, there is no strong rationale for preferring either assumption for when price information is acquired. This is especially so since the ‘law of one price’ is known to fail, and persistent price dispersion is widely observed even in essentially homogenous goods markets (e.g. Brynjolfsson and Smith 2000, Sorensen 2000, and Baye, Morgan and Scholten 2004).

Most of the theoretical literature that models price dispersion has employed costly buyer search (e.g., Stigler 1961; Salop and Stiglitz 1977, 1982; Stahl 1989, 1996) or costly seller advertising (Butters 1977; Robert and Stahl, 1993) to generate dispersed prices.\(^2\) Gale (1988), on the other hand, models price dispersion in a rather stark form, using only two sellers and one buyer. This can provide a modeling foundation for some types of multilateral bargaining such as in concentrated intermediate goods markets. Sellers are uncertain whether the buyer is receiving price offers from both (*ex ante* pricing) or one (*ex post* pricing) of them at any given time. If the buyer’s sample contains both offers with a positive but not certain probability \(\gamma\), a unique dispersed price equilibrium exists that shifts systematically with \(\gamma\). Extending this static model to multi-round pricing with time discounting, Gale examines the impact of greater buyer patience—modeled as a higher discount factor—on the equilibrium price level and price dispersion. This is intended to approximate market conditions with many buyers where trade continues over time, as can occur also in durable goods settings. As buyers become more patient, sellers must compete

\(^1\) The fact that equilibrium outcome may change dramatically for apparently small changes in the extensive form of the games is well known (e.g. Fudenberg, Levine and Tirole 1985).
\(^2\) For example, Stahl (1989) assumes that if some buyers have zero search costs while others have positive search cost, then there is a unique symmetric Nash equilibrium price distribution that ranges from competitive pricing to monopoly pricing.
not only with the other seller but also with their own future price offers; consequently, the equilibrium price distribution becomes concentrated at lower prices.

This paper presents the first laboratory experiment that studies the interaction of buyer patience and search with multi-round pricing by competing sellers. Specifically, we focus on prices posted by competing sellers in a noisy search environment where buyers can wait for more price offers. This enables us to explore how the timing of buyer’s purchase decisions influences sellers’ pricing strategy, which is not captured by the stationary equilibrium of the theoretical model. The experiment includes both a static treatment, where agents have only one opportunity to trade each period, and a dynamic treatment where trading opportunities may continue for future rounds of price offers with a positive and known probability, $\delta$. One interpretation of these single-round trading and multiple-round trading treatments is that the former refers to a disposable goods and the latter to a durable goods environment. The model’s predictions that prices decrease if the buyer is more patient or is more likely to receive both price offers are intuitive, but the available evidence from previous durable goods and bargaining experiments provides only weak support for theory. Furthermore, implications of multiple price offers from competing sellers have never been studied previously in experiments with durable goods and multiple-round trading, which have focused on single seller environments. As discussed in the next section, results from multiple-round monopoly or bilateral bargaining experiments often fail even to support many of the comparative statics predictions.

Our results, by contrast, provide support for the Gale (1988) model’s comparative statics predictions. In particular, prices decrease as the likelihood of the buyer observing multiple prices ($\gamma$) increases and as the buyer’s patience level ($\delta$) increases. The former result is consistent with costly buyer search experiments where prices decrease as the sample size of seller price offers increases (Cason and Friedman, 2003). The decrease in prices as a result of buyer patience is in the spirit of Coase conjecture, since the inability of sellers to commit to price over time leads them to compete with themselves across rounds. Prices do not reach the extreme levels predicted for the highest $\gamma$ and $\delta$ treatment, however, indicating that the buyers in the experiment do not take full advantage of their market power. Average transaction prices are also lower than predicted when only one round of offers is possible, and higher than predicted in the multiple-round game. Furthermore, contrary to the stationary equilibrium, buyers sometimes reject profitable price offers.
Our experiment contributes to a line of research exploring buyers’ strategic behavior (e.g., Normann, Ruffle and Snyder, 2007). Posted-offer experiments overwhelmingly focus on seller pricing behavior, often controlling for potential influences of human buyers by replacing them with computer algorithms. These robot buyers are pre-programmed to search according to an equilibrium reservation price strategy; by contrast, human buyers’ expectations and behavior respond to observed non-equilibrium prices. In the present study we explore the counteracting role of this (human) buyer strategic behavior, which has explicit equilibrium implications for sellers’ pricing. Our results are consistent with previous studies which have concluded that the presence of human buyers has a disciplining effect on sellers’ pricing behavior (Davis and Williams, 1991; Ruffle, 2000; Cason and Friedman, 2003; Mago, 2010).

It is well established that in a single-round buyer-seller interaction, adding uncertainty regarding the sample size of price offers available to the buyer affects seller pricing (Burdett and Judd, 1983). When buyer-seller interaction can potentially extend to multiple rounds, however, the buyer’s ability to reject initial price offers also becomes important (Gale, 1988). In equilibrium, sellers offer prices that are attractive to buyers in the first round, so they will not have any incentive to defer purchase to later offer rounds. In practice, however, buyers may nevertheless reject profitable initial price offers in anticipation of lower future prices. Sellers may anticipate the strategic benefits of buyers’ ability to wait, and post lower initial prices to avoid demand withholding and induce buyers to purchase early. Yet another possibility is that multi-round pricing allows sellers to extract greater surplus from impatient or risk averse buyers (similar to the “buy it now” option available on eBay), lowering prices later for more price-sensitive buyers. Such pricing strategies arise in equilibrium in durable goods monopoly environments when the seller is perfectly informed about demand (Bagnoli et al., 1989). Our experiment explores how buyers time their purchases and sellers choose their prices to systematically influence the dynamics of transaction prices. These within-period dynamics are not captured by the stationary equilibrium of the theoretical model since in equilibrium all transactions occur in the first round. To the best of our knowledge, our experiment is the first to consider such temporal pricing predictions with competing sellers.

---

3 Engle-Warnick and Ruffle (2005) report that these forces emerge when even a monopolist seller is confronted with a small number of buyers. They refer to potential buyer withholding as the “buyer withholding hypothesis” and seller’s response to the implicit threat as the “cautious monopolist hypothesis”.

The remainder of the paper is organized as follows: Section 2 describes how both the static and dynamic versions of the model relate to some of the existing literature. Section 3 presents the model details and our testable hypotheses. Section 4 describes the experimental design and procedures. Section 5 presents the results and Section 6 concludes.

2. Related Literature

Gale’s static model can be viewed as a simplified version of Burdett and Judd’s (1983) noisy search model. In both models, the equilibrium price distribution is truly dispersed, i.e., it has a positive density over a non-trivial range of prices for most parameter values of the likelihood of the buyer observing multiple prices, but for extreme values the distribution degenerates into a unified competitive or a unified monopoly price. Cason and Friedman (2003) test Burdett and Judd model in a laboratory experiment, and similar to our study, observe that seller prices are decreasing in the probability that buyers observe more than one price offer. The main difference between the two studies lies in the mechanism that generates demand uncertainty. In Cason and Friedman, the driving force behind price dispersion is costly buyer search whereas in our setup, search is not costly but there is an exogenous likelihood that the buyer observes multiple prices.

