

# **Costly Buyer Search in Laboratory Markets with Seller Advertising<sup>\*</sup>**

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## **Abstract**

In this laboratory experiment sellers simultaneously post prices and choose whether to advertise this price. Buyers then decide whether to buy from a seller whose advertisement they have received, or engage in costly sequential search to obtain price quotes from other sellers. In the unique symmetric equilibrium, sellers either charge a high unadvertised price or randomize in an interval of lower advertised prices. Increases in either search or advertising costs raise equilibrium prices, and equilibrium advertising intensity decreases with lower search costs and higher advertising costs. Our results support most of the model's comparative static predictions, and sellers also post lower advertised than unadvertised prices as predicted. In all treatments, however, sellers price much lower than the equilibrium price interval and earn very low profits. Buyers' search decisions are approximately optimal, but sellers advertise more intensely than predicted. Consequently, market outcomes more closely resemble a perfect information, Bertrand-like equilibrium than the imperfect information, mixed strategy equilibrium that features significant seller market power.

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## 1. Introduction

If buyers are perfectly informed about seller prices of a homogeneous product, then the outcome of Bertrand competition is marginal-cost pricing. Imperfect information about seller prices, however, can lead to market power. At the extreme, if buyers must search for prices sequentially with strictly positive search costs, then in equilibrium no buyer would search and all sellers would charge the monopoly price (Diamond, 1971). But as Robert and Stahl (1993) emphasize, sellers have an incentive to advertise lower prices, thereby undermining the monopoly equilibrium. They introduce advertising in a sequential costly buyer search model, where the differentially-informed buyers yield a market equilibrium that is characterized by price dispersion. This price variance gives buyers the incentive to search for lower prices. Non-dispersed price equilibria do not exist because of a cyclical best response structure for the sellers: the best response to a rival charging some price  $p$  is to charge a price fractionally below  $p$  (as in Bertrand competition), but unlike perfect information models there typically exists some lowest price  $\underline{p}$  for which the best response is not undercutting but is instead charging a high unadvertised price and selling to uninformed buyers.

The “law of one price” is not an empirical regularity; in fact, even Stigler (1961, pg. 213) observed that “dispersion [of prices] is ubiquitous even for homogenous goods”. Economists’ interest in price dispersion has been renewed recently based in part on field evidence that it persists even as information technologies have reduced search costs. For example, Brynjolfsson and Smith (2000) document substantial price dispersion on Internet price comparison sites, and Baye, Morgan and Scholten (2004) find large and persistent price dispersion in what appears to be essentially homogenous goods markets. But one limitation of the field evidence is that it rarely can include truly homogeneous products as typically assumed in theory. Even when the items being purchased are identical products produced by the same manufacturer (as Baye et al. consider), the retail distribution typically features differences in customer service, reputations, and (particularly relevant for Internet retailing) beliefs in delivery reliability. The observed price dispersion in the field data might therefore reflect some of these unobserved differences between sellers of an identical product. Laboratory methods provide alternative empirical evidence by controlling and manipulating these variables that are difficult to measure in the field.

In this paper we examine laboratory markets that are broadly consistent with assumptions typically made in competitive models of costly buyer search and informative price advertising.

The experiment is specifically structured by Robert and Stahl's stylized model in which buyers' information is endogenously determined along with seller prices, advertising and profitability. Sellers are not capacity constrained, and buyers demand at most one unit per trading period. In the unique symmetric equilibrium, sellers either charge a high unadvertised price or randomize in an interval of lower advertised prices, and buyers conduct at most one search per period. Increases in either search or advertising costs raise equilibrium prices, and equilibrium advertising intensity decreases with lower search costs and higher advertising costs. Our results are consistent with the pattern from previous posted-price market experiment in that the behavior deviates from quantitative theoretical predictions, but broadly conforms to the equilibrium comparative statics (Brown-Kruse et al., 1994, Morgan et al. 2006a,b). Sellers in our experiment also post lower advertised than unadvertised prices, as predicted. In all treatments, however, prices are significantly lower than the equilibrium price interval and sellers earn profits that are a fraction (12 to 40 percent) of the equilibrium level. Prices are also not as dispersed as predicted by theory. Buyers' search decisions, although approximately optimal, exhibit a small bias towards under-searching. Sellers advertise more intensely than in equilibrium, which results in widespread diffusion of information. Consequently, market outcomes more closely resemble a perfect information, Bertrand-like equilibrium than the imperfect information, mixed strategy equilibrium that features significant seller market power.

These results with human buyers contrast sharply with our previous study (Cason and Datta, 2006), which reports sessions with robot buyers that are pre-programmed to search according to an observable equilibrium reservation price strategy. Those sessions with robot buyers provide almost uniformly positive support for the theoretical model. The data support all of the model's comparative static predictions; and similar to this study, the only systematic deviation from the quantitative predictions is that observed advertising rates exceed the predicted rates. The crucial difference however is that unlike this study, the observed price *levels* in robot buyer sessions are broadly consistent with the predicted equilibrium price levels. A comparison between these two studies indicates that a fundamental difference exists in the *behavioral* equilibrium when the robot buyers' reservation price search strategies are replaced with human buyers that make (possibly non-optimal) search and purchase decisions. This difference stems from the assumption, imposed on the robot buyers, that buyers' expectations and behavior is unaffected by repeated observation of non-equilibrium prices. With human buyers, low seller

prices and advertising encourages differing buyer search behavior and pushes prices to still lower levels, away from equilibrium. While the empirical relevancy of any model can be assessed fully only with data from multiple sources, these laboratory results suggest that this type of equilibrium involving two levels of mixed strategy—for advertising and pricing—may not be robust to bounded rationality or joint buyer-seller learning (e.g., Hopkins and Seymour, 2002).

We discuss later the contrast between sessions with human and robot buyers, and only point out here that such dramatic differences in outcomes are not anticipated by earlier research that does not feature seller advertising. For example, Cason and Friedman (2003) and Davis and Williams (1991) employ both robot and human buyers in different posted offer market treatments. They find that although the results were more variable in the human buyer sessions than in the robot buyer sessions, the equilibrium predictions were generally supported even with human buyers.

The remainder of the paper is organized as follows. Section 2 presents the unique equilibrium of the Robert and Stahl (1993) model of costly advertising and search, simplified to the experimental conditions and parameters chosen for our laboratory implementation. It also summarizes the model’s comparative statics and hypotheses for the experiment, based on formal propositions and proofs drawn from Cason and Datta (2006). Section 3 provides details of the experimental design and procedures, and Section 4 contains the empirical results. Section 5 concludes.

