Do Buyers Always Act as Passive Price-Takers?
Evidence from Experimental Posted-Offer Markets

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Abstract

Both oligopoly theory and experiments are concerned almost uniquely with the behavior of sellers. Buyers' ability to exhibit non-trivial behavior in different market institutions remains unaddressed. This paper investigates the impact of three variables (number of buyers, surplus division at the market-clearing price and revelation of information) on strategic and fairness-motivated buyer behavior. Buyers are shown to be able to withhold demand, sometimes intensely. Demand withholding and its ability to force lower prices increase as the number of buyers or the share of surplus earned by the buyers decrease. However, increasing the information revealed to subjects about the surplus inequality favoring sellers actually mildly facilitates collusion among sellers rather than provoking demand withholding as conjectured.

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1 Introduction

1.1 Motivation

The overwhelming majority of industries in all but retail sales are characterized by bilateral oligopoly: a handful of sellers confronting a handful of buyers. Yet, industrial organization theory, laboratory oligopoly experiments and antitrust legislation all neglect the potential strategic, counteracting role of buyers in markets. Oligopoly theory treats buyers as price-takers where sellers are the only strategic players. Oligopoly experiments focus on seller behavior (e.g. signaling and collusion), often actively censoring the role of human buyers by employing a computer algorithm to simulate buyer behavior. And antitrust policy ignores the possibility that a few, powerful buyers may offset what appears to be an anticompetitive industry structure.

Using a posted-offer market, this paper initiates a line of research intent on exploring buyers’ ability to exhibit non-trivial behavior in various market institutions. In the posted-offer institution, a period begins with each seller simultaneously choosing a price and a quantity to make available at that price. Buyers then proceed sequentially to make the purchases each desires. Thus, the only choice available to buyers is to accept or reject a posted price. Admittedly, this limited strategy space differs from that typically available to the large industrial buyers this research aims at understanding. The posted-offer institution has instead been noted to characterize the structure of retail markets.¹ Nonetheless, we begin by examining buyer behavior in this very structured bargaining setting as a first step towards more complicated, less structured settings.

¹ Ketcham, Smith and Williams (1984) provide a brief history of the posted-offer institution in retail trade.
1.2 Why Would Buyers Withhold Demand?

Buyers may be motivated to reject profitable purchases, that is to withhold demand, for fairness or strategic reasons. One interpretation of fairness is a concern for relative payoffs.\textsuperscript{2} Evidence from the experimental bargaining game literature suggests that people will reject unequal divisions of surplus. Ultimatum-game responders often reject offers less than one half and rejection rates increase as the offer decreases as a fraction of the available surplus.\textsuperscript{3} The posted-offer institution is the natural, multi-player, market extension of the ultimatum game. Sellers post prices which buyers can then either accept or reject. Acceptance yields sellers a payoff determined by the difference between the price they post and their cost on each unit sold. Buyers earn the difference between their valuation and the purchase price on each unit bought. If a buyer rejects a particular seller’s posted price, both both buyer and seller receive zero surplus. The natural question to ask is, does the concern for relative payoffs in the ultimatum game extend to the posted-offer market?

Buyers may also forego a profitable purchase with the intent to force sellers to lower their prices in future periods. This non-myopic, strategic purpose is likely to be more successful the more concentrated the buyers’ side of the market.

1.3 The Experiment

Three variables are studied which are conjectured to matter to buyer behavior. The variables the number of buyers, the surplus division between buyers and sellers at the competitive price and the amount of information revealed to subjects

\textsuperscript{2} Other fairness-related motivations for demand withholding are not explored in this paper. 
\textsuperscript{3} The ultimatum game involves two players, a proposer and a responder. The proposer’s task is to divide an amount between the two players. The responder can accept or reject the proposed division. If the responder accepts the division, then players receive the amounts indicated by the division. If she rejects, both players receive nothing.
are each investigated at two levels. Unable to run the entire $2^3$ factorial design due to a budget constraint, I faced the decision of which treatments to run and which ones to omit from the study. To resolve this problem, I introduce a methodology from the design of experiments literature in industrial engineering. I select an experimentation strategy which involves conducting a complete $2^{3-1}$ fractional factorial (a half-fraction) at four replicates.

Decreasing the number of buyers from four to two and increasing the seller:buyer surplus inequality at the market-clearing price from 3:1 to 6:1 both increase demand withholding which lowers posted prices significantly. In order to make the earnings inequality more salient to the buyers, the high-level of the information variable reveals all participants’ profits at the end of each period in addition to providing full, symmetric information with regard to the demand and cost configurations. Instead of provoking buyers to withhold demand, more information – the revelation of subjects’ (very unequal) profits – is found to facilitate slightly price coordination among sellers.

The remainder of this paper proceeds as follows: section 2 reviews previous posted-offer experiments which consider buyer behavior and fairness in markets. Section 3 details the experimental model and its theoretical predictions. The experimentation strategy is discussed in section 4. Section 5 presents and analyzes the experimental results. Section 6 examines the strategic versus fairness motivation for the observed buyer withholding and its profitability. Section 7 concludes.
2 Related Literature

2.1 Buyer Behavior in Previous Posted-Offer Experiments

The role of buyers in markets remains unaddressed. A glance at previous posted-offer experiments, in particular, illuminates the overwhelming focus on seller pricing.\(^4\) Buyer behavior is often actively censored by employing a computer algorithm to simulate buyers.\(^5\) The buyer simulation algorithms employed generate fully-demand-revealing buyers who continue to purchase from the lowest-price seller as long as the price is less than (or equal to) the buyer's valuation. With human buyers replaced by a computer algorithm payments to subjects are reduced; furthermore, demand withholding is prevented, thus simplifying the interpretation of experimental results. Sellers may exploit all available gains from trade without fear of buyer repercussions. Tacit collusion, the exertion of seller market power or, more generally, pricing above the competitive equilibrium is given its 'best shot' with human buyers removed from the experiment.