Most of the theoretical and experimental work on buyer search features single round pricing. Another new feature of the present experiment is the dynamic aspect of multiple rounds of price offers in a noisy search environment. Our dynamic treatment draws on the literature on durable goods monopoly and sequential bargaining where the focus is on the implications of (potential) repeated purchase opportunities on market outcomes. Central to the durable goods framework is the Coase conjecture - if goods are durable, then in equilibrium the monopolist seller’s initial price offer falls as the discount factor rises and it converges to marginal cost as the discount factor approaches unity (Coase 1972, Stokey 1981, Gul, Sonnenschein and Wilson 1986). Laboratory studies that have examined equilibrium predictions of these models (e.g., Rapoport, Erev and Zwick 1995; Reynolds 2000; Cason and Sharma 2001) provide generally weak support for the Coase conjecture. With the exception of Cason and Sharma (2001), these studies find that initial price offers are higher for higher discount factors. In the present study we find that initial

---

4 This equilibrium result is sensitive to the underlying assumptions. Ausubel and Deneckere (1989) establish the existence of multiple equilibria when time horizon is infinite. Bagnoli, Salant and Swierzbinski (1989) show that when the seller has complete information about the valuations for a finite number of buyers, she can price discriminate over time.
price offers decrease as discount factor increases. This indicates that the threat of demand withholding (which increases the likelihood that other seller’s price is observed) further magnifies seller competition to induce lower prices. Thus, our results provide empirical evidence consistent with the spirit of the Coase conjecture in a competing seller environment.

We can also draw parallels between our study and the ultimatum game with proposer competition. For example, Abbink et al. (2000) consider a ‘competitive ultimatum game’: three proposers take turns to make an offer to split a surplus with a single responder. If the responder accepts the first offer, the game ends. Otherwise, the second proposer makes an offer; and in the third stage, the game resembles the standard ultimatum game. They find that competition pushes the first and second proposers to offer, on average, more than half the available surplus. Gneezy, Haruvy and Roth (2003) argue that proposer competition not only strengthens the bargaining position of the responder, but it also dilutes the notion of altruism and equity. The intuitive analog for our setup is that seller competition yields lower prices, especially if competition can extend over multiple rounds.

Our study is also related to bilateral bargaining models with complete- and incomplete-information. In his seminal article, Rubinstein (1982) assumes that time is divided into discrete periods and bargainers alternate in making offers and counteroffers. The incentive to agree to early offers arises from the opportunity cost of delay, such that the value of potential agreement shrinks according to a discount factor. In equilibrium, bargaining is resolved immediately with no delay at all. This result is similar to the equilibrium prediction in the present model that all transactions occur in the first round. Experimental studies in the Rubinstein complete information bargaining environment indicate that agents do respond to changes in bargaining power, such as those due to changes in the discount factor, but that their response is incomplete and splits of the bargaining surplus are biased towards equal earnings (Roth, 1995). This has been attributed to concerns about fairness of bargaining outcomes (e.g., Goeree and Holt, 2000). The present experiment features prices that bias exchange surplus towards equality, which could be due to similar preference considerations.

Bargaining models that incorporate incomplete information, on the other hand, formalize the notion that bargaining is a process of communication, and that communicating private

---

5 Also see, Güth, Marchand and Rulliere (1997) and Grosskopf (2003) for responder competition in ultimatum games.
information credibly via a sequence of offers and counteroffers can result in a delay in reaching the agreement (Kennan and Wilson, 1993). In our experiment, buyers may have individual reservation prices – price offers above this threshold are rejected – but this information is privately known and heterogeneous across buyers. This could arise, for example, from private information about buyers’ risk preferences or from social (“fairness”) preferences. The delay in accepting an offer (demand withholding) can therefore be interpreted as buyers’ communicating their private information to the sellers. Similarly, sellers’ private information regarding their social and risk preferences may also impact market outcomes. These concerns are, of course, outside the theoretical model which is based on the assumption of monetary payoff maximization.

3. Theoretical Model

Consider a homogenous goods market where two identical sellers compete to supply an indivisible unit of the good to a single buyer. The buyer’s maximum willingness to pay for the good is normalized to \( r = 1 \), while sellers’ marginal cost of production is normalized to zero. Both sellers simultaneously announce the price they offer for the good \( p_i \in [0,1] \) and the buyer receives a random sample of the sellers’ posted prices. The sample contains both prices with probability \( \gamma > 0 \) and one randomly selected price with probability \( 1 - \gamma \). When only one price is displayed, the probability that a particular seller’s price offer is displayed to the buyer is one-half. The sellers are uncertain whether the buyer is receiving offers from one or both of them in any given round. If the buyer sees one price, she can either accept the offer or refuse to trade. Similarly, if the buyer sees both prices, she can either accept one of the two offers or refuse to trade. The payoff of the successful seller is the traded price \( p \), the buyer’s payoff is \( 1 - p \) and the other seller receives a payoff of zero.

The concept of equilibrium we employ is that of subgame perfect Nash equilibrium. Gale (1988) show that there exists a unique mixed strategy Nash equilibrium given by the price distribution \( F(\cdot) \), which is also symmetric i.e. \( F_1 = F_2 \).

**Theorem 1** (Gale, 1988). *There exists a unique symmetric mixed strategy equilibrium in which each seller chooses a price randomly from the distribution*

\[
F(p) = 1 - \frac{1}{2} \left( \frac{1-p}{p} \right) \left( \frac{1-\gamma}{\gamma} \right)
\]
where the lower bound of the distribution is given by \( p_l = \frac{1-\gamma}{1+\gamma} \) and the maximum price is the buyer’s reservation price \( r = 1 \).

Note that as \( \gamma \to 1 \), that is, as the probability that the buyer sees both prices increases, the equilibrium price distribution converges to the perfectly competitive price of \( \{0\} \). Likewise, as \( \gamma \to 0 \), that is, as the probability that the buyer sees only one price increases, the equilibrium price distribution converges to the monopoly price of \( \{1\} \).

This simple game is somewhat unrealistic because of its one-shot nature. For instance, if the buyer sees the price of only one seller, she does not get an opportunity to visit the other seller. Furthermore, if the buyer refuses the seller offer(s) the entire surplus is lost and no opportunity exists for additional price offers. To address this, Gale also considers a dynamic version where time is divided into discrete rounds \( (t = 1, 2, 3 \ldots) \). At \( t = 1 \), both sellers set their prices. As before, with probability \( \gamma > 0 \) buyer sees prices posted by both sellers and with probability \( 1 - \gamma \) buyer sees only one randomly selected price. If the buyer accepts a price offer, the game ends. But if buyer refuses the offer(s), then with a continuation probability \( 0 \leq \delta < 1 \) sellers have another opportunity to post prices. That is, for any round \( t > 1 \) the game proceeds to round \( t + 1 \) with probability \( \delta \). In the next round, both sellers again set their prices while the buyer sees one or both price offer(s). The game proceeds in this manner until the buyer accepts an offer. The likelihood of the buyer seeing one or both prices in round \( t \) is stochastically independent from the same likelihood in round \( t + 1 \). There is no additional source of discounting future payoffs. In each round sellers only know their own posted price, their individual pricing history and whether or not trade has occurred. A seller does not learn the pricing history of the other seller. Similarly, the buyer can only recall the previously observed prices and does not observe the sellers’ complete pricing history.

As is common in the literature, we can interpret the above model to be one in which payoffs of all players shrinks according to a commonly known discount factor, \( \delta \), and the game proceeds to the next round with probability one. This interpretation of the continuation probability as the discount factor implies that if a buyer accepts an offer \( p \) at time round \( t \) then her payoff is \( \delta^t(1-p) \), the payoff of the successful seller is \( \delta^t p \) while the other seller receives zero. As before, if the buyer does not accept any price offer, all agents receive zero. Gale (1988) proves

---

6 Abrams, Sefton and Yavas (2000) and Gale (1988) refer to these boundary cases as the Bertrand paradox \( (\gamma = 1) \) and the Diamond paradox \( (\gamma = 0) \).
the following result.