## 2. Theoretical Model

Consider a market where  $n$  identical sellers compete to supply a homogenous product to a fixed number of buyers who have an identical valuation  $v$  for one unit of the good. Each seller produces at a constant marginal cost, which is normalized to zero, and has no fixed costs or capacity constraints. The sellers can inform the buyers about their price through advertising at a cost  $A$ . We assume that if sellers choose to advertise, they reach a fixed proportion  $\alpha$  of the buyers.<sup>1</sup>

Buyers are *a priori* uninformed about the prices in the market but can obtain this information either through receiving an advertisement from sellers or by conducting search at a

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<sup>1</sup> This is a simplifying assumption. In the original Robert and Stahl model, sellers also choose their advertising intensity; i.e., the proportion of buyers that they wish to reach. Making the advertising intensity decision exogenous, however, has no impact on the qualitative results.

cost  $c$  per price quote. This search is without replacement and with perfect recall. Each buyer has an independent probability of being informed of seller  $j$ 's price. The ads are assumed to be randomly distributed across buyers; i.e., sellers cannot target their advertising nor can the buyers influence the probability of receiving an advertisement.

At the beginning of each period, all sellers choose simultaneously their price and make their binary advertising decision—whether or not to advertise this price. After advertised prices are conveyed to (some of the) buyers, all buyers make their search decision. Buyers who receive no ad must search to receive their first price quote. Buyers who receive an ad can choose to buy from a seller whose ad they have received or conduct costly sequential search to obtain additional price quotes from other sellers.

Optimal buyer search endogenously determines a unique reservation price,  $r$ , which equates the marginal benefits of search to the cost of search,  $c$ . According to the reservation price strategy, buyers will continue search until they find a price that is less than or equal to  $r$ . Further, each buyer buys one unit of the good from the seller offering the lowest advertised price,  $p_j$ , only if  $p_j + c \leq \min\{r, v\}$ .<sup>2</sup>

In the unique symmetric perfect Bayesian equilibrium the sellers randomize between advertising and not advertising. The (mixed) price strategy is given by the price distribution  $F(\cdot)$  with support contained in  $(0, v)$ . More specifically, the support of the distribution is the union of the interval  $[p_l, r-c]$  and the reservation price  $\{r\}$ , where  $p_l$  is the lower bound of the equilibrium distribution.<sup>3</sup> Since buyers will never purchase at a price greater than their reservation price,  $r$  is the maximum price that the sellers will ever charge. Moreover, the distribution has a mass point at  $r$  since the sellers will never charge a price between  $r$  and  $r-c$ .<sup>4</sup> Finally, there is no mass point in the distribution at or below  $r-c$  since it is always profitable to break a potential tie by marginally decreasing the advertised price.

The specific functional form of the equilibrium seller advertising and pricing strategy is summarized in the following proposition.<sup>5</sup>

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<sup>2</sup> This follows from the fact that a buyer who decides to buy at the advertised price will still have to incur a one-time transportation cost of  $c$  to procure the good from the seller.

<sup>3</sup> Since advertising intensity is exogenously fixed at  $a > 0$ , the equilibrium outcome does not converge to Bertrand equilibrium as informational costs go to zero.

<sup>4</sup> The choice of a price less than  $r$  is justified only if the seller decides to advertise the price, but given the buyer's search/transportation cost  $c$  to purchase at the advertised price, this price must be at most  $r-c$ .

<sup>5</sup> For formal proof see Cason and Datta (2006).

**Proposition 1:** Given search cost  $c > 0$ , advertising intensity  $\alpha > 0$  and  $n \geq 2$  sellers, if the advertising cost  $A$  is strictly less than  $\frac{(v-c)(n-1)\alpha}{n}$ , there exists a unique symmetric mixed strategy equilibrium wherein sellers set price according to the following distribution function:

$$F(p) \equiv \begin{cases} \frac{1}{\alpha} \left[ 1 - \left[ \frac{A[(na+1-\alpha)(r-c)-p(1-\alpha)]}{pa[(na+1-\alpha)(r-c)-r]} \right]^{\frac{1}{n-1}} \right] & \text{if } p \in [p_l, r-c] \\ F(r-c) & \text{if } p \in (r-c, r) \\ 1 & \text{if } p \geq r \end{cases} \quad (1)$$

where the lower bound of the distribution is given by  $p_l = \frac{A(na+1-\alpha)(r-c)}{\alpha((na+1-\alpha)(r-c)-r)+(1-\alpha)A}$

and the (maximum) reservation price,  $r$ , is implicitly given by  $c = \frac{\int_{p_l}^{r-c} (1-\alpha)F(p)dp}{[1-F(r-c)]}$ .

Figure 1 illustrates the equilibrium price distributions for parameter values used in the experiment. It also provides a graphical presentation of the comparative statics regarding search and advertising costs. Formal statements of the comparative statics and other technical details are contained in Proposition 2 and 3 of Cason and Datta (2006).<sup>6</sup>

Table 1 summarizes the parameter values used in the experiment and the theoretical predictions for the various treatments. In most experimental studies, such strong quantitative predictions rarely hold very precisely. Our empirical analysis will therefore focus on the weaker, comparative static predictions summarized by the following hypotheses. The first three hypotheses pertain to seller pricing and advertising behavior in response to varying levels of search and advertising cost. The last two hypotheses concern buyer search behavior.

***Hypothesis 1a:* An increase in search cost results in higher prices.**

***Hypothesis 1b:* An increase in search cost results in increased incentives for the sellers to advertise, and higher seller profits.**

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<sup>6</sup> Formal proofs of comparative statics require certain elasticity conditions (elasticity of  $r$  with respect to  $A$  and  $c$ ) to be satisfied. These in turn depend on the ratio of search cost to advertising cost. For formal statements please refer to Cason and Datta (2006). Numerical computations show that for  $n=4$  and  $\alpha=0.4$  all elasticity conditions are satisfied when the two information costs differ by at least two orders of magnitude (in fact, whenever  $c:A < 100:1$ ). However, making such large differences in information costs is unrealistic and also fails to represent a situation in which both seller advertising and buyer search costs can significantly affect equilibrium outcomes, which is our primary interest in this study.

As search cost increases, buyer search propensity decreases. This decline in buyer search has two effects. One, it gives the sellers more market power, which manifests itself in higher prices. Two, it creates an incentive for the sellers to inform the buyers through advertising. Since the benefit of higher prices may be offset by increased advertising expenditure, the impact of search cost on seller profit would appear to be ambiguous. However, for a wide range of parameters the price effect dominates the increased advertising expenditure effect so that the profit increases as  $c$  increases.