But what about giving buyers their 'best shot' at strategic behavior, or behavior motivated by something other than myopic material-payoff maximization? There are several studies which run at least one replication with human buyers and compare the results obtained with other replications involving simulated buyers. These include Cason and Williams (1990), Davis and Williams (DW) (1991) and Kruse (1991). DW and Kruse both observe that the mere presence of human buyers (i.e. the threat of demand withholding) has a disciplining effect on sellers. This paper takes these insights seriously by studying buyer behavior and seller responsiveness to it.


\(^5\)In fact, this censorship of buyer behavior dates back to the earliest oligopoly experiments (Fouraker and Siegel, 1963, and Friedman, 1963, 1967).
2.2 More on Fairness in Markets

Franciosi et al. (1995) use a posted-offer market to examine the willingness of buyers to accept price increases depending on whether they are justified by increases in costs or not. If subjects are made aware of the unequal division of profits favoring sellers, profit-seeking behavior is initially blunted. Prices begin lower than in other treatments where sellers' profits are not revealed; however, even in the profit-disclosure treatments, prices soon converge to the competitive equilibrium as sellers gradually increase their posted prices in the face of excess demand.

Researchers conducting ultimatum games have attempted to extrapolate subjects' concern for relative payoffs to posted-offer markets. After all, a posted offer by a seller is identical to a take-it-or-leave-it offer issued by the proposer in an ultimatum game. Context and (perhaps) the number of players are the only differences between the two environments. Hoffman et al. (1994) attempt to reduce contextual differences between the two environments by framing the ultimatum game as a posted-offer market. For instance, they conduct the ultimatum game with the players labeled “seller” and “buyer” rather than “person A” and “person B”. This produces significantly lower offers without affecting rejection rates. Yet this simple one-shot, one-on-one bargaining environment cannot claim to capture the richness and dynamics of a multi-player posted-offer market. Rather, the Hoffman et al. finding indicates the sensitivity of offers in an ultimatum game to contextual variables. The experiment conducted here examines buyer and seller behavior directly in a posted-offer market.
3 Experimental Procedure and Design

3.1 Posted-Offer Institution

The experimental implementation of the posted-offer institution has been carried out using the NovaNet (PLATO) software. Subjects are randomly assigned to the role of either buyer or seller. Each period consists of the following sequence of events. Sellers simultaneously decide on a price, followed by a quantity to make available at that price (up to their capacities). After all sellers have made a price and quantity choice for the period, each seller's price (but not quantity) is revealed to the buyers and all other sellers. Buyers then proceed in random order to make their desired purchases. Purchase decisions are made privately so that buyers are unable to observe the purchases (or sacrifices) of other buyers. When it is a buyer's turn to shop, she sees only the posted prices of each seller, displaced by the message "Out of Stock" when a seller has sold all available units. The period ends when the last buyer has finished shopping. Buyers earn the difference between their valuations (or resale values) and the price they pay on each unit purchased. Sellers earn the difference between the price they post and the cost of the unit for each unit sold. They do not incur costs for units offered that remain unsold.

3.2 Experimental Design

The cube in Figure 1 displays the $2 \times 2 \times 2$ experimental design where the three treatment variables are: number of buyers, surplus division, and information revelation. Each treatment variable is explored at two levels. I faced a trade-

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6 See Ketcham, Smith and Williams (1984) for a detailed exposition of the features of this software.

7 The NovaNet software restricts sellers to offering a maximum quantity such that each unit may be sold at a profit at the chosen price.
off between the number of variables and the number of levels within a variable to explore. The former was chosen at the expense of the latter. As this is the first systematic study of buyer behavior in posted-offer markets, little is known about the variables that impact upon buyers’ decisions to purchase. Rather than expend resources on exploring more extensively one or two variables – which may or may not be important to buyer behavior – this initial investigation attempts to identify factors that affect buyer behavior. Future research can be focused on a more in-depth study of the variable(s) determined to matter most. Furthermore, there is no a priori reason to suspect the relationship between any of the treatment variables and sellers’ prices (or buyer withholding) to be non-monotonic. This implies that two levels for each variable is sufficient to identify the major trend, if any. In addition, the specific levels for each treatment variable were chosen with the thought in mind that if the weaker level of each variable fails to stimulate withholding, then the stronger level should.

The first treatment variable is the number of buyers, \( b \). Two \((2b)\) and four \((4b)\) are the numbers investigated here.\(^8\) It is important to keep in mind that the number of sellers is fixed at two for all treatments.

The surplus division variable, \( s \), indicates the ratio of the profits of each seller to each buyer at the competitive price. The ratios of 3:1 \((3s)\) and 6:1 \((6s)\) were selected based on rejection rates in ultimatum, bargaining games. A vast number of ultimatum game experiments suggest that responders reject unequal divisions of surplus. A 3:1 ratio of surplus inequality favoring the proposer is typically sufficient to elicit substantial rejection frequencies among proposers. Does this finding extend to the market version of the ultimatum game? If not, perhaps a

\(^8\)Isaac and Reynolds (1989) present empirical findings from the Arizona gasoline market and anecdotal evidence from the actions of antitrust officials that suggest a qualitative difference in market performance in going from two to four sellers. They design an experiment to test their ‘two-versus-four’ hypothesis. Their experimental evidence indicates that in the face of periodic supply shocks, two firms are better able to sustain prices above the competitive price than four.
Figure 1: Geometric representation of the $2^3$ factorial design.
6:1 earnings inequality will evoke demand withholding?

The third treatment variable of interest is the information revealed to subjects. The low-level information condition examined here provides subjects with full information about the market configurations (M); that is, all subjects are given each buyer's valuations and each seller's costs in tabular form. (See Appendix A.) In the high-level information condition, in addition to the market configurations, the profits of each subject are made public at the end of each period. The intent is to make the earnings inequality more salient to buyers in an attempt to incite them to forego profitable purchases. I thus refer to the high-level information condition as the fairness condition (F).