**Theorem 2** (Gale, 1988). There exists a unique symmetric mixed strategy stationary equilibrium in which buyer makes the purchase in round 1 and sellers set price according to the following distribution function:

\[ F(p) = 1 - \frac{1}{2} \left( \frac{1 - \gamma}{\gamma} \right) \left( \frac{1 - \delta \nu - p}{p} \right) \]

where the lower bound of the price distribution is given by \( p_l = \frac{(1 - \gamma)(1 - \delta \nu)}{1 + \gamma} \) and the upper bound of the price distribution is given by \( (1 - \delta \nu) \). The buyer’s equilibrium payoff is denoted by \( \nu \) and is given by \( \nu = \frac{(1 - k)}{(1 - \delta k)} \) where \( k = (1 - \gamma) \left[ \frac{1}{2} + \frac{1}{2} \left( \frac{1 - \gamma}{2\gamma} \right) \ln \frac{1 + \gamma}{1 - \gamma} \right] \).

The equilibrium price distribution in the dynamic version of the game (Theorem 2) is similar to the equilibrium price distribution in the one-shot version (Theorem 1), with the exception that the maximum reservation price is \( (1 - \delta \nu) \) in the case of time discounting rather than 1. The analysis concerning the limiting case of \( \gamma \), the probability of observing both price offers, is also similar to the one-shot version. More specifically, for a given value of \( \delta \), the buyer’s payoff, \( \nu \), is monotonically increasing in \( \gamma \). Thus, as \( \gamma \to 1 \), the equilibrium price distribution converges to the competitive price of \( \{0\} \).

\[ \lim_{\gamma \to 1} k = 0 \Rightarrow \lim_{\gamma \to 1} \nu = 1 \Rightarrow \lim_{\gamma \to 1} F(p) \to \{0\} \]

Conversely, as \( \gamma \to 0 \), the equilibrium price distribution converges to the monopoly price of \( \{1\} \) and the buyer’s payoff decreases to zero.

Another important comparative static result concerns \( \delta \), the discount factor or the continuation probability. For any fixed value of \( \gamma \) (or equivalently, for any fixed value of \( k \)),

\[ \lim_{\delta \to 1} \nu = 1 \quad \text{and} \quad \lim_{\delta \to 0} \nu = (1 - k) \]

This implies that irrespective of the probability of observing both prices, as the continuation probability increases, the equilibrium price distribution converges to the competitive price of \( \{0\} \) and buyer’s payoff converges to the maximum possible surplus of 1. In other words, when the buyer can wait indefinitely for a better offer, sellers lose their bargaining power and competitive forces drive the equilibrium price to zero. Thus, the interplay of buyer’s patience and its impact on sellers’ strategy leads to a more competitive pricing structure. Note that although this result is similar to Coase conjecture in spirit, where buyer patience also leads to competitive prices even
under a monopoly market structure, the underlying cause differs in the two settings. Specifically, to obtain competitive equilibrium prices as $\delta \to 1$, the Coase conjecture requires that at least some buyers place a very low valuation on the good.

Finally, note that the buyer’s threat to wait is not credible, and in the subgame perfect equilibrium she buys in the first round. Thus, buyer’s bargaining position cannot be solely attributed to the discount factor or her patience level. As Gale (1988, pg. 736) notes, “the role of the patient buyer is simply to rob the sellers of the minimal degree of uncertainty about prices that is necessary to prevent them from engaging in cutthroat competition.”\footnote{Rapoport, Erev and Zwick (1995) study a multiperiod bargaining negotiation between a buyer and a single seller where buyer’s valuation is not commonly known. They also find that in the equilibrium, the seller’s bargaining power is eroded if buyer has the option to pass and is patient.} As mentioned at the end of the introduction, however, the complete information environment that leads to the first-round purchases may not hold with human traders who have private information about their own risk and social preferences. Moreover, first-round purchases may not occur in nonstationary equilibria, which are intractable in this environment. These considerations provide further motivation for gathering empirical evidence through this experiment.

Table 1 summarizes the parameter values used in the experiment and the theoretical predictions for the stationary equilibrium in the various treatments. Figure 1 illustrates the equilibrium price distribution for the chosen parameters. We shall compare our laboratory market outcomes to the quantitative predictions shown in the table, but based on the previous experimental results we do not expect strong, quantitative predictions to hold very precisely. Therefore our analysis will focus on the comparative statics predictions summarized by the following hypotheses.

**Hypothesis 1:** An increase in the probability of observing prices of both sellers, $\gamma$ results in lower prices.

**Hypothesis 2:** An increase in the continuation probability, $\delta$ results in lower prices.

### 4. Experimental Design and Procedures

#### 4.1 Experimental Design

Each market comprises 2 sellers and 1 buyer. We employ the standard posted offer institution to focus on price competition. The experiment employs a $2\times2$ design with two treatment
variables – probability of the buyer observing price offers from both sellers (γ) and continuation probability (δ). We vary the continuation probability within sessions and the probability of observing multiple prices across sessions. Table 2 presents the experimental design. In sessions referred to as “High-Low,” sellers face a high continuation probability (δ = 0.9) in the first 30 periods, and a low continuation probability (δ = 0) in the next 30 periods. To control for order effects, this order is reversed in the four “Low-High” sessions. The probability of buyer observing both offers is varied at 2 levels: γ = 0.67 and γ = 0.33. Our design identifies the effect of a change in γ through across-session comparisons and the effect of a change in δ through within-session comparisons. As is common in the literature on duopoly experiments, to limit repeated game effects and to reduce the incentives for collusive behavior, we randomly re-match subjects into new markets each period.

Note that δ = 0 represents the static game where agents have only one opportunity to trade. The treatment with δ = 0.9, on the other hand, represents the dynamic game where it is not necessary to trade immediately. Our choice of δ = 0.9 was motivated by two considerations. First, it has been widely employed in prior literature on buyer-seller negotiations and sequential bargaining (for e.g., Rapoport, Erev and Zwick 1995, Cason and Sharma 2001, Srivastava 2001). Second, it provides a benchmark for an extreme case of buyer patience. For a given γ, the expected range of posted prices does not overlap when δ = 0 compared to when δ = 0.9 (cf Figure 1).

4.2 Experimental Procedures

We report results from eight experimental sessions conducted at the Vernon Smith Experimental Economics Laboratory at Purdue University. The experiment was programmed and conducted with the software z-Tree (Fischbacher, 2007). A total of 96 subjects participated in the experiment, all of whom were recruited by e-mail from the undergraduate student population. No subject participated in more than one session, although some had participated in other economics experiments that were unrelated to this research. Upon arrival, subjects were seated randomly at visually-isolated computers. Each received a set of written instructions and record sheets (included in the Appendix). Instructions were read aloud at the beginning of the experimental

---

8 Patience is an attribute that is inherent to each individual subject and cannot be exogenously imposed. We use the term “buyer patience” for δ=0.9 treatment following similar usage by Gale (1988).
session, and new instructions pertaining to the second treatment were read at the beginning of the second sequence. Since these instructions were read aloud, we assume that the information they contain was common knowledge. Throughout the session no communication between subjects was permitted and all choices and information were transmitted via the computers. At the end of the session, subjects were paid in cash by converting their total profits from experimental dollars into US dollars at a privately known fixed rate. This conversion rate differed for buyers and sellers. Sessions lasted about 105 minutes and subject payments averaged about $25 each.

The 12 subjects in each session were divided into 4 markets, with two sellers and one buyer in each market. The subjects were randomly assigned the role of either a buyer or a seller and their role remain unchanged for the entire session. The random matching process involved both types of agents; i.e., in each period there was a new random allocation of buyers and sellers to each market. Both sellers had the same homogenous good whose cost of production was normalized to zero. The buyer demanded at most one unit, and received a resale value of 100 experimental dollars if they purchased this unit. In all treatments, sellers were not allowed to post a price above this commonly known reservation price. To bring the laboratory environment closer to its field counterpart and to the theoretical model with continuous prices, we allow for a fine grid of prices (i.e., prices up to 2 decimal points).

Each session proceeded through a sequence of 60 trading periods. In the $\delta = 0.9$ treatment a period could last multiple rounds and was terminated if either (a) buyer accepts a price offer or (b) period was terminated randomly using a die roll. To implement our continuation probability, at the end of every round if the buyer refused to purchase at the offered price(s), the computer threw a “virtual” 10-sided die. If the outcome of the die roll was a 10, then the period ended immediately; otherwise the period continued to an additional round of seller price offers within the same period.