***Hypothesis 2a: An increase in advertising cost results in higher posted prices.***

***Hypothesis 2b: An increase in advertising cost reduces the sellers' propensity to advertise and results in higher profits.***

The direct effect of an increase in advertising cost is to reduce the seller's incentive to advertise. The indirect effect of an increase in advertising cost is a downward shift in the cumulative price distribution so that sellers place a greater weight on higher prices. Higher prices combined with lower propensity to advertise result in increased profit.

***Hypothesis 3: Unadvertised prices are higher than advertised prices.***

This follows directly from the characterization of the equilibrium: sellers either charge a high unadvertised price or randomize in the interval of lower advertised prices. The reservation price  $r$  is the maximum price charged by a seller. Advertising this price will not induce the informed buyers to visit the seller to make a purchase, since the effective purchase price becomes  $r+c$ . Conversely, a seller will choose a price below  $r-c$  only if she advertises it.

***Hypothesis 4: Controlling for observed prices and beliefs, buyers search more frequently when search costs are lower.***

Laboratory studies by Schotter and Braunstein (1981) and Cason and Friedman (2003) have documented the monotonic relationship between cost of search and propensity to search.<sup>7</sup> In the present model, a lower cost of search implicitly yields a lower reservation price  $r$ . Therefore, the likelihood that any given price distribution includes prices greater than  $r$  is higher when the

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<sup>7</sup> Our experiment differs from these studies in two key respects: it allows for seller advertising, and buyers can perfectly recall previously observed prices.

search cost is low. Accordingly, buyers are more likely to search in case of low search cost. Additionally, Kogut (1990) notes that buyer search decisions are also influenced by the “sunk” search cost and suggests that subjects’ account for their total profit and not just their marginal profit from additional search. This implies that buyers are more likely to end search prematurely (and return to a previously observed price), when the cost of search is higher.

***Hypothesis 5: Buyers search according to an optimal search rule.***

The perfect Bayesian Nash equilibrium is characterized by “no real search.” That is, in equilibrium, sellers do not price above the reservation price  $r$  and therefore, buyers do not find it optimal to search more than one seller. This result, however, is based on a number a strong assumptions that may not hold in practice. Differing experience is likely to encourage differing beliefs and behavior, which may delay or even prevent convergence to equilibrium. In particular, buyers in the experiment may hold imprecise beliefs because they face an endogenous price distribution that is both unknown and unstable. Sellers’ pricing and advertising strategies may in turn be responsive to the (possibly non-equilibrium) buyer search strategy.

This does not imply, however, that buyers do not follow a search rule. Hey (1982, pg. 72) suggested that most subjects follow some sort of self-imposed reservation rule, wherein “they stop search if a price quote is received that is ‘sufficiently’ low.” The fact that this reservation price need not be optimal forms the basis for Sonnemans’s (1998) conjecture that subjects may be “satisfiers” rather than “maximizers” as assumed by economic theory. While it is plausible that human buyers follow some search rule, they may not strictly follow a reservation price strategy, much less an identical and unchanging reservation price strategy as called for in the equilibrium. Therefore, assessment of the optimality of some particular search behavior should account for the actual price draws the buyer can receive, and additional search should be regarded as optimal if the expected price reduction exceeds the cost of search. Our analysis compares the buyers’ search decisions to an optimal search rule that is based on an “empirical” reservation price which changes over time in response to the history of seller price offers.<sup>8</sup>

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<sup>8</sup> This is only an approximation since buyers’ beliefs are not observed directly. Moreover, since our design limits the number of sellers in each market, consistent with the finite horizon search literature, the reservation price should be increasing in the number of searches. In a labor market context with a search environment similar to ours, both the theoretical (e.g. Gronau, 1971, and Lippman and McCall, 1976) and the experimental literature (e.g. Schotter and Braunstein, 1981, and Cox and Oaxaca, 1989) have concluded that “the introduction of a finite horizon leads to abandonment of the constant reservation wage property ...[although] the qualitative implications of the model for

### 3. Experimental Design and Procedures

#### 3.1 Experimental Design

Each market comprises 4 sellers and 5 buyers. The trading institution modifies the standard posted-offer environment by incorporating two treatment variables – seller advertising and buyer search. Sellers can reach a fixed proportion  $\alpha = 0.4$  of the buyers (that is, 2 of the 5 buyers) by incurring an advertising cost  $A$ . Buyers can obtain price quotes from sellers by engaging in search at a cost  $c$  per quote. The experimental design is summarized in Table 2.

We vary advertising costs within sessions and search costs across sessions.<sup>9</sup> In six of the markets, referred to as “High-Low-High,” sellers face a high advertising cost ( $A = 5$ ) in the first 25 periods, low advertising cost ( $A = 2$ ) in the next 25 periods and high advertising cost again in the last 25 periods. The order is reversed for the six “Low-High-Low” markets. The two levels of buyer search cost used in the experiment are  $c = 1$  and  $c = 6$ . The data identify the effect of a change in search cost by making the relevant across-sessions comparisons while within-session comparisons assess the effect of change in advertising cost.

To minimize repeated game effects and reduce the incentives for collusive behavior, we randomly re-match subjects each period. We made this design choice because we are testing a static model. The drawback of this design feature is that only the six of the 12 markets are statistically independent; however, the data analysis accounts for the correlation of repeated observations contributed by individual subjects through random effects error specifications.

#### 3.2 Experimental Procedures

The experiment consisted of six 120-minute sessions, each containing 18 subjects, all conducted in the Vernon Smith Experimental Economics Laboratory at Purdue University. A computerized interface using the software z-Tree was used to implement the experimental environment (Fischbacher, 2007). The subjects were recruited from undergraduate economics classes, and all were inexperienced in the sense that no one participated in more than one session of this type. Upon arrival, the subjects were seated at separate, visually isolated computer terminals and no communication was permitted throughout the session. Each subject received a

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changes in variables such as the direct costs of search are unchanged” (Cox and Oaxaca, 1989, pg. 306). Schotter and Braunstein's data show decreasing reservation wages for their experiments which is consistent with the finite horizon search theory.

<sup>9</sup> Morgan et al. (2006b) also vary advertising cost within session.

set of instructions and record sheets, included as Appendix A. The instructions were read aloud, so we assume that the information contained in them was common knowledge.