Since we are interested in the ability of buyers to withhold demand, the model to be tested is constructed to hold constant across treatments the buyers' side of the market to the extent possible. In this manner, differences in observed levels of demand withholding (and seller pricing) across treatments can be attributed to changes in the levels of the treatment variables, as opposed to variations in the design in moving from one treatment to another. We thus hold fixed the aggregate demand curve across all treatments. To vary the number of buyers from four to two, the units of demand of the third and fourth buyers are redistributed to the first two buyers, as shown in Figure 2. In so doing, this would double the earnings of each of the two buyers relative to their cohorts in the four-buyer treatments. To control for this, an exchange rate of two experimental dollars for one U.S. dollar is introduced in those treatments with two buyers. The end result is that, at the competitive price and full efficiency, all buyers earn the same amount ($0.40 per period) regardless of identity or treatment.

Changes in the surplus division are accomplished by shifts in the cost curve. Figure 2 displays three distinct cost functions. The middle one of the three, labeled "2b3s/4b6s", is relevant for four treatments, 2b3sM, 2b3sF, 4b6sM, and 4b6sF. To see this, consider the treatment 4b6sM, for instance. For the cost curve
indicated, each of the two sellers earns six times as much as each of the four buyers at full efficiency at the competitive price. If we reduce the number of buyers to two, the ratio of the earnings inequality falls to 3:1, thus yielding 2b3sM. The three cost functions given therefore cover all eight treatments of interest.

### 3.3 Theoretical Predictions

The ten-cent vertical overlap of the demand and cost configurations produces a unique competitive quantity prediction of eight units with a competitive range of prices. The midpoint of the $0.10 competitive tunnel is treated as the competitive price for ease of exposition. All subsequent prices are stated as deviations from this competitive price.

As discussed above, subjects were given full information regarding the market conditions. This serves two purposes. First, it speeds up subjects’ learning process thereby quickening convergence, if any, to observed outcomes.

Secondly, full, symmetric information of the market configurations and public knowledge of the exchange rate (the payoff function) makes this a repeated game with complete information. We may therefore compute sellers’ Nash equilibrium and cooperative strategies.⁹ For treatments involving two buyers, seller i’s best-response price function to seller j is provided by equation (1).¹⁰ For simplicity of exposition, it assumes seller j chooses the optimal quantity for a given price. The best-response function reveals that there does not exist a pure-strategy Nash

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⁹Note well that such a computation assumes buyers as price takers, that is, non-strategic players. Bilateral oligopoly remains unexplored in oligopoly theory.

¹⁰The extension to the four-buyer case involves a probabilistic assessment of the different possible orderings of the non-identical buyers. Appendix B characterizes seller i’s best-response function when faced with four buyers.
Figure 2: Market configurations for all eight treatments. The three distinct cost curves share common fourth and fifth steps at $p = -.05$ and $p = .35$, respectively. The labels above (below) the demand (cost) curve(s) refer to the buyer (seller) to whom the unit belongs. “B1/B3” indicates that buyer 1 (3) owns the unit in treatments with two (four) buyers.
equilibrium (PSNE) in prices for this model.

\[
p_i^*(p_j) = \begin{cases} 
+.20, & q_i^* = 4 \text{ if } +.20 < p_j \\
p_j - .01, & q_i^* = 4 \text{ if } +0.05 < p_j \leq +.20 \\
+.20, & q_i^* = 3 \text{ if } p_j \leq +0.05
\end{cases}
\]

(1)

where \(q_i^*\) is firm \(i\)'s sales which are \(\leq\) its choice of quantity.

To understand this result intuitively, note that seller \(i\) will price at +0.20 as long as he is able to sell 3 or more units of production. This, he achieves as long as his competitor, seller \(j\), prices at, or below, the top of the competitive range \((p_j \leq +0.05)\), or strictly greater than +0.20. Once seller \(j\) raises her price above the competitive tunnel but less than +0.20 she reduces seller \(i\)'s sales to two units. Seller \(i\)'s best response is then to undercut seller \(j\) by 0.01. With \(p_j = +0.20\), seller \(i\) also responds optimally by charging +0.19 and selling four units. Given seller \(j\)'s symmetric best-response function, there does not exist a pair of prices such that neither seller cannot increase its profits by changing its price. The non-existence of a PSNE is a product of the sequential ordering of buyers in the posted-offer institution. With the efficient-rationing rule where the highest valuation units are purchased first, a symmetric PSNE exists with prices set at +0.05 (and sales of four units for each firm).

There does exist a unique, symmetric, mixed-strategy Nash equilibrium for each treatment. It involves seller \(i\) choosing prices \(p_i = (+.05, +.20)\) with probabilities \((4/5, 1/5)\), \((4/9, 5/9)\), and \((4/17, 13/17)\) for treatments 4b3s, 2b3s/4b6s, and 2b6s, respectively.\(^\text{11}\) Note that the expected price from playing the mixed-strategy equilibrium increases as the number of buyers decreases or the surplus inequality increases – a striking observation once we allow buyers to play a role.

The monopoly (or joint-profit-maximizing) outcome occurs at +0.20. As a point of reference, we may similarly compute the monopsonist price, as if this were

\(^{11}\text{To obtain these probabilities, solve for the mixture between } p_i = +.05 \text{ and } p_i = +.20 \text{ that equates seller } j\text{'s profits from } p_j = +.05 \text{ and } p_j = +.20.\)
a posted-bid auction. It turns out that buyers’ profits are jointly maximized at a price equal to the third step on the sellers’ cost curve with six units purchased.

4 Method of Experimentation

This section briefly describes the experimentation strategy I adopt in order to resolve the problem of which treatments to run given a budget constraint. The procedure I employ is new to economics, but commonly used by industrial engineers faced with large experimental designs and binding budget or time constraints.

To conduct a single replication of each of the cells of this $2^3$ factorial experiment$^{12}$ requires eight runs. Human variability demands that each cell be replicated a number of times, say four, thereby requiring thirty-two runs. The budget of the experimenter permitted four cells at four replications each. How does one decide which four cells to omit from the investigation, without dropping one of the three treatment variables?