In every round both sellers post a price. With a pre-determined probability known to all subjects ($\gamma = 0.33$ and $\gamma = 0.67$) the buyer sees either one or both price offers. Each seller’s price is equally likely to be displayed to the buyer. The buyer then makes the “accept” or “reject” purchase decision. To be consistent with the theory, at the end of each trading round, sellers receive individual feedback on their market - their own price, their profit and whether buyer accepted any price offer. They do not learn the price of the other seller. Similarly, buyer’s information is limited to the observed price offers and their profit from the transaction. At the
end of each period, however, agents learn prices offered by both sellers in all rounds of the current period and also which price(s) the buyer observed in each round. Subjects are then randomly re-matched for the next period.

5. Results

We divide the results into four subsections. Section 5.1 presents a summary of the transaction prices. Section 5.2 reports the tests of the comparative static predictions and compares prices to the equilibrium distribution. Sections 5.3 and 5.4 examine the buyer purchase behavior and seller pricing behavior, respectively.

5.1 Overview

We have a panel dataset of price and purchase decisions made by 96 subjects across 60 periods for 8 independent sessions. Table 3 reports the median and mean transaction prices for each session. In all sessions, aggregate price behavior exhibits the predicted pattern and appears to conform to the model’s comparative statics predictions. Overall, prices tend to be lower than predicted when buyers and sellers have only one opportunity to make a transaction ($\delta = 0$) and higher than predicted when a period may last multiple rounds ($\delta = 0.9$). The fact that prices in move in accordance to the directional prediction of the model is also illustrated in Figures 2-5. These figures present the time series of median transaction prices in each session for different $\gamma$ and $\delta$ combinations.

The fact that prices are not as extreme as predicted by the theory indicates that neither the buyers or sellers took full advantage of their market power. There seems to be no hysteresis effect arising from the conditions of the previous treatment/sequence ordering, but the time trend for these prices is fairly substantial.\(^9\) With the exception of the $\delta = 0$, $\gamma = 0.33$ treatment, prices tend to decline over time as is commonly observed in other posted offer experiments. We are interested in testing equilibrium predictions, so in the formal hypothesis tests below we exclude the first 15 periods of each treatment run, since in these periods subjects are learning about the

\(^9\) This time trend is clearly inconsistent with the mixed strategy equilibrium prediction of i.i.d price draws each period. Prices exhibit too much intertemporal and cross-sectional correlation, which is documented in related (static pricing) environments in Cason and Friedman (2003) and Cason, Friedman and Wagener (2005), so we do not pursue it further here.
market and the incentives they face. We therefore employ 30 out of 60 total periods for these tests: periods 16-30 (sequence 1) and periods 46-60 (sequence 2).

5.2 Comparative Statics and Equilibrium Comparison

**Result 1:** Median and mean transaction prices decrease as the probability of observing both prices increases (support for Hypothesis 1).

**Support:** Table 3 reports the summary statistics for each session. When \( \delta = 0 \), shown in the left half of the table, the highest session mean transaction price when \( \gamma = 0.67 \) (19.66) is lower than the lowest session mean transaction price when \( \gamma = 0.33 \) (26.73). Consequently, a conservative non-parametric Mann-Whitney test \((n = m = 4)\) based on one observation from each of these 8 statistically independent sessions rejects the null hypothesis that probability of observing multiple price offers does not affect seller pricing behavior (p-value = 0.02). A similar conclusion holds for the median (instead of mean) transaction price.

When \( \delta = 0.9 \), shown in the right half of Table 3, there is a slight overlap in the distributions of the transaction prices, but independent across-session comparisons using the Mann-Whitney test still rejects the null hypothesis of no treatment effect in favor of the alternative hypothesis that an increase in the probability of observing prices of both sellers results in lower prices at the 5-percent significance level.

In addition to these simple unconditional nonparametric tests, we can make statistical inferences using panel data econometric methods that model the correlation of observations (and errors) due to the repeated measures drawn from the same set of subjects. These multivariate random effects regression models include clustering on sessions, order dummies to capture the sequence ordering effects, and 1/period to capture the time trend. Thus, for a given continuation probability \( \delta \), the subject level random effect regression equation is

\[
p_{i,t} = \alpha + \beta_i D + \beta_s (1/t) + \lambda s + \epsilon_{i,t}
\]

where

- \( p_{i,t} \) is subject i's price in period t
- \( D = 1 \) if probability of seeing multiple prices is higher (\( \gamma = 0.67 \))
- \( s \) is an sequence order dummy
- \( \epsilon_{i,t} \) is the composite error term.
The detailed regression results are omitted to save space and because they provide conclusions analogous to the non-parametric results: the null hypothesis that prices are the same across different $\gamma$ treatments is rejected at any conventional level of significance. Prices are lower when the probability of buyer seeing multiple price offers is higher, both for $\delta = 0$ (t-statistic = -2.91, p-value <0.01) and for $\delta = 0.9$ (t-statistic = -2.62, p-value <0.01).

**Result 2**: Median and mean transaction prices decrease as the continuation probability increases (support for Hypothesis 2).

**Support**: Our design varied the continuation probability within sessions. Since subjects made decisions under both $\delta = 0$ and $\delta = 0.9$ treatments in each session, with the treatment order varied, we can construct statistically independent pairwise differences for each session to conduct conservative non-parametric sign tests and signed rank tests. For example, in session 1, the mean price when $\delta = 0$ is 18.21 and when $\delta = 0.9$ is 9.25 (Table 1), and so the difference of 8.96 is one of the four pairwise differences when $\gamma = 0.67$. Since all four pairwise differences are positive for both values of $\gamma$, sign tests reject the null hypothesis of no continuation probability treatment effect (one-tailed p-value=0.03). Pooling observations in the two $\gamma$ treatments increases the sample size to 8, which is sufficient to conduct a nonparametric Wilcoxon signed rank test. The 8 positive differences for each price summary statistic leads to a test statistic value of 2.52, which is significant at the 1-percent level. Finally, random effects regression models similar to those described above also support the conclusion that prices are lower when the period can last multiple rounds, both for $\gamma = 0.67$ (t-statistic = -6.51, p-value < 0.01) and for $\gamma = 0.33$ (t-statistic = -2.70, p-value <0.01).

**Result 3**: Prices are lower than predicted when traders have only one opportunity to make a transaction ($\delta = 0$), and higher than predicted when a period may last multiple rounds ($\delta = 0.9$).

**Support**: The model predicts price dispersion as the outcome of a mixed strategy equilibrium. To compare prices to this equilibrium, we construct an empirical price distribution using aggregate data (across sessions, within a treatment) for the late 15 periods. Figures 6 and 7 illustrate the theoretical and the empirical cumulative price distributions for both levels of continuation probability. In both cases the changes in the distribution are in the directions predicted by the
theoretical model. However, when $\delta = 0$ (Figure 6) the equilibrium price distribution first order stochastically dominates the empirical distribution, with mean prices of 18.66 vs. 23.1 in the $\gamma = 0.67$ treatment and 44.23 vs. 56.8 in the $\gamma = 0.33$ treatment. The lower bound of the empirical distribution is also far below that predicted by the model. Conversely, observed transaction prices tend to be higher than predicted when the continuation probability is high, as shown in Figure 7, with mean prices of 11.25 vs. 2.9 in the $\gamma = 0.67$ treatment and 20.33 vs. 11.6 in the $\gamma = 0.33$ treatment.