Each session proceeded through a sequence of 75 trading periods. All sellers had the same homogenous good whose cost of production was normalized to zero. The sellers did not face any capacity constraint. Each buyer demanded at most one unit, and received a resale value of 60 experimental francs if they purchased this unit. At the start of a trading period, each seller posted a single price offer and chose whether to advertise this price. After all sellers made their pricing and advertising decision, some of the buyers received a price advertisement. Each advertising seller's price was equally likely to be shown to each buyer and the advertisements were distributed randomly. Note that some buyers could receive multiple ads while others in the same market might not receive any ads. Buyers then made their search and purchase decisions. The buyers who received advertisement(s) decided whether to search for other prices or to buy a unit at an advertised price. If a buyer decided to search other sellers, he had to pay the transportation cost for each different price quote. If he decided to buy at the advertised price, he had to pay a one-time transportation cost to obtain the good from the seller. All transactions, costs and earnings were in experimental francs, which were converted to U.S. dollars at the end of the experiment using a known but private dollar conversion rate. The earnings typically ranged between \$15 and \$40 per subject, with an average of \$25.50.

At the end of each period, each seller was informed about the number of units he or she sold, and each buyer and seller received a summary of their own current period and cumulative earnings. Following Cason and Friedman (2003) and Morgan, Orzen and Sefton (2006b), at the end of each period in four of the six sessions all buyers and sellers also learned the prices, quantities sold and advertising decisions of all sellers in their market. These prices were displayed from the lowest to the highest and did not reveal the identities of the individual sellers.<sup>10</sup> In the analysis we code these four sessions as *full information* sessions, and the other two sessions (which reported only the subjects' private outcomes) as *partial information* sessions. The difference in information feedback led to only minor differences in results.

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<sup>10</sup> Abrams, Sefton and Yavas (2000) did not reveal to the seller the prices posted by other sellers in the market. They found that prices, even in the later periods, deviated significantly from the predicted level. Cason and Friedman (2003) on the other hand, found a much stronger support for the theoretical prediction. Part of this difference in the results might be explained by difference in the information feedback to the sellers. Offerman, Potters and Sonnemans (2002) manipulate the feedback in a quantity-setting oligopoly experiment without search or advertising, and find that outcomes vary with the feedback in directions predicted by models of behavioral dynamics.

## 4. Experimental Results

We divide the results into four subsections. Section 4.1 presents an overview of the price and advertising data to orient the reader. Section 4.2 provides analysis of seller pricing and advertising behavior and section 4.3 analyses buyer search and purchase behavior. Section 4.4 calculates the seller best-responses, given the buyer search behavior and other sellers' choices.

### 4.1 Overview of Posted Prices

Figures 2 through 4 summarize the prices and present the most striking departures from the equilibrium model that we are aware of, in the experimental literature on market with incomplete information. Figures 2 and 3 report all individual prices in all 75 periods in two of the six sessions. Open circles denote advertised prices and closed squares denote unadvertised prices. The connected dashed and solid lines display median advertised and unadvertised prices, and the horizontal lines indicate equilibrium price predictions. The equilibrium predictions shift in periods 26 and 51 because we switched advertising cost every 25 periods.

The figures indicate that prices tend to begin above, within or below the equilibrium range for the first few trading periods. Without exception, however, sellers eventually post prices that fall below 5 experimental francs. Only the treatment switchovers that occur every 25 trading periods reliably interrupt the downward price trends, although in some sessions (such as the last few trading periods shown in Figure 3) sellers are able to increase prices within a treatment run. Figure 4 shows the median posted prices for all sessions, with different treatments separated in different panels. It clearly indicates that downward price pressure is a robust, dominant feature of our data. Sellers ultimately post prices that are almost entirely below the lower endpoint of the equilibrium price interval in all sessions and all treatments. Median prices typically fall below 5 francs, except in the lower-right treatment that features the highest advertising and search costs.

Figures 2 and 3 also provide an initial impression of the “over-advertising” that we document formally in the next subsection. The open circles vastly outnumber the closed squares, indicating that sellers more often choose to advertise their prices.

### 4.2 Seller Advertising and Pricing Behavior

Seller Advertising Behavior. Panel A of Table 3 presents the observed frequency of advertising in the first 10 as well as the last 15 periods of each treatment run for different search cost-

advertising cost combinations. A comparison to the theoretical prediction reveals that the observed advertising rate always exceeds the model's prediction. Equilibrium advertising rates range between 0.31 and 0.63 across the four treatments, while the actual advertising rates average between 0.53 and 0.94 when calculated over the first 10 periods of each treatment run. The frequency of advertising declines in later periods, but still remains well above predicted levels in all treatments. While aggressive advertising behavior is a prominent feature of the data, note that the ordering of the advertising propensity across various treatments is nevertheless consistent with the comparative statics predictions of the model. Advertising rates always increase with higher buyer search costs and decrease with higher advertising costs. This result of "ordered over-advertising" is consistent with the results of robot buyer sessions with search or advertising costs documented in Cason and Datta (2006) and Morgan et al. (2006b).

In order to assess the statistical significance of these results we use panel data econometric models with a subject level random effects error specification. Panel B of Table 3 reports the results of probit models for seller advertising decision. The models include 1/period to control for time trend. Since the time trend is more pronounced in the early periods of each run, we present estimates based on all 25 periods in Models 1 and 2, as well as based on the last 15 periods of each treatment run in Models 3 and 4.<sup>11</sup>

***Result 1: An increase in advertising cost reduces the sellers' propensity to advertise.***

Support: Panel A of Table 3 indicates that in both search cost treatments, the advertising rate is always lower with higher advertising costs (0.38 to 0.70) than with lower advertising costs (0.61 to 0.83). The probit models shown in Panel B indicate that this impact of advertising cost on seller advertising is significant at one-percent level in all specifications and for both all periods and late periods data.

***Result 2: An increase in search cost increases the sellers' propensity to advertise.***

Support: As search cost increases, buyer search intensity decreases. This creates increased incentives for the sellers to inform the buyers about their prices. Panel A of Table 3 provides

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<sup>11</sup> We also examined a variety of alternative model specifications. For example, we added an interaction term for the high search cost and high advertising cost dummy variables to allow for different advertising rates in each of the four treatments. This interaction term was always statistically insignificant and including it does not change any of the general conclusions we draw in the reported analysis.

strong support for this prediction. For instance, when  $A = 5$ , as search cost increases from  $c=1$  to  $c=6$  the late periods' frequency of advertising almost doubles from 0.38 to 0.70. The regressions in Panel B provide statistical evidence that enables us to reject the null hypothesis of no search cost treatment effect at any conventional level of significance, for different model and period specifications. In fact, a comparison of the advertising cost and the search cost coefficient estimates suggests that the indirect effect of search cost on seller advertising propensity is at least as important as the direct effect of advertising cost.

Note that although the advertising rate generally exceeds the model's prediction, the positive coefficient estimate on  $1/\text{period}$  indicates that the frequency of advertising tends to decrease over time. This decline in advertising propensity may be related to the decline in prices, which is documented in greater detail in the next subsection.