One possibility would be to begin with a particular cell in the $2^3$ design (say 4b3sF), replicate the cell four times and analyze the data. If the data analysis yields the desired result, say an appreciable degree of demand withholding or deviation from the predicted price, then the experimenter may want to ‘back off’ on this cell and proceed to a ‘weaker’ cell, in this case 4b3sM, in an attempt to determine necessary conditions for the confirmation of the research hypothesis. If, however, the effect is not observed in the original cell, then the experimenter may continue to an adjacent vertex on the cube by strengthening one of the treatment variables, holding all others constant. In general, this sequential, one-factor-at-time (OFAT) experimentation strategy may continue until the experimental hypothesis is substantiated, or not. Such a procedure appears careful, even me-

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$^{12}$A factorial experiment combines all levels of a given factor with all levels of every other factor in the experiment.
thodical, as one factor is investigated at a time while all others are fixed. It has the appeal of providing immediate feedback on the effect of factor changes after each run. However, it introduces experimenter bias into the experiment: the experimenter somehow decides with which treatment to begin, which treatments follow and the order to proceed through the design. Besides, OFAT is an inefficient way to explore fully the parameter space.\footnote{Gunst and McDonald (1996) provide a detailed exposition of the pitfalls of the OFAT approach.}

In fact, there is an efficient alternative which avoids experimenter bias without the need to reduce the size of the study in face of a budget constraint. The method of experimentation employed here is to conduct a fraction of the factorial design, a fractional factorial. I choose to run a particular half of the $2^3$ factorial design, namely, a $\frac{1}{2}2^3 = 2^{3-1}$ fractional factorial (a half-fraction). This entails choosing the treatments to run in advance in a specified way.\footnote{The notation indicates that the design involves three variables, each at two levels, but that only only $2^{3-1} = 4$ treatments are conducted.}

The first criterion is that the treatments must be chosen so that each factor level occurs the same number of times among the treatments selected. For a $2^{3-1}$ half-fraction, each factor level appears twice in the design. This amounts to conducting exactly two treatments on each side of the (six-sided) cube. Doing so offers superior coverage of the parameter region compared to other experimentation strategies, including OFAT. Yet there still remains six sets of four treatments from which we must choose, as illustrated in Figure 3.

Which one of these half-fractional designs is best rests on what we hope to learn from the data. The primary interest of this study is to assess the impact of
each of the three treatment variables on demand withholding and seller pricing. In statistical terms, we seek estimates of the main effects of the three variables, with the two- and three-variable interactions of secondary importance. With this in mind, we are able to narrow our choice set to two sets of four treatments, indicated by cubes (e) and (f) in Figure 3. Cube (e) consists of treatments complementary to those in cube (f), and vice-versa. Either of these experimentation procedures will yield estimates of the main effects of the three variables. The cost of not conducting the full factorial design is that the interaction effects are confounded. By contrast, the other four choices we eliminated by applying this second criterion each yields an estimate of one main effect, one two-variable interaction effect and the three-variable interaction effect.\textsuperscript{16}

I opt for cube (f). The main effect of a treatment variable, $m$, is calculated by taking the average difference between the mean of the response variable (say seller

\textsuperscript{16}A demonstration of this is available from the author upon request; or consult any Design of Experiments textbook.
i's period t posted price, \( p_t \) at the high level of \( m \) and the mean of the response variable at the low level of \( m \) for those treatments conducted.\(^{17}\) Consider the computation for the main effect of the buyer variable where the treatment labels refer to the means of the response variable for that treatment.

\[
\text{buyr} = \frac{1}{2}[(4b3sM + 4b6sF) - (2b3sF + 2b6sM)]
\]

Similarly,

\[
\text{surp} = \frac{1}{2}[(4b6sF + 2b6sM) - (2b3sF + 4b3sM)]
\]

\[
\text{info} = \frac{1}{2}[(4b6sF + 2b3sF) - (2b6sM + 4b3sM)]
\]

Not coincidentally, the main effects are equal to the regression coefficients where the independent variables are the three treatment dummy variables, each with a 0 or 1 realization.\(^{18}\)

As noted above, the two-variable interaction effects, typically of appreciably smaller magnitude than the main effects, are confounded. The interaction between two variables, say \( \text{surp} \) and \( \text{info} \), is measured by the average of the difference between the surplus effect at the high level of \( \text{info} \) and the surplus effect at the low level of \( \text{info} \). That is,

\[
\text{surp-info} = \frac{1}{2}[(4b6sF - 2b3sF) - (2b6sM - 4b3sM)]
\]

And thus the calculation of the buyer and the surp-info interaction effects are equivalent.

Each treatment in cube (f) was replicated four times. This yields a balanced, \( 2^{3-1} \) design at four replicates. After a total of 16 runs of the four treatments,

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\(^{17}\)If we place the levels of a variable on the real line, the larger value indicates the high level. For the qualitative variable of information, the level revealing more information (F) is chosen as the high level.

\(^{18}\)Without intending to jump ahead, the main effects for the experiments conducted here are given by the 20-period regression coefficients of Table 3 in Appendix D.
there still remained enough money to conduct two or three more experiments. I chose to run three replications of 2b3sM – the cheapest of the four remaining treatments.

5 Experimental Findings

5.1 Subject Pool

A total of 19 sessions were conducted at the University of Arizona’s Economic Science Laboratory. Each of the 92 subjects participated in a single treatment as either a buyer or a seller. Subjects were paid a $5 participation fee in addition to their experimental earnings. The average experimental earnings per subject were $16.25. Buyers earned on average $7.25, while sellers took away $29.25, not including their participation fees. Reading the computerized instructions and one-page handout took up the first 30 minutes in all sessions. The shorter sessions (with two buyers and no revelation of profits) took about 1 hour in total while those with four buyers and revelation of profits required up to 1 hour and 40 minutes.