The result that prices in either $\delta$ treatment do not reach the extreme levels predicted suggests that both buyers and sellers in the experiment do not take full advantage of their market power. One limiting factor may be fairness considerations. In the $\delta=0$ treatment, if the seller foresees that the buyer is willing to reject an “unfair” offer even if this demand withholding means a payoff of zero, then the seller may decrease price in order to ensure a sale. This is analogous to proposers’ fear of rejection in ultimatum bargaining experiments, which can cause offers to deviate from equilibrium predictions (Camerer, 2003, ch. 2). On the other hand, in the $\delta = 0.9$ treatment if the buyer is more likely to accept a more egalitarian split of surplus immediately, as also suggested by previous ultimatum bargaining experiments, then it is plausible for the seller to make a sale at a higher price despite competition. This also avoids the unfair outcome of a highly asymmetric distribution of exchange surplus.

Deviations from the equilibrium predictions could also be due to violations of the model’s assumption of risk neutrality. If subjects are risk averse, as is often observed in experiments, prices may deviate from the risk-neutral prediction, but the direction of this deviation could depend on how such risk attitudes are modeled. It is well documented that risk averse buyers tend to be less price sensitive in search environments; i.e., they settle for higher prices and are willing to accept some prices rejected by risk neutral buyers in the same situation (Schotter and Braunstein, 1981). Risk averse sellers, by contrast, might engage in price-cutting to increase the likelihood of a sale compared to risk neutral sellers. Modeling the interaction of risk averse buyers and sellers for this market setting is a complex and open problem, and it is unclear which of these effects dominates theoretically.

Finally, our result that seller competition may not always lead to extreme prices predicted by the theory is consistent with previous literature, both experimental and theoretical. For instance, Bayer (2010) investigates the impact of competition on markets for non-durable goods
and finds that increased seller competition reduces prices, but by far less than predicted. Abrams et al. (2000) study a posted offer market with costly buyer search and find that prices are closer to the midpoint than to either the Bertrand or the Diamond extreme. In a durable goods model, Sobel (1984) shows that high prices with periodical discounts can be sustained as an equilibrium pricing strategy even in the presence of competing sellers.

5.3 Buyer Purchase Behavior

When a period lasts only one round (δ = 0), demand withholding is not a rational strategy for any buyer.\(^{10}\) Accordingly, we find only seven instances of demand withholding across 480 buyer purchase decisions (1.5 percent) when buyers observe prices of both sellers with probability γ = 0.67. However, when the buyer is less likely to see both price offers (i.e., γ = 0.33), no-trade occurs significantly more often, about 7.3 percent of the time.\(^{11}\)

The more interesting case is when a period may last for multiple rounds (δ = 0.9). In equilibrium, a buyer cannot credibly threaten to wait and should purchase in round 1. Off-equilibrium, however, a buyer who has the option to defer purchase until later may wait for better price offers even though the current offer(s) yield positive payoff. Figure 8 shows that in the δ = 0.9 sessions, on average, more than 30 percent of the transactions occur in later rounds, with little difference across the two γ treatments. However, despite deferring purchase to later rounds, nearly all exchanges eventually do occur in the δ = 0.9 treatment. No-trade occurs 5 percent of the time in γ = 0.33 treatment and 3.54 percent of the time in γ = 0.67 treatment, leading to overall efficiency that is similar to the δ = 0 treatment.

To explore buyer purchase behavior more systematically we use panel data econometric models with subject level error clustering. Table 4 reports the marginal effects of probit models for purchase decisions in round 1 by all buyers. The likelihood of purchasing in round 1 is higher when a buyer observes both price offers or when the (minimum) observed price is lower. Accounting for past experience (column 2) indicates that buyers who made their purchase early in the previous period are more likely to accept price offers in round 1, and the likelihood of

\(^{10}\) Rejection of a price offer that would provide the buyer a positive payoff is termed ‘demand withholding.’ Brown-Kruse (1991) and Reynolds (2000) report examples of demand withholding in contestable and posted offer markets, respectively.

\(^{11}\) Conservative non-parametric Mann-Whitney test rejects the null hypothesis that the rate of demand withholding is the same across the two γ treatments (p-value = 0.03). Panel data probit models that control for time trend and order fixed effects also support this conclusion (p-value = 0.04).
making a round 1 purchase in the current period is increasing in transaction price paid in the previous period. Consistent with Figure 8, we find that the probability of purchasing in round 1 does not depend on the probability of observing one or both prices ($\gamma$).  

Most of these results also hold when focusing exclusively on buyers who exhibit demand withholding. We define a buyer to be a ‘withholding’ buyer if she refuses round 1 price offers at least 33 percent of the time—that is, at least 5 times in the final 15 periods. Table 4 reports a sole exception is that these buyers are less likely to purchase in round 1 in the treatment with a higher likelihood of receiving two price offers ($\gamma=0.67$). Similar behavior for the withholding and non-withholding buyers may be one reason why demand withholding does not increase buyer profit. We find no difference between the profits earned by withholding buyers and by those who more frequently accept the initial price offers (p-value = 0.9).

Recall that in equilibrium, the buyer’s threat to defer purchase is not credible, and price offers made in round 1 are always accepted. The predictive power of theory, however, is based on a number of strong assumptions that may not hold in practice. For instance, buyers in the experiment may hold imprecise beliefs because they face an endogenous price distribution that is both unknown and unstable. Evaluating buyer behavior is complicated further by the obvious seller deviations from equilibrium documented above. An assessment of the optimality of buyer purchase behavior should therefore account for the actual price draws the buyer can receive. Since more than 85 percent of the transactions occurred in the first 2 rounds (cf. Figure 8), we restrict our analysis to actual price draws a buyer could have received in rounds 1 and 2. We assess the optimality of buyer’s purchase strategy by employing the following rule: rejecting the initial price offer is regarded as optimal if the expected benefit from delay (expected decrease in price from deferring purchase to round 2) exceeds the cost of delay (expected profit from accepting price offer in round 1×$(1-\delta)$). To model buyers’ price expectations and account for evolution of prices over time, we assume that they have adaptive expectations and approximate the expected price in rounds 1 and 2 on an historical three-period moving average.

---

12 In an unreported alternative specification, we added an interaction term between the $\gamma$ treatment indicator and the indicator for when both prices are observed, in an attempt to identify which treatment is responsible for the significant impact of the buyer observing both prices. This interaction term was never even close to significant. Including the interaction term does not substantially change the other parameter estimates, but it does increase some of the standard errors and consequently some coefficients become significant at the 5% or 10% level rather than the 1% or 5% level in the reported specification.

13 According to this definition, 34.4 percent of the buyers can be classified as ‘withholding.’
Next, we compare actual purchase decision in round 1 to the (approximately) optimal rule. When buyers purchase decision is not optimal, it is useful to divide their mistakes into 2 types of errors: Type 1 error (Buyers did not reject the initial offer when they should have; i.e., expected decrease in price in round 2 is more than the cost of delay) and Type 2 error (Buyers rejected the initial offer when they should have purchased in round 1; i.e., expected decrease in price in round 2 is less than the cost of delay). Table 5 presents the optimal purchase comparisons for decisions made in round 1 of each period. For both \( \gamma \) treatments, more than 70 percent of the purchase decisions are optimal. Errors that occur more commonly take the form of Type 1 error rather than Type 2 error. This bias towards accepting the initial offers too quickly may stem from risk aversion among buyers.

5.4 Seller Pricing Behavior

When agents have only one opportunity to trade (\( \delta = 0 \)), buyers do not have the strategic incentive to withhold demand. Therefore, analysis of the prices posted by sellers closely mirrors the transaction prices analysis documented in Section 5.2. In particular, random effects regression results show that sellers respond predictably to an increase in the likelihood of buyer receiving multiple price offers - by lowering their price offers (t-statistic = -2.79, p-value < 0.01).