Seller Pricing Behavior. Panel A of Table 4 summarizes the mean price in the last 15 periods for different cost treatments. The over-advertising documented in the previous subsection results in a more transparent pricing environment, which appears to lead sellers to price more aggressively than predicted in equilibrium. Observed prices are always too low compared to the theoretical expected price, and in fact they are too low even compared to the theoretical minimum price.

***Result 3: An increase in advertising cost leads to higher prices, but only in the presence of high buyer search costs.***

Support: An increase in advertising cost shifts the theoretical distribution such that more weight is placed on higher prices. Both Cason and Datta (2006), using a posted offer environment similar to ours, and Morgan et al. (2006b), using a clearing-house model, find support for this hypothesis. The observed mean prices in our study (Panel A of Table 4), however, provide only mixed support. As advertising cost increases from  $A=2$  to  $A=5$ , the mean advertised price increases substantially when  $c=6$  but it declines slightly when  $c=1$ . Similarly, although the random effect regression models (Panel B of Table 4) reject the null hypothesis that there is no advertising cost treatment effect at conventional levels of significance in all specifications and for both all and late periods data; we find that advertising cost acts as a “facilitating device” to raise prices only when search costs are high. Higher advertising costs exert a smaller but statistically significant downward influence on prices when search costs are low.

**Result 4: An increase in search cost leads to higher prices, but only in the presence of high advertising costs.**

Support: Numerous experimental studies on search models have found that in the absence of public information about prices, search costs do tend to raise prices although monopoly prices as implied by the Diamond paradox are not consistently observed.<sup>12</sup> Price averages in panel A and random effects regressions in Panel B of Table 4 indicate that in spite of the surprisingly low prices, the data support the comparative statics for search cost when advertising costs are high. Search costs do not significantly influence prices when advertising costs are low, perhaps because advertising is very frequent in this case (recall Table 3).

**Result 5: Unadvertised prices are higher than advertised prices**

Support: Analyzing the data for each search-ad cost difference separately (Panel A of Table 4), in all cases, except one, the average unadvertised price exceeds the average advertised price. Random effects models which control for time trend and sequence fixed effects also provide statistical evidence in favor the alternative hypothesis that advertised price is lower than the unadvertised price. The current period advertising decision is obviously endogenous, so we use an instrumental variables approach in which the actual advertising choice is replaced by the predicted advertising probability based on the probit models reported in Table 3. The negative advertising probability coefficients in models 2 and 4 of Table 4 indicate that advertised prices are lower than unadvertised prices.

### **4.3 Buyer Search Behavior**

Cason and Datta (2006) examines an identical market environment with automated buyers who follow the reservation price strategy. Unlike the present study, there we found that despite aggressive seller advertising the results support all the model's comparative statics price predictions and price levels were not so dramatically different from equilibrium levels. The next obvious question is whether the very low prices observed here are a consequence of human buyer search behavior.

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<sup>12</sup> Grether, Schwartz and Wilde (1988), Davis and Holt (1996), Dufwenberg and Gneezy (2000), Abrams, Sefton and Yavas (2000), Cason and Friedman (2003), Morgan, Orzen and Sefton (2006a).

Panel A of Table 5 presents overall search rates by treatment for buyers who receive at least one ad. These rates indicate the probability that the buyer does not buy immediately at the advertised price, but instead decides to search another seller. We include in this analysis only the nondegenerate cases in which buyers have received at least one advertised price but less than all four advertised prices. Panel B of Table 5 presents the rates of the first “non-trivial” search for buyers who receive no ad. Recall that buyers who do not receive any ad must search to get their first price quote, so these rates are the probability that such a buyer searches more than one seller. The table presents search frequencies based on the first 10 as well as the last 15 periods of each 25-periods treatment run.

Recall that in equilibrium, buyers search and purchase from only one seller because sellers should never post prices above buyers’ reservation price. In the experiment, nearly all the posted prices were below the equilibrium reservation price, so according to the optimal search strategy, the equilibrium search rate for all cells of Table 5 would be near zero. Out of equilibrium, imprecise buyer beliefs, disequilibrium price distributions that change over time, or other factors, make searching more attractive. Table 5 indicates that search frequency typically declines in the later 15 periods compared to the first 10 periods as prices tend to stabilize following initial adjustment to the new treatment conditions. Comparing search rates across treatment variables, an increase in search costs clearly decreases the frequency of search. For example, Panel A indicates that the search frequency of ad-receiving buyers more than doubles (from 9 percent to 24 percent) in the  $c=6$  treatment compared to the  $c=1$  treatment in the later periods of the treatment runs. The corresponding increase in Panel B is also high. The impact of advertising cost on buyer search decisions is indirect in theory and in practice differs greatly depending upon whether or not buyer receives an ad. If buyer receives at least one ad, advertising cost does not influence her propensity to engage in further search (16 versus 15 percent in late periods when  $A=2$  and  $A=5$ , respectively). If on the other hand, a buyer does not receive an ad, she is more likely to search when the ad cost is low (29 versus 18 percent in late periods when  $A=2$  and  $A=5$ , respectively).

A series of (unreported) random effect probit regressions formally document these observations. For instance, controlling for a variety of other factors, we find that the impact of search costs on search frequency is significant at the one-percent level in various specifications and for both the late periods and all periods data. Moreover, including a range of behavioral

variables, we find that on the whole buyers respond reasonably to the potential search benefits. Buyers search with greater frequency when the lowest price advertisement they receive is higher, and also when they only receive one advertised price, compared to when they receive two or three advertised prices.

The above documentation of search behavior does not indicate whether buyers are searching optimally. Previous experimental research that has studied the simpler problem of sequential search for a price (or wage) given a fixed and known price or wage distribution (e.g., Schotter and Braunstein, 1981; Cox and Oaxaca, 1989; Harrison and Morgan, 1990) indicates that searchers behave approximately optimally with a small bias towards stopping search too soon.<sup>13</sup> However, unlike this earlier research, buyers in our study face an unknown and unstable price distribution. Moreover, evaluating the optimality of buyer search is complicated further because the realized distribution of seller prices differs vastly from the equilibrium distribution. The unique equilibrium reservation price strategy is obviously no longer optimal. Indeed, depending on the buyers' beliefs, a reservation price strategy may not even be optimal (Cox and Oaxaca, 2000). Nevertheless, we can still apply the logic of an optimal stopping rule for this sequential search problem to estimate whether the buyers' search strategy, *ex post*, is approximately optimal. Our analysis strategy involves comparison of the search behavior and expected returns from search to estimate whether buyers tend to over- or under-search given the observed prices and advertising decisions of sellers.