5.2 Observed Outcomes

The data from all five treatments is summarized in Table 1. Appendix C provides a graph of the mean contract price for the five treatments pooled across replications. The price graphs of the individual 19 experimental sessions also appear in Appendix C. The vertical axis plots the price as a deviation from the competitive equilibrium. For each period, $t$, on the horizontal axis, sellers’ posted

\footnote{The complete data set from all sessions run is archived on the University of Arizona NovaNet computer network. For those interested, the author can also provide the data in the form of text files.}
prices are indicated by an "x" if at least one unit was purchased at that price, or an "o" if no units were sold. A "*" designates the mean contract price for each period with a line connecting the 20-period sequence. The quantities, \( Q_t \), traded in each period are displayed along the bottom of the graph. Below the quantities appear the sales lost to demand withholding, \( W_t \), in each period. This value indicates the additional units of production that would have traded if buyers made all purchases yielding a profit of at least $0.01. It therefore provides a measure of the impact of non-trivial buyer behavior on sellers.

Notably, it was not the case that withholding was attempted early in the experiment and then abandoned. In many cases, buyers did not begin resisting sellers' prices until after five or six periods and withholding, where observed, continued at a more or less steady rate until the final couple of periods (19-20) at which point buyers resumed accepting all profitable prices.

4b3sM: Four buyers, 3:1 surplus division, full Market info

All four replications are similar in that prices converge to the midpoint or top of the competitive tunnel from above and efficiencies are typically above 90% for

\[ P_t = \frac{\sum_{i=1}^{n} q_{it} p_{it}}{Q_t} \]

where \( P_t \) is the mean contract price for period \( t \), \( Q_t \) is the number of units purchased (from seller \( i \)) in period \( t \), and \( p_{it} \) is seller \( i \)'s period \( t \) posted price.

Although the sales lost to demand withholding may be less than the actual number of units withheld, I use the two terms synonymously. Because the posted-offer software does not keep track of the random order in which the buyers proceed in each period, we sometimes cannot determine with exact precision the number of purchases withheld. Ambiguity arises in cases where a buyer makes no purchases in a period and sellers post different prices. In such instances, we sometimes are not able to determine if the buyer (having had the opportunity to purchase first) withheld demand or (having been last in the buyer queue) was unable to purchase profitably. Also, units passed up by one buyer in a given period may be subsequently purchased by another buyer later in the queue making the number of sales lost to withholding less than the number of units withheld.
Table 1: Summary statistics for the five treatments conducted where all replications within a treatment are pooled. For all statistics each row reports the mean for the entire 20 periods, last 15 periods (pooled across replications) with the standard deviations for the respective means in parentheses beneath. For “Sales Lost to Demand Withholding”, the number given is a total for the entire 20 periods, last 15 periods.
the last 10 periods of each session. Attempts at buyer withholding are limited to, at most, one or two units in a period. When attempted, withholding is ineffective in bringing down posted prices.

In fact, prices in this treatment were higher than in any other. Of the total 80 periods played, at least one seller posted a price at the top of, or above, the competitive tunnel ($\geq +0.05$) in an astonishing 63 periods! This left buyers 1 and 2 no opportunity to make a positive profit on their fourth units of demand. Furthermore, the mean contract price was $\geq +0.05$ 27 times. As a result of sellers’ high prices, efficiency levels in this treatment were regularly the second or third lowest among the five treatments.

**2b3sM:** Two buyers, 3:1 surplus division, full Market info

Reducing the number of buyers from four to two causes sellers to price more cautiously initially, it would appear. In the three replications of this treatment, four of the six sellers’ posted prices begin below the competitive tunnel. In the absence of buyer resistance, sellers unanimously increase their prices. Convergence to the competitive price from below is thus observed. Pricing and efficiency levels in the latter periods match those in 4b3sM.

**2b3sF:** Two buyers, 3:1 surplus division, Fairness

The price graphs for this treatment reveal the tendency for prices to fall over time. In two of the four replications (2b3sF1 and 2b3sF3), prices start out at, or below, the bottom of the competitive tunnel and decay gradually. Slow convergence from above is observed in the other two replications (2b3sF2 and 2b3sF4). Overall, demand withholding is stronger and more persistent in this treatment: at least one unit of sales was lost to withholding in 35/80 periods run with three or more sales lost in 12 periods. Consequently, efficiency levels are notably less than in the aforementioned treatments.

**2b6sM:** Two buyers, 6:1 surplus division, full Market info
This treatment is exceptional in the intensity of buyer withholding and its ability to force lower posted prices. Prices did not converge to the Nash or competitive price. Instead, beginning in period 6, prices fell continuously throughout the session in all four replications. The mean contract price in the terminal period ranged from $-0.10$ to $-0.42$. Efficiency levels actually decrease throughout the experiment as withholding intensified and posted prices fell out of the competitive tunnel (thereby allowing a maximum of six units to trade).

Early attempts at demand withholding versus later ones show a differential impact on sellers’ prices. It is in the early periods that sellers may establish a reference profit. That is, if sellers post prices at or near the competitive equilibrium early on and manage to sell all available units, later attempts at demand withholding by buyers will be met with resistance; namely, sellers will be reluctant to offer price reductions. On the other hand, buyers who withhold demand early on reduce sellers’ profits to considerably less than the available surplus. Sellers are therefore likely to respond by dropping prices in an attempt to get buyers to make purchases and increase their own profits.

The first and fourth replications of this treatment illustrate these divergent phenomena. In the first replication (2b6sM1), buyer 1 boycotted the market entirely beginning in periods 1, 3, 5-8. This left the two sellers competing in price for the business of the remaining buyer. Prices fell steadily throughout the twenty periods with an average contract price of around $-0.36$ over the last five periods. The combined earnings of the two buyers was $19.88$.