The more interesting case is when additional purchase opportunities may be available to the buyer (\( \delta = 0.9 \)). To begin with, it is important to understand the impact that potential demand withholding has on the initial price offers made by the sellers, as this likely determines the buyer purchase decision as well as the path of subsequent offers. Comparing across the two \( \delta \) treatments, regression results show that initial price offers made by the sellers are lower when the probability of continuation is higher, both for \( \gamma = 0.33 \) (t-statistic = -2.48, one-tailed p-value < 0.01) and for \( \gamma = 0.67 \) (t-statistic = -1.76, one-tailed p-value = 0.04). This suggests that sellers account for buyers’ strategic ability to withhold demand and accordingly post lower initial prices to induce them to purchase early. Despite these lower prices however, demand withholding is observed more than 30 percent of the time across all 30 periods, as documented in the previous subsection. This raises the natural question: How do seller price offers vary across different rounds in a period? And how do sellers in this multi-round pricing game respond to a rejection by the buyer? Recall that the stationary equilibrium provides no predictions about seller pricing behavior over multiple rounds since all transactions should occur in the first round.
Tables 6A and 6B present the mean and median posted prices in each of the first three trading rounds for $\delta = 0.67$ and $\delta = 0.33$, respectively. The columns of the table correspond to the round in which buyer made the purchase, and the rows summarize the seller price offers in a given round. For instance, column 3 of Table 6A indicates that when the transaction occurs in round 2, the median prices posted by the sellers in rounds 1 and 2 are 18 and 13.74 respectively. These prices illustrate the general tendency for price offers to fall as the period progresses over multiple rounds. Random effect regressions that include clustering on sessions, time trend and order fixed effects provide statistical support for this observation (for 1/round: t-statistic = 3.7 and p-value < 0.01). Also note that the average price offer in round 1 increases for periods in which the transaction occurs in a later round, indicating that buyers are rejecting higher offers and are accepting lower offers in round 1. In general, these patterns of posted prices suggest that some sellers used the multiple rounds of price offers to extract greater surplus from impatient or risk averse buyers. However, random effect regressions analyzing individual seller profit (not shown) show that these attempts at discrimination are largely unsuccessful.

Figures 9 and 10 summarize all individual price offers for sessions with positive probability of continuation. The solid diamonds represent posted prices that result in a transaction and the open diamonds represent unaccepted price offers. The perfectly horizontal lines display the theoretical price predictions, with the equilibrium maximum price the higher solid line and the equilibrium minimum price the lower solid line. The figures also show the median transaction price for each period. For both $\gamma = 0.33$ and $\gamma = 0.67$, the distribution of accepted and unsold price offers seems to oversample higher prices, often beyond the equilibrium range. The unaccepted price offers tend to be higher than the accepted price offers, of course, but the proportion of unsold offers declines over time as posted (and transaction) prices decrease and buyers make their purchase in round 1.

6. Conclusion

Theoretical research has shown that equilibria in oligopoly pricing games are sensitive to subtle information conditions, the timing of moves, and the patience of buyers and sellers. Gale (1988) provides a simple and elegant model that captures the interplay between buyers’ patience to wait for additional price offers and sellers’ beliefs about how many offers the buyers observe in different rounds. These factors determine how closely the unique mixed strategy pricing
equilibrium approximates competitive (Bertrand) or monopoly (Diamond) levels. This approach is insightful because it provides a modeling foundation for the multilateral bargaining process that can occur in concentrated intermediate goods markets common in industrial procurement, contracting services, and many other markets. The multiple rounds of price offers in Gale’s model also can be interpreted as durable goods oligopoly competition. The model provides an equilibrium explanation for persistent price dispersion observed in relatively homogenous product markets, which could arise in part from strategic buyer behavior. Even in restrictive posted offer settings, where buyers are limited to accepting or rejecting prices offers, buyers may forego myopically profitable purchases with the intent of forcing sellers to lower prices in the future. Accounting for this strategic behavior could be important for antitrust policy, which should consider how concentrated industry structure on the selling side may be counterbalanced by the presence of a small number of strategic buyers.

This paper examines the implications of buyer patience and its interaction with their noisy search for price offers. We use highly controlled laboratory markets that manipulate the expected number of price offers shown to buyers and their likelihood of receiving future offers. Consistent with the model’s comparative static predictions, price offers decrease when buyers are more likely to receive multiple price offers and when they become more patient. This support for theory is considerably stronger than in related durable goods monopoly and bilateral bargaining experiments with incomplete information, where data are frequently inconsistent with even the main comparative statics. However, our data do not support the equilibrium point predictions of the model: the model over-predicts the ability of buyers to obtain low, near-competitive prices when they can wait for new price offers (i.e., the treatments with $\delta = 0.9$), as well as the ability of sellers to charge close to the monopoly price when only one rounds of offers is possible (i.e., the treatments with $\delta = 0$). This could be due in part to social preferences that bias prices toward the middle of the feasible price range, since such prices provide buyers and sellers with similar exchange surplus, as observed in bilateral bargaining experiments with complete information (Roth, 1995; Goeree and Holt, 2000). Risk aversion could also cause prices to deviate from the risk neutral equilibrium. Nevertheless, considering that the equilibrium model is based on fully-rational, risk neutral and self-regarding agents, while human buyers and sellers in the lab are boundedly rational and surely have more complicated motivations, overall the qualitative support for the theoretical predictions is still impressive.
Probability of observing both price offers $\gamma = 0.67$ (high) and $\gamma = 0.33$ (low)

Continuation probability $\delta = 0.9$ (high) and $\delta = 0$ (low)

One buyer and two sellers in each market

Buyer’s value = 100 and Seller’s cost = 0

<table>
<thead>
<tr>
<th>Experimental Parameters</th>
<th>Transaction Price</th>
<th>Posted Price</th>
<th>Expected range of Posted Price</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Median</td>
<td>Mean</td>
</tr>
<tr>
<td>$\gamma = 0.67$, $\delta = 0$</td>
<td>23.09</td>
<td>28.19</td>
<td>39.93</td>
</tr>
<tr>
<td>$\gamma = 0.67$, $\delta = 0.9$</td>
<td>2.91</td>
<td>3.56</td>
<td>5.04</td>
</tr>
<tr>
<td>$\gamma = 0.33$, $\delta = 0$</td>
<td>56.82</td>
<td>58.22</td>
<td>69.6</td>
</tr>
<tr>
<td>$\gamma = 0.33$, $\delta = 0.9$</td>
<td>11.63</td>
<td>11.92</td>
<td>14.24</td>
</tr>
</tbody>
</table>

Table 1: Summary of parameter values and theoretical predictions.

<table>
<thead>
<tr>
<th>Continuation Probability ($\delta$)</th>
<th>Probability of observing both price offers ($\gamma$)</th>
<th>$\delta = 0$, $\delta = 0.9$ (Low – High)</th>
<th>$\delta = 0.9$, $\delta = 0$ (High – Low)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\gamma = 0.67$</td>
<td>2 sessions of 12 subjects (Sessions # 1 and 2)</td>
<td>2 sessions of 12 subjects (Sessions # 3 and 4)</td>
<td></td>
</tr>
<tr>
<td>$\gamma = 0.33$</td>
<td>2 sessions of 12 subjects (Sessions # 5 and 6)</td>
<td>2 sessions of 12 subjects (Sessions # 7 and 8)</td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Experimental Design.
<table>
<thead>
<tr>
<th>Session #</th>
<th>Probability of observing both price offers ($\gamma$)</th>
<th>Continuation Probability*</th>
<th>Continuation Probability</th>
<th>Continuation Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$\delta = 0$</td>
<td>$\delta = 0.9$</td>
<td>$\delta = 0$</td>
</tr>
<tr>
<td></td>
<td>Transaction Price</td>
<td>Median</td>
<td>Mean</td>
<td>Median</td>
</tr>
<tr>
<td>1</td>
<td>$\gamma = 0.67$</td>
<td>16.04</td>
<td>18.21</td>
<td>7.90</td>
</tr>
<tr>
<td>2</td>
<td>15.48</td>
<td>18.33</td>
<td>9.26</td>
<td>11.64</td>
</tr>
<tr>
<td>3</td>
<td>15.46</td>
<td>19.66</td>
<td>10.15</td>
<td>10.13</td>
</tr>
<tr>
<td></td>
<td>Equilibrium Prediction</td>
<td>28.19</td>
<td>23.10</td>
<td>3.56</td>
</tr>
<tr>
<td>5</td>
<td>$\gamma = 0.33$</td>
<td>50.57</td>
<td>52.87</td>
<td>31.72</td>
</tr>
<tr>
<td>7</td>
<td>29.33</td>
<td>30.29</td>
<td>19.81</td>
<td>19.64</td>
</tr>
<tr>
<td>8</td>
<td>67.17</td>
<td>67.01</td>
<td>13.65</td>
<td>13.45</td>
</tr>
<tr>
<td></td>
<td>Aggregate Observed</td>
<td>42.88</td>
<td>44.23</td>
<td>20.30</td>
</tr>
<tr>
<td></td>
<td>Equilibrium Prediction</td>
<td>58.22</td>
<td>56.80</td>
<td>11.92</td>
</tr>
</tbody>
</table>