First, we calculate an approximate "empirical" reservation price. Analogous to its equilibrium counterpart, this reservation price equates the expected benefit from search to the cost of search. The primary difference, however, is that in this case the conditional expectation of price is computed over *actual* price draws that a buyer could have received upon search. To account for the steep decline in prices typically observed in the initial periods of a treatment run, for the first 15 periods we base this expected value on an historical three-period moving average, followed by a fixed 10-period average during the final ten periods of the treatment run where prices are more stable. The empirical reservation price indicates whether searching an additional seller is optimal or not, based on the actual price draws available to the buyers.

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<sup>13</sup> Hey (1981, 1982) and Sonnemans (1998) explain this more common error of stopping search too soon by noting that expected losses from errors are asymmetric, with smaller losses from a higher-than-optimal reservation price.

Second, we compare actual buyer search behavior to the (approximately) optimal search rule. As before, we draw a distinction between a buyer who receives at least one ad and a buyer who receives no ads. Recall that the search cost must be paid to buy from an advertising seller, so for a buyer who receives ad(s) search is optimal if the (minimum) observed price *plus* the search cost is greater than the empirical reservation price. By contrast, a buyer who receives no ad must search to receive a price quote, so the search cost becomes sunk and the decision of whether an additional search is optimal depends simply on whether the minimum observed price exceeds the empirical reservation price.

When buyers fail to search optimally, it is useful to divide their mistakes into 2 types of errors: undersearch and oversearch.<sup>14</sup> Table 6 presents the optimal search comparisons for the first two search decisions made in each period.<sup>15, 16</sup> When  $c=6$ , shown in the lower part of the table, 85 to 90 percent of the search decisions are optimal. Errors that occur more commonly take the form of undersearch rather than oversearch. In cases where a buyer receives at least one ad, undersearch is ten times more common than oversearch, while for a buyer who receives no ad undersearch is more than twice as common as oversearch. When  $c=1$ , the proportion of optimal search decisions is slightly lower but still quite high. Oversearch and undersearch rates are similar when  $c=1$ , in contrast to the more systematic undersearch when  $c=6$ .

Overall, the observed search choices compared to an empirically-based optimal reservation price strategy indicates that the buyer search behavior is close to optimal. Consistent with the previous literature on sequential search, the pattern of error exhibits a bias towards stopping too soon (undersearch), especially with high search costs.

#### 4.4 Seller Best Responses

The previous section documents that buyer search decisions are approximately optimal given seller pricing and advertising. In this section we show that the low prices posted by sellers

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<sup>14</sup> Type 1 error or undersearch: Buyers did not search when they should have searched i.e., buyers did not search when the observed price draw (possibly inclusive of search cost) is greater than the empirical reservation price. Type 2 error or oversearch: Buyers searched when they should not have searched i.e., buyers searched when the observed price draw (possibly inclusive of search cost) is less than the empirical reservation price.

<sup>15</sup> The first two search decisions comprise about 95 percent of decisions made by buyers in case of low search cost. When  $c=6$ , search propensity decreases further and therefore these computations include 99.4 percent of all buyer search decisions.

<sup>16</sup> We focus on the impact of varying levels of search cost on buyer search decision. Search costs enter buyer decisions directly, and as discussed earlier in this subsection, have a pronounced and predictable effect on search behavior. The impact of ad cost, on the other hand, is indirect since it operates through changing seller behavior.

in later periods, though far from the equilibrium predictions, are close to best-responses to the pricing and advertising decisions of other sellers and the search decisions of buyers.

To document this we calculate the sellers' empirical best responses based on buyer search behavior and on 1000 simulated iid draws of three rival sellers advertising and pricing strategies. We select these draws from all sellers choices during the final 15 periods of each treatment, where prices tended to stabilize following the initial adjustment period to a new treatment condition. The simulation accounts for buyer search and purchase behavior by translating each combination of four advertising and price choices into an expected sales quantity using an ordered logit model, also estimated on these final 15 periods of each treatment. This generates a probability of selling zero through 5 units, which in turn determines the expected profits for that price and advertising choice.<sup>17</sup> In other words, we estimate the expected profitability of each possible price and advertising strategy by simulating 1000 rival seller strategies and a probabilistic model of buyer search and purchasing strategies, all based on the late periods of each treatment. Finally, the simulation employs a grid search over prices (at 5-cent increments) to identify the best strategy.

Table 7 summarizes the best-response advertising and pricing strategy for the different treatments. In three out of the four treatments, the best strategy for the seller is to advertise and post relatively low prices. In particular, with  $A=2$ , the best strategy is to advertise and set a price of 4.45 or 4.65. Best Response prices are higher for higher advertising costs, so that with  $A=5$  and  $c=6$ , the best strategy is to advertise a price of 8.35. It is only when  $A=5$  and  $c=1$  that advertising is not the best strategy for the seller. Due to the inexpensive search cost, on average the sellers are not able to recover enough of their advertising cost to make advertising worthwhile, and an unadvertised but low price of 5.95 yields the greatest expected profit. Figures 5 and 6 illustrate the expected profit from the binary advertising decision for a range of price levels, where profit calculations are based on the simulations described above. In all three of treatments where advertising is an optimal strategy, expected profits from advertising are 15 to 20 percent higher than the most profitable non-advertised price.<sup>18</sup>

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<sup>17</sup> We estimated separate ordered logit models for the different number of advertised prices, and included own and rival prices (ordered from lowest to highest and distinguishing advertised and unadvertised prices). We also included an indicator dummy variable to identify high prices—those more than one standard deviation above average prices—because sales data indicate a substantial drop in realized sales quantity for prices well above the mean level.

<sup>18</sup> Although the expected profit curves are relatively flat near the best response, recall that they are absolutely flat in the mixed strategy equilibrium.

The right side of Table 7 permits a comparison of the best-response advertising and pricing strategy with the observed seller choices. The best-response prices, ranging from 4.45 to 8.35, are not very different from the observed average prices. Furthermore, consistent with the observed prices, the best-response prices calculated from these simulations are well below the lower bound of the equilibrium price distribution. Observed advertising rates are by far the lowest (38 percent) in the only treatment where advertising is not a best-response ( $c=1$ ,  $A=5$ ). The remaining three treatments have the highest advertising rates in equilibrium (Table 1) and also the highest observed advertising rates, ranging from 61 to 83 percent during the late periods. This analysis, while admittedly ad hoc, suggests that sellers' price and advertising decisions did not deviate substantially from their empirical best-responses calculated from rival sellers' strategies and buyer search decisions.