The fourth replication (2b6sM4), on the other hand, reveals that buyers did not even attempt to withhold demand until period 5. By this point, having previously enjoyed sales of at least three units each at similar prices, neither seller was willing to acquiesce. As a result, prices in the last five periods of this experiment were a less impressive $-0.11$. This is particularly striking in view of the fact that total demand withholding in 2b6sM4 (39 units) significantly
exceeded that in 2b6sM1 (26 units). What is more, in both of these sessions the first-period contract prices and the overall efficiencies for the twenty periods (about 70%) were almost identical, yet the price paths differ markedly due to the timing of the withholding.

Seller resistance to later attempts at demand withholding are captured by the written comments of seller 2 in 2b6sM4 in a post-experiment questionnaire filled out by all subjects. In response to a question asking participants to “describe the decisions you made in this experiment and your reasons for making these decisions”, seller 2 responded, “at the beginning I started with medium prices and then began increasing because I figured the buyers would buy more at the start … As the experiment progressed, the buyers were more controlling of the market so my prices dropped in order to sell more units.” Seller 2’s perception that buyers “were more controlling of the market” is humorous. With sellers’ prices above the competitive equilibrium in periods 2-7, they each earned about 7 times more than each buyer. When buyers became “more controlling of the market” and prices fell slightly below the competitive equilibrium in periods 8-20, buyers reduced this earnings inequality to 5:1 in favor of the sellers. Not surprisingly, the buyers in this session saw things differently. Buyer 1 wrote, “Since both the sellers were quoting high prices (and gaining high profits) I decided to try and bring the prices down. At times I wouldn’t even buy but prices never went down.” Buyers in this session earned a total of $12.25. The moral of the story is that if buyers are to have an impact on posted-offer sellers’ prices, they need to ‘take it to’ the sellers early; that is, don’t let the sellers get used to a comfortable profit level.

4b6sF: Four buyers, 6:1 surplus division, Fairness

Sellers again begin pricing very tentatively. In 3/4 replications, mean contract prices start out well below the competitive tunnel. However, attempts to withhold demand are either weak or non-existent signaling to sellers the potential
to raise profitably their prices. By period 9, prices in all sessions are within the competitive range where they remain for the duration. Again (as in 2b3sM), despite an earnings imbalance in their favor, sellers push upward their prices when left unchecked by buyer withholding.

Seller boldness and buyer passivity in this treatment despite the extreme earnings inequality are exemplified in the third replication (4b6sF3). Prices begin at, or above, the top of the competitive range. Seeing buyers’ willingness to accept purchases that yield a non-negative profit, sellers make use of the revealed profits (and the observable prices) to coordinate. By period 11, they seem to have comfortably settled in at the top of the competitive range, each selling four units per period. At these prices, buyers 1 and 2 are ‘gobbling up’ the pennies: buyer 1 or 2 accepted prices which yielded a profit of either $0.00 or $0.01 in periods 1, 5, 9-15, 18-20.

5.3 Data Analysis

Let us now assess the quantitative impact of each of the three treatment variables and demand withholding on sellers’ posted prices. Table 3 of Appendix D reports the results of four OLS regressions using the data from all 19 experimental sessions.\textsuperscript{22}

The buyer and surplus treatment variables are highly statistically significant no matter the collection of right-hand-side (RHS) variables. The impact of increasing the number of buyers from two to four is that each seller increases his

\textsuperscript{22}The only data points not included in the regressions are periods 19 and 20 of 2b3sF1 where a post-experiment conversation with seller 1 revealed that he inadvertently posted a price above buyers’ maximum valuations. For the last-15-period regression, I use periods 4-18 for this session. Session 2b3sM3 was allowed to run for 25 periods due to an error in the parameter file in period 1. I use the last 20 periods of this session in all data and regression analyses.
per period posted price by an average of 2.2 cents. Increasing the surplus inequality favoring sellers from 3:1 to 6:1 decreases each seller’s posted price by 2.4 cents on average. The information variable is only found to be significant when the first five periods are dropped. It is typical for data from early periods to be quite noisy in market experiments as subjects figure out what to do and how to respond to the actions of other participants. Interestingly, the sign on the information variable is positive: revealing profits to subjects actually increases the prices sellers post in each period by approximately one cent. From treatment 4b6sF, we saw that sellers made use of the observability of each other’s posted price and resultant profits to coordinate; they learned to post similar, if not identical, prices and extract most of the gains from trade.

Table 2 presents a series of qualitative response models for seller pricing in profit revelation treatments 2b3sF and 4b6sF. The level of support for the various models makes clear the logic behind seller price collusion: the seller whose profit was the lower of the two in period $t-1$ typically adjusts his period $t$ price in the direction of the high-profit seller’s period $t-1$ price (rows 1 and 2); whereas the aggregate data of the high-profit seller (rows 3 and 4) appear as if he plays a mixed strategy, keeping his period $t$ price constant roughly half the time and the other half of the time increasing and decreasing his price with approximately equal frequency.

The use of four regressors for the quantity of sales lost by seller $i$ due to demand withholding in period $t-1$, $W_{1,t-1}$, $W_{2,t-1}$, $W_{3,t-1}$, $W_{4,t-1}$, permits withholding to affect pricing non-linearly. The finding that $W_{1,t-1}$ is insignificant comes as no surprise in view of the market configurations: a sale lost at the competitive price costs a seller a mere $0.05; whereas the steepness of the MC curve makes foregone sales due to withholding the second, third and fourth units of production very costly. The coefficient of $-0.044$ on $W_{2,t-1}$ indicates that if

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23The (normalized) market-clearing price in all treatments was $1.90.
seller $i$ loses two sales to demand withholding in period $t-1$, he lowers his period $t$ posted price by 4.4 cents. The loss of the third and fourth units ruffles a seller even more, causing him to drop his subsequent period price by 6.3 and 5.9 cents, respectively.\footnote{The significance of these three withholding variables are robust to whatever data set is used, as are the significance of the own lagged price, $p_{it-1}$, and other lagged price, $p_{jt-1}$, variables. Interaction variables composed of the withholding variables and each of the three variables turn out to be insignificant, as do withholding variables for period $t-2$, $W_{1t-2}, W_{2t-2}, W_{3t-2}, W_{4t-2}$.} Interestingly, the decision to withhold three units dominates four units of withholding.