*Shaded area indicates the treatment in the first 30 periods.

Table 3: Median and Mean Transaction Price in the final 15 periods of each treatment condition
<table>
<thead>
<tr>
<th>Dependent Variable: Buyer Purchases in Round 1</th>
<th>All Buyers</th>
<th>Withholding Buyers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Model (1)</td>
<td>Model (2)</td>
</tr>
<tr>
<td></td>
<td>Model (1)</td>
<td>Model (2)</td>
</tr>
<tr>
<td>Gamma = 0.67 (indicator variable)</td>
<td>-0.15</td>
<td>0.004</td>
</tr>
<tr>
<td></td>
<td>(0.08)</td>
<td>(0.06)</td>
</tr>
<tr>
<td>Both price offers are observed (indicator variable)</td>
<td>0.11**</td>
<td>0.08*</td>
</tr>
<tr>
<td></td>
<td>(0.03)</td>
<td>(0.03)</td>
</tr>
<tr>
<td>Minimum price that is observed</td>
<td>-0.02**</td>
<td>-0.03**</td>
</tr>
<tr>
<td></td>
<td>(0.003)</td>
<td>(0.003)</td>
</tr>
<tr>
<td>Round of purchase in the previous period</td>
<td>-0.06*</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>(0.02)</td>
<td>(0.04)</td>
</tr>
<tr>
<td>Purchase price in the previous period</td>
<td>0.03**</td>
<td>0.04**</td>
</tr>
<tr>
<td></td>
<td>(0.003)</td>
<td>(0.01)</td>
</tr>
<tr>
<td>1/period</td>
<td>2.58</td>
<td>5.59</td>
</tr>
<tr>
<td></td>
<td>(2.13)</td>
<td>(5.84)</td>
</tr>
<tr>
<td>Observations</td>
<td>480</td>
<td>165</td>
</tr>
<tr>
<td>Log-likelihood</td>
<td>-190.24</td>
<td>-78.35</td>
</tr>
</tbody>
</table>

Notes: Clustered standard errors are robust to unspecified correlation within subjects and are shown in parentheses. Models include significant treatment sequencing effects (not shown). ** denotes significantly different from zero at 1 percent level; * denotes significantly different from zero at 5 percent level (all two-tailed tests).

Table 4: Probit Models of Buyer’s Purchase Decision in Round 1 (Marginal Effects Displayed)
Table 5A: Comparison of Buyer Purchase Choices in Round 1 to Optimal Rule in $\gamma = 0.67$ and $\delta = 0.9$ treatment: $307/416 = 73.8\%$ of purchase decisions are optimal

<table>
<thead>
<tr>
<th>Purchase in Round 1</th>
<th>Delay Not Optimal</th>
<th>Delay Is Optimal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>210</td>
<td>64 (39.8% Type 1 error)</td>
</tr>
<tr>
<td>Delay Purchase</td>
<td>45 (17.6% Type 2 error)</td>
<td>97</td>
</tr>
</tbody>
</table>

Table 5B: Comparison of Buyer Purchase Choices in Round 1 to Optimal Rule in $\gamma = 0.33$ and $\delta = 0.9$ treatment: $308/428 = 72\%$ of purchase decisions are optimal

<table>
<thead>
<tr>
<th>Purchase in Round 1</th>
<th>Delay Not Optimal</th>
<th>Delay Is Optimal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>229</td>
<td>44 (35.7% Type 1 error)</td>
</tr>
<tr>
<td>Delay Purchase</td>
<td>76 (24.9% Type 2 error)</td>
<td>79</td>
</tr>
<tr>
<td>Transaction Round</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>-------------------</td>
<td>-----------</td>
<td>-----------</td>
</tr>
<tr>
<td>Price in Round 1</td>
<td>16.59 (17.14)</td>
<td>26.50 (21.61)</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>18</td>
</tr>
<tr>
<td>Price in Round 2</td>
<td>19.52 (17.81)</td>
<td>13.74</td>
</tr>
<tr>
<td></td>
<td></td>
<td>15</td>
</tr>
<tr>
<td>Price in Round 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of Observations</td>
<td>356</td>
<td>100</td>
</tr>
</tbody>
</table>

Table 6A: Prices across rounds in $\gamma = 0.67$ and $\delta = 0.9$ treatment

<table>
<thead>
<tr>
<th>Transaction Round</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price in Round 1</td>
<td>24.72 (13.09)</td>
<td>30.1 (19.62)</td>
<td>32.51 (23.47)</td>
</tr>
<tr>
<td></td>
<td>21</td>
<td>23</td>
<td>22</td>
</tr>
<tr>
<td>Price in Round 2</td>
<td>22.68 (14.47)</td>
<td>19.98</td>
<td>26.66 (17.75)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>20</td>
</tr>
<tr>
<td>Price in Round 3</td>
<td></td>
<td></td>
<td>19.26 (9.05)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>18.25</td>
</tr>
<tr>
<td>Number of Observations</td>
<td>330</td>
<td>98</td>
<td>32</td>
</tr>
</tbody>
</table>

Table 6B: Prices across rounds in $\gamma = 0.33$ and $\delta = 0.9$ treatment

Notes: The first number is the mean posted price and the second number is the median posted price. Standard deviation is in parentheses.
Figure 1: Equilibrium price distribution for various parameter values.

Figure 2: Median Price in $\delta = 0$ and $\gamma = 0.67$ sessions
Figure 3: Median Price in $\delta = 0.9$ and $\gamma = 0.67$ sessions

Figure 4: Median Price in $\delta = 0$ and $\gamma = 0.33$ sessions
Figure 5: Median Price in $\delta = 0.9$ and $\gamma = 0.33$ sessions

Figure 6: Empirical and Equilibrium CDF for $\delta = 0$ for the final 15 periods
Figure 7: Empirical and Equilibrium CDF for $\delta = 0.9$ for the final 15 periods.

Figure 8: Frequency of Transactions made in a given round in $\delta = 0.9$ sessions (all 30 periods)
Figure 9: Prices in $\gamma = 0.67$ and $\delta = 0.9$ sessions

Figure 10: Prices in $\gamma = 0.33$ and $\delta = 0.9$ sessions


Appendix: Experiment Instructions

General

This is an experiment in the economics of market decision making. The instructions are simple and if you follow them carefully and make good decisions you can earn a considerable amount of money that will be paid to you in cash at the end of the experiment. It is in your best interest to fully understand the instructions, so feel free to ask any questions at any time. It is important that you do not talk or discuss your information with other participants in the room until the session is over.

All transactions in today’s experiment will be in Experimental Dollars. These Experimental Dollars will be converted to real US Dollars at the end of the experiment, at a rate of 1 Experimental Dollar = $1. This conversion rate is your own private information and it may be different from other participants’ conversion rates. Notice that the more experimental dollars you earn, the more US dollars you earn. What you earn depends partly on your decisions and partly on decisions of others.