We conclude our discussion of the experimental results by drawing parallels between this study and Cason and Datta (2006). The only difference is that our earlier study imposed an equilibrium search strategy upon the robot buyers, while the present study allows for the possibility of disequilibrium (human buyer) search behavior. In both studies, (1) sellers advertise more frequently than predicted so that buyers are much more price informed than in equilibrium, (2) seller advertising rates are ordered according to the equilibrium predictions, and (3) advertised prices are usually lower than unadvertised prices. However, while the advertising behavior is consistent across the two studies, the pricing behavior is very different. In a model where agents on each side of the market are *ex ante* identical but information dissemination and acquisition makes the buyers *ex post* heterogeneous, Robert and Stahl have shown that the unique symmetric equilibrium involves dispersed prices. In both of our laboratory studies, aggressive seller advertising results in widespread diffusion of information that considerably reduces buyer heterogeneity. While with robot buyers sellers still post dispersed prices that correspond to the equilibrium predictions of the model, the observed price levels in the present study are neither quantitatively as high nor as dispersed as predicted by theory. What is the plausible explanation for this divergence between the pricing behavior of the two studies?

In Cason and Datta (2006), buyers are programmed to follow the equilibrium reservation price strategy, and so they will not search if the expected price (inclusive of search cost) is less than unique theoretical reservation price. Thus, for these automated buyers only the absolute price levels matters while the relative ranking of prices across sellers is immaterial. The human

buyers in this study, on the other hand, have no reason to maintain unrealistic beliefs about the equilibrium price distribution and adhere to the equilibrium reservation price strategy. They should instead update their beliefs and search strategies when they observe lower prices in the early periods. Moreover, their willingness to search, combined with sellers' propensity to over-advertise, makes the buyers more price sensitive because they frequently observe more than one price offer before purchase. Table 8 indicates that in equilibrium, the probability that a buyer observes more than one price prior to purchase ranges from 8 to 26 percent across treatments. By contrast, the rate that buyers actually observe more than one price before purchase is 2 to 6 times higher than the equilibrium rate, typically near 50 percent during the first 10 periods. While this rate declines somewhat in the later periods, buyers always observe multiple prices more often than in equilibrium, which translates into a more price elastic demand facing the individual sellers. This drives seller prices below equilibrium. In the spirit of Burdett and Judd (1983) and Gale (1988), our results confirm that that prices move towards the perfectly competitive outcome as the buyer's probability of observing more than one price increases. Our results are also consistent with the competitive pricing typically observed in posted offer laboratory markets with perfect price information and with three or more sellers.<sup>19</sup>

## 5. Conclusion

Economists have developed a variety of search models to help understand how costly information acquisition by buyers can generate dispersed price equilibria in homogeneous goods environments (Salop, 1973; Varian, 1980; Burdett and Judd, 1983; Stahl 1989, 1996). This experimental study tests a simplified version of Robert and Stahl's (1993) model that introduces seller advertising in a sequential buyer search framework. This environment allows information to be both disseminated by the sellers and acquired by the buyers, which is more realistic than the more simplified, perfect information posted offer environment often studied in the laboratory.

The experiment provides mixed support for the theoretical mixed strategy equilibrium. On the one hand, the model is very successful at predicting how subjects' decisions adjust to

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<sup>19</sup> See, for example, Holt (1995) for an early survey. Two other experimental studies deserve mention. Coursey et al. (1984) and Brown-Kruse (1991) present the comparison of human subjects buyers with computer simulation of demand in contestable market experiments. They find that the mere potential for demand withholding imparts the greater "disciplining power" to the buyers and therefore, the presence of human buyers facilitates faster convergence to the competitive equilibrium. While demand withholding does not feature in our data (less than 0.3 percent of the observations), its potential use may have influenced sellers.

changes in the underlying market environment. As seller advertising cost and buyer search cost change, seller prices and advertising rates change in the direction predicted by the comparative statics analysis. Sellers also post higher unadvertised than advertised prices, and buyers' search behavior adjusts to increases in search costs as predicted. On the other hand, the data clearly indicate a systematic departure in the direction of more aggressive advertising and more competitive pricing behavior than theory predicts. Thus, although seller advertising behavior responds to changes in the cost of advertising and search, sellers advertise more frequently than predicted. Likewise, while seller pricing behavior responds to changes in the underlying parameters, sellers set prices that robustly approach a fairly narrow non-equilibrium range near the Bertrand price.

In our previous study that employed automated buyers (Cason and Datta, 2006), we found that despite overly-aggressive seller advertising, prices correspond closely to the equilibrium prediction. Although adding human buyers obviously increases the complexity of the problem facing sellers, especially because buyer behavior may be changing over time, our analysis suggests that the results are not due simply to decision errors that can arise in this more complex setting. While the observed behavior does not correspond to the theoretical mixed strategy equilibrium, on average it does not differ substantially from the best-response. Buyers' search decisions are approximately optimal given sellers' pricing and advertising strategies, although they tend to search too little when high search costs are high. Likewise, aggressive advertising and low prices are a seller's best response to the other sellers' strategies and observed buyer search behavior. In the unique symmetric equilibrium of the model (Proposition 1), sellers can also sell at high prices and "cream skim" off non-searching buyer. Empirically, however, such high prices lead to buyer search and no sales. Thus, while over-advertising in both studies creates an environment with "too much" price information, it is the human buyers' search strategy and the manner in which it filters back into the sellers' pricing and advertising behavior that leads to lower prices. These low non-dispersed prices can therefore be interpreted partly a consequence of seller over-advertising and partly a result of buyers who search when observing high prices.

The differences documented between human and automated buyer treatments suggest directions for future theoretical work aimed at explaining the descriptive limitations of Nash equilibrium in these markets with imperfect price information. Hopkins and Seymour (2002)

examine the dynamic stability of dispersed price equilibria in a related imperfect-information, price-setting environment under conditions of both seller learning and joint buyer-seller learning. Although equilibrium strategies require randomization over an infinite number of prices, they find that sellers can adaptively learn their way to equilibrium when buyer behavior is assumed to be fixed. However, this dispersed price, seller learning equilibrium is stable only under condition of “sufficient ignorance,” i.e. when the number of informed buyers is sufficiently low. Sellers in our experiment advertise too intensely, particularly in the early periods of the experimental sessions. Therefore, deviations from the equilibrium information conditions are in the opposite direction—toward overly-informed buyers. Furthermore, they show that inclusion of joint buyer-seller learning dynamics rules out convergence to any stable price equilibria. Prices in this experiment remain at these low levels and did not follow cycles as in Cason et al. (2005), which suggests the existence of some suboptimal learning or bounded rationality, or perhaps cycles that require more time than our treatment runs allowed.

Although their modeling framework differs from ours in numerous ways, Hopkins and Seymour’s results make us skeptical that it will be possible to identify learning dynamics that are either consistent with the observed laboratory behavior or converge to the Perfect Bayesian Nash equilibrium. As they note, “In these games with a large number of players, it would only need a positive measure of agents to adopt a learning rule for which the equilibrium was unstable to destabilize the equilibrium as a whole. In contrast, for an equilibrium that is not robustly stable to be an attractor, it would require all agents to adopt an appropriate rule” (page 1178). Our results add some empirical doubt to accompany the theoretical doubt raised by Hopkins and Seymour on the stability of price dispersion under joint buyer-seller learning.

**Table 1: Summary of Parameter Values and Theoretical Predictions**

Advertising intensity ( $\alpha$ ) = 0.4 Advertising cost $A = 2$ (low) and $A = 5$ (high) Search cost $c = 1$ (low) and $c = 6$ (high) Number of sellers ( $n$ ) = 4 Number of buyers = 5						
Experimental				Prob. of	Expected	Expected
Parameters		$[p_l, r-c]$	$r$	Advertising	Price	Profit
$A = 2$	$c = 1$	[8.08, 12.37]	13.37	0.42	11.99	9.66
$A = 2$	$c = 6$	[10.41, 20.87]	26.87	0.63	19.38	14.11
$A = 5$	$c = 1$	[18.94, 25.79]	26.79	0.31	25.34	22.37
$A = 5$	$c = 6$	[22.2, 38.69]	44.69	0.52	36.79	27.64

**Table 2: Experimental Design**

	<b>Seller Advertising Cost High-Low-High (<math>A=5, 2, 5</math>)</b>	<b>Seller Advertising Cost Low- High-Low (<math>A=2, 5, 2</math>)</b>
<b>Low Buyer Search Cost (<math>c = 1</math> per search)</b>	18 subjects (2 randomly-regrouped markets of 9 subjects per market)	36 subjects (4 randomly-regrouped markets of 9 subjects per market)
<b>High Buyer Search Cost (<math>c = 6</math> per search)</b>	36 subjects (4 randomly-regrouped markets of 9 subjects per market)	18 subjects (2 randomly-regrouped markets of 9 subjects per market)

**Table 3: Frequency of Advertising and Probit Models of Seller Advertising Decision***Panel A: Frequency of Advertising in Each Treatment Run*

Search Cost	[First 10 periods    Last 15 Periods    (Equilibrium Prediction)]							
	Advertising Cost				Totals			
	2		5					
1	0.72	0.61	(0.42)	0.53	0.38	(0.31)	0.63	0.51
6	0.94	0.83	(0.63)	0.73	0.70	(0.52)	0.82	0.76
Totals	0.82	0.70		0.64	0.56		0.73	0.63

The first entry in each cell denotes the advertising frequency observed in the first 10 periods and the second entry denotes the advertising frequency observed in the last 15 periods of each treatment run. The third entry in parenthesis indicates the equilibrium advertising rate.

*Panel B: Probit Models of Seller Advertising Decision Each Period*

	Model (1) all periods	Model (2) all periods	Model (3) late 15 periods	Model (4) late 15 periods
Search Cost = 6 dummy variable	0.79** (0.08)	0.54** (0.16)	0.84** (0.14)	0.52** (0.20)
Advertising Cost = 5 dummy variable	-0.54** (0.05)	-0.35** (0.06)	-0.53** (0.07)	-0.36** (0.07)
Full end period information dummy variable	0.11 (0.07)	-0.17 (0.16)	-0.002 (0.15)	-0.34 (0.20)
Last period advertising decision dummy variable		0.92** (0.06)		0.95** (0.08)
Number of sellers that advertised previous period 1/period		0.12** (0.04)		0.12** (0.05)
	0.67** (0.13)	1.03** (0.26)	6.64** (2.15)	3.17 (2.25)
Constant	0.52** (0.07)	-0.14 (0.11)	0.11 (0.18)	-0.09 (0.23)
Observations	3583	3441	2147	2147
Log-likelihood	-1702.6	-1472.4	-1032.1	-937.4

Notes: Since information of the number of sellers that advertised last period is available only in the full information treatment, this variable is interacted with the information dummy. Standard errors 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: Mean Prices and Random Effects Models of Seller Pricing Decision***Panel A: Mean prices in the last 15 periods*

Experimental Parameters	Equilibrium Prediction	Observed Mean Price				
	$[p_l, r-c]$	Overall Price	Advertised price	Unadvertised Price	Full Information	Partial Information
$A = 2 \quad c = 1$	[8.08, 12.37]	6.81	5.68	8.59	6.91	6.68
$A = 2 \quad c = 6$	[10.41, 20.87]	7.46	5.61	16.45	8.05	5.70
$A = 5 \quad c = 1$	[18.94, 25.79]	4.46	5.30	3.94	3.81	6.42
$A = 5 \quad c = 6$	[22.2, 38.69]	10.08	9.12	12.31	11.93	7.30

*Panel B: Random Effects Models of Seller Pricing Decision Each Period*

	Model (1) all periods	Model (2) all periods	Model (3) late 15 periods	Model (4) late 15 periods
Search Cost = 6, Ad cost = 2 dummy variable	0.29 (0.93)	0.98 (0.91)	0.12 (0.89)	1.63 (0.92)
Search Cost = 6, Ad cost = 5 dummy variable	4.02** (0.92)	4.37** (0.89)	3.80** (0.88)	4.54** (0.88)
Search Cost = 1, Ad cost = 5 dummy variable	-0.74* (0.31)	-1.49** (0.32)	-2.18** (0.38)	-3.19** (0.40)
Full end period information dummy variable	2.45** (0.96)	2.17* (0.92)	1.49 (0.91)	1.40 (0.90)
Predicted Adv. Probability (Instrumental Variable)		-3.03** (0.70)		-5.66** (0.86)
1/period	15.49** (0.50)	25.87** (0.95)	40.10** (7.95)	47.47** (7.96)
Constant	6.12** (0.92)	7.33** (1.00)	4.24** (1.00)	7.76** (1.12)
Observations	3583	3441	2147	2147
Log-likelihood	-11603.5	-10914.17	-6820.7	-6799.36

Notes: Standard errors 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 5: Buyer Search Frequencies***Search Frequency in first 10 and last 15 Periods of Each Treatment Run**Panel A: Buyers Receiving at least one Advertisement (first search decision)*

Search Cost	Advertising Cost