### 6 Fairness versus Strategically Motivated Withholding

Contrary to the passive price-takers of oligopoly models, buyers in these experiments exhibit non-trivial behavior in their frequent rejection of myopically profitable purchases. In this section we examine the motives underlying the observed withholding and its profitability.
For a given price, the punishment to sellers of rejecting a profitable purchase is greater the more extreme the earnings inequality. The observation that, for a given number of buyers, withholding is more frequent the larger the surplus inequality is therefore consistent with fairness. Consider, for instance, the four-buyer treatments 4b3sM and 4b6sF. Despite lower initial prices in 4b6sF than in 4b3sM, buyers in the former treatment withheld 30 units of demand, three more than in 4b3sM. Similarly, demand withholding was significantly higher in 2b6sM than the other two-buyer treatments explored. The frequent rejection of profitable prices in 4b6sF and especially 2b6sM reflects perhaps an intent to punish sellers' unwillingness to divide more equally the large, available surplus.

On the other hand, buyers' intensified withholding in treatments involving the 6:1 earnings inequality may be purely strategic. Recognizing sellers' ability to post prices significantly below the competitive price, buyer withholding may be viewed as an attempt to force lower prices. From the regression analysis of section 5.3 we learned that every sale lost to demand withholding lowered that seller's posted price in the subsequent period by just less than 2 cents. Still, was withholding profitable? Did the lower prices (at which buyers subsequently purchased) make up for the foregone gains from withholding?

The choice to withhold poses a free-rider problem for the buyers. Buyers benefit from withholding in the form of lower prices, but prefer others to do the withholding. Buyers who withheld heavily made considerably less than their session cohorts who free rode. Session 2b6sM1 provides an extreme example of the earnings inequality that can develop between buyers. All of the 26 sales lost to withholding can be attributed to buyer 1. His efforts earned him a mere $4.43 compared to buyer 2 who free rode off of 1's withholding and pocketed $15.45.²⁵ The results of the regression on buyer earnings reported in equation (2) concretize

²⁵ All payments made to subjects were actually rounded up to the nearest quarter.
the gains from having cohort buyers withhold.

\[ \Pi_{k_{\text{buyer}}} = 5.460 + 0.178 W_{-k} - 7.716 \tilde{P}_1 \]

\[ (0.000) \quad (0.000) \quad (0.000) \]

\[ \tilde{R}^2 = 0.537 \quad n = 54 \]

The \( W_{-k} \) variable represents the total number of units withheld in a session except those units withheld by buyer \( k \). The coefficient of 0.178 (p-value=0.000) indicates that every unit of demand withheld in a session by buyers other than \( k \) adds $0.18 to buyer \( k \)'s total earnings.

Further, there is evidence that on average buyers are made better off by withholding, their own included. In the treatment where withholding was greatest (113 units withheld in 2b6sM), buyer earnings were highest ($9.36 on average). Buyers in treatment 2b3sF withheld less and earned less, a total of 73 units withheld and $7.19 on average. In 4b3sM buyers earned still less, $5.42 on average, in conjunction with their withholding a mere 27 units of demand in total. While buyers in 4b6sF withheld only 3 additional units of demand (30 in total), initial prices below the competitive equilibrium account for their appreciably higher average earnings of $7.50. The importance of initial prices on buyers' earnings is captured by the regression coefficient of \(-7.716\) (p-value=.000) on \( \tilde{P}_1 \): a $1.00 decrease in the first-period mean contract price increases a buyer's earnings by $7.72.\(^{26}\) Initial prices below the competitive price in 2b3sM and 4b6sF provided a rare opportunity for significant single-period earnings for the buyers since prices in these treatments quickly rose to the competitive price and beyond.

This observed tendency of convergence to the competitive equilibrium from below in 2b3sM and 4b6sF speaks to the issue of fairness on the sellers' side of the market. An oft-heard question in the experimental bargaining game literature

\(^{26}\)None of the treatment variables nor a dummy variable for buyer identity, B1, B2, B3, B4, were found to be significant.
is: are subjects’ bothered by unequal divisions of surplus when they are the ones receiving the disproportionate share? Already enjoying almost three or even six times as much earnings as buyers, sellers’ willingness to increase their initial prices when left unchecked by buyer withholding answers this question with an emphatic no.

7 Final Remarks

7.1 Conclusions

This paper establishes that buyers may not always play the passive, price-taking role allotted to them by oligopoly theory. Even in the restrictive posted-offer institution which limits buyers to accepting or rejecting proposed prices (i.e. buyers are unable to make a counter-offer or negotiate a better price), buyers appear able to form long-term strategies and forego myopically profitable purchases. As a result, sellers were forced to lower their prices in order to increase sales. Yet an active, or at least influential, role for buyers depends on their numbers and the surplus division between buyers and sellers at the competitive price.

Four-buyer treatments reveal buyers’ ineffectiveness against sellers: sellers resisted buyer attempts at demand withholding and maintained prices at, or above, the competitive price. Two buyers, on the other hand, ‘go after’ the sellers, often intensely withholding demand and successfully drive prices down well below the Nash and competitive equilibrium predictions.\textsuperscript{27} This is particularly true in

\textsuperscript{27}As noted in the discussion of treatment 2b6sM in section 5.2, this observation may be an artifact of the experimental design in which the boycott of the market by a single buyer forces the sellers to compete for the business of the remaining buyer. To determine whether four buyers are truly ineffective in this environment, a subsequent design involving four buyers, each with market power. Ruffle (1999) pursues this issue in a monopoly setting and confirms the result found here: two buyers are more effective at bringing down prices than four buyers,
the face of large earnings inequalities between buyers and sellers. Even in the four-buyer treatment involving extreme (6:1) earnings inequalities, buyers resist equilibrium prices early on, but eventually concede. Buyers lack of persistence in this treatment is an indication that, individually, they feel powerless when there are three others. Sellers, on the other hand, do not mind the earnings inequality. Their pricing behavior reveals that as long as buyers are willing to buy, they will increase the price if it is profitable to do so.