In this experiment, we are going to conduct markets in which you will be a participant in a sequence of market trading periods. The experiment consists of 2 sequences, where each sequence will consist of 30 periods each. The instructions for each sequence will be given at the start of that sequence.

In every period, you will be either a buyer or a seller of a fictitious good X, and you will remain in this role throughout the experiment. The 12 participants in today’s experiment will be randomly re-matched every period into 4 markets with 2 sellers and 1 buyer in each market. Therefore, the other traders in your market will change randomly after each period. Buyers earn money from buying a single unit of good X, and Sellers earn money from selling a single unit of good X.

Buyers

Exactly one buyer will participate in each separate market, and this buyer can purchase at most one unit of good X per trading period. A buyer who purchases a unit of X earns money by reselling this unit to the experimenter at a set price of 100. The profits from each resale are
computed by taking the difference between the resale value of 100 and the price paid for the unit. That is,

\[ \text{[your earnings} = (\text{resale value}) – (\text{purchase price})] \]

Suppose, for example, that you pay 75 to purchase a unit of X. Your earnings are:

\[ \text{Earnings} = 100 – 75 = 25 \]

Buyers who do not buy a unit automatically earn a profit of zero that period.

**Sellers**

Two sellers will participate in each separate market. Each seller is endowed with a single unit of good X, i.e. it costs a seller nothing to produce good X. Since the buyer will buy only one unit of X per period, it follows that only one seller can make the sale per trading period. The seller who makes the sale earns profit equal to the sale price of the unit, and the seller who is unable to make the sale earns zero profit. Suppose, for example, that you sell a unit at a price of 37. Your earnings are 37 while the other seller in your market earns 0.

**Buying and Selling Procedures for Sequence 1**

At the beginning of the period, sellers post their offer prices, indicating the amount they wish to receive to sell their unit of good X, using a decision screen as shown in Figure 1 on the next page. Price must be greater than or equal to 0 (the cost of the unit) and less than or equal to 100 (the buyers’ resale value). Up to two decimal places are allowed in setting these price offers. Thus, 3.69, 45.01, 96.35 are all acceptable prices.

After both sellers have posted their prices, the buyer will decide whether he or she wants to buy the unit at the offered price or prices. The buyer will sometimes observe price offers of both sellers in his or her market, as shown on Figure 2. Other times the buyer will only observe one (randomly-chosen) price offer chosen by one of the sellers in his or her market, as shown on Figure 3. There is a 2/3 chance that the buyer sees only one price and a 1/3 chance that the buyer sees both price offers. This probability is also displayed on the computerized decision screens as shown in Figures 1 - 3. These probabilities mean that about one-third of the time buyers will see both price offers. The chance of observing one or two prices does not depend on whether one or two prices were shown recently, or on any other activity in any market. It is completely random.
Figure 1: Seller’s Decision Screen (Price Offers)

The buyer indicates whether he or she wants to purchase a unit, and from which seller (if two price offers are available), by clicking the Accept or Reject buttons on their decision screen (Figures 2 or 3).

Length of a period in Sequence 1

Each period will last for one or more rounds depending on the decisions made by the participants in the experiment as well as a roll of die, as described below.

In every period, once all buyers in the experiment have had an opportunity to purchase a unit in the first round, the experiment will continue onto the next period if all buyers bought a unit. If any buyer has not yet purchased, the current period may be extended to a second round of
seller price offers. To determine whether or not a second round occurs, first the computer will check whether any buyer has not yet purchased in the current period. If any buyer has not yet purchased, then the computer will throw a “virtual” 10-sided die (see Figure 4). If the die comes out 10, the period ends immediately and we move on to the next period. If the 10-sided die roll comes up with anything except 10, then we continue with an additional round of seller price offers within the same period. Thus, there is a 9/10 chance that we will move to another round of offers within the same period if not all buyers have purchased yet. Sellers who are in a market where the buyer has already purchased cannot make a price offer in this next round. However, sellers who are in a market where the buyer has not already purchased will make price offers as described above. The round then continues onto the buyer purchase decisions as described above. If all buyers make the purchase in the second round, we move on to the next period. However, if there is any buyer who has not yet purchased, the current period may be extended to a third round of seller price offers as long as the roll of a die does not come up with 10. This process continues and the number of rounds could go on indefinitely (as long as 10 doesn’t come up a die roll) when buyers don’t purchase. Thus, it could go on 2, 3, 6, 8, 10 or more rounds.

Note that in each new round the buyer will again randomly observe either one or two prices. The chance of seeing one or two prices is not affected by the participant’s previous decisions or by whether or not two prices were displayed in the previous round. Note that the two sellers’ prices are randomly shuffled each round to determine which is shown on the left and right.

Recall that each time the experiment moves onto another period, the sellers and buyers will be randomly re-shuffled into new three-person groups to form new markets. At the beginning of a new period, sellers start over again with 1 unit of good X that they can sell, and buyers can again purchase 1 (and only 1) unit. Each period proceeds in an identical fashion.
Figure 2: Buyer’s Decision Screen when two prices are observed

At the End of the Period

When all buyers have finished purchasing or when the period ends because a 10 appears on the die roll, every trader’s screen will summarize the period’s activities for each of the three traders in the market, as in the example shown in Figure 5. The history table on the bottom of the screen includes prices offered by both sellers in all rounds of the current period and indicates which price(s) the buyer observed in each round. The two sellers’ prices are randomly shuffled each round into the right and left columns on this history table. The top half of the screen includes the purchase price (if any) by the buyer, round of purchase or sale and the calculation of your profit for the period. You must enter this information in your Personal Record Sheet.
Period 3

Two sellers and one buyer are in each market.

The buyer sees one price with probability 2/3 and sees two prices with probability 1/3.

This is Round 1 of price offers this period.

A Seller’s Price

\[
\begin{array}{c}
24.00 \\
\end{array}
\]

- **Accept**
- **Reject**

<table>
<thead>
<tr>
<th>Period</th>
<th>Round</th>
<th>One Seller’s Price</th>
<th>The Other Seller’s Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>32.00</td>
<td>24.00</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>24.00</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>3</td>
<td>24.00</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>24.00</td>
<td>47.00</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>24.00</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 3: Buyer’s Decision Screen when one price is observed**
Summary

- Each market contains 1 buyer and 2 sellers.
- Each buyer can buy up to 1 unit per period and each seller can sell up to 1 unit per period.
- All buyers have a resale value of 100 per unit.
- All sellers have a cost of 0 per unit.
- Buyer earnings = resale value of 100 – purchase price
- Seller earnings = sale price of unit – cost of 0
- Buyers and sellers will be randomly re-shuffled into new markets each period with different buyers and sellers.
- Sellers make a single price offer in each offer round.
- Buyers may observe both sellers’ prices or only one, randomly-determined seller’s price.
- If buyers decide not to purchase a unit in a round, a die roll will determine whether another round of offers takes place. Another round occurs as long as 10 does not come up on a 10-sided die. This die role takes place every round when at least one buyer has not purchased a unit in the current period.

![Figure 5: Example Seller Outcome Screen](image)
Instructions for Sequence 2

This sequence of 30 periods is similar to sequence 1. As in the previous sequence, each seller has to decide what price to set for a unit of good X and each buyer has to decide the seller from whom to make the purchase. As before, each seller has only 1 unit of good X and each buyer can purchase at most 1 unit. However, in this sequence, each period will last for only one round.

Recall that each time the experiment moves onto another period, the sellers and buyers will be randomly re-shuffled into new three-person groups to form new markets. At the beginning of a new period, sellers start over again with 1 unit of good X that they can sell, and buyers can again purchase 1 (and only 1) unit. Each period proceeds in an identical fashion.