7.2 Future Research

This initial paper in strategic buyer behavior in experimental markets raises many, as yet, unanswered questions. Future research into the role of buyers in experimental markets should proceed along two lines. First, consideration of other variables potentially relevant to buyer behavior and a more in-depth study into the robustness of these initial findings to changes in design characteristics both seem in order. Second, as noted earlier, in those industries in which (industrial) buyer market power is observed, buyers are not limited to merely accepting or rejecting sellers' posted prices. Future research should therefore expand into different, less structured market institutions to explore more fully the potential of strategic buyer behavior.

References


Etceteris paribus.


Appendix A: Instructions

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<th>Valuations</th>
<th>Costs</th>
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<td></td>
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<tr>
<td>Buyer 1</td>
<td>Buyer 2</td>
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<tr>
<td>Seller 1</td>
<td>Seller 2</td>
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<td>Unit 1</td>
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<td>Unit 2</td>
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<td>Unit 3</td>
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<td>Unit 4</td>
<td>1.95</td>
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<td>Unit 5</td>
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In addition to the standard NovaNet, computerized instructions, a supplementary page of instructions was provided to all subjects which explained the exchange rate, payment procedure and provided all subjects with the underlying market conditions (demand and cost configurations). The instructions for 2b3sM and 2b3sF are provided below. The instructions for all other treatments differed only in the table of valuations and costs, and in the 1:1 exchange rate in the treatments with four buyers. To ensure public knowledge of the payoff structure and exchange rate, the instructions were read aloud by the principal investigator.

ADDITIONAL INSTRUCTIONS FOR ALL PARTICIPANTS

In this experiment, you have been paid $5 for your participation. You may earn additional amounts of money during the experiment. Each experimental dollar will be exchanged for $0.50 U.S. (2 experimental dollars = $1 U.S.). All experimental earnings will be paid in cash at the end of the experiment. The experiment will last 20 periods.

[Market] At the end of 20 periods, you will be called by name one at a time to the room from which you entered in order to be paid.

[Fairness] At the end of each period, each subject's total earnings to date and earnings for that period will be displayed in experimental dollars on the front screen according to identity number. No other subject need know your identity number. To ensure the privacy of your earnings, you will be called by name at the end of the 20 periods one at a time to the room from which you entered in order to be paid.

After you have been paid the experiment is over and you are free to leave.

In the table above, the valuations of each buyer according to buyer number and the costs of each seller according to seller number are given for each unit of the good. These costs and valuations remain valid for all 20 periods.

If you have any questions during the experiment please raise your hand and a monitor will come to assist you.
Appendix B: Best-Response Function for Four Buyers

In those treatments where sellers are faced with four, rather than two, buyers, it turns out that a seller’s optimal price choice depends on the order in which the buyers shop. Since the random sequence of buyers is determined after the sellers have made their price and quantity decisions, sellers cannot condition their prices on the buyer sequence. Instead, sellers treat the random ordering as a probabilistic event in their choice of strategy. There are 24 possible orderings of buyers, only six of which are distinct from the point of view of the two sellers in this design. Below are the various orderings grouped according to sameness from the sellers’ standpoint. Each four-digit cluster of numbers represents the sequence in which the four buyers proceed. For example, “3124” in equation (d) indicates buyer 3 shops first, followed by buyer 1, then buyers 2 and 4, respectively.

1234=1243=2134=2143 (a)
1324=1423=2314=2413 (b)
1342=1432=2341=2431 (c)
3124=4123=3214=4213 (d)
3142=4132=3241=4231 (e)
3412=4312=3421=4321 (f)

Among these six groupings, four (b),(c),(d), and (e)) are strategically equivalent to the two-buyer case from the point of view of the sellers. To see this, recall that two buyers are obtained from four in this model by combining the units and corresponding valuations of buyer 3 or 4 with those of buyer 1 or 2. Thus, a “13” sequence of buyers is the equivalent of buyer 1 (or 2) in the treatments with two buyers. Similarly, “14”, “23”, and “24” are equivalent to “1” or “2” in the two-buyer treatments. Thus, for the orderings indicated by (b),(c),(d), and (e) above, each seller’s best-response price function remains unchanged, and is given by (1) of section 3.3. For the orderings given in (a) above, the only change to (1) is seller i’s sales when seller j prices at or below the top of the competitive tunnel. If the two buyers with valuations at +0.20 (buyers 3 and 4) proceed last (as in (a)), the high-price seller will sell all four units it makes available at +0.20. This change in sales is not relevant to sellers’ strategies: it is always a seller’s weakly-dominant strategy to offer the maximum permissible quantity.

The only change to seller i’s price function (given in (3)) occurs when buyers 3 and 4 shop first, as in ordering (f). In this case, being the high-price seller at a price above the competitive tunnel restricts sales to two units if the low-price seller is able to sell four units (by pricing in the competitive tunnel for instance). Two sales at +0.20 are dominated by a guaranteed four sales at the top of the competitive tunnel.

\[ p^*_i(p_j) = \begin{cases} 
+.20, q^*_i = 4 & \text{if } +.20 < p_j \\
 p_j -.01, q^*_i = 4 & \text{if } +.05 < p_j \leq +.20 \\
+.05, q^*_i = 4 & \text{if } -.05 \leq p_j \leq +.05 \\
+.20, q^*_i = 4 & \text{if } p_j < -.05
\end{cases} \tag{3} \]

where \( q^*_i \) is firm i’s sales which are \( \leq \) its choice of quantity.
However, because ordering (f) arises with only probability 1/6 and sellers are unable to condition on this event, sellers' symmetric, best-response functions remain as given by equation (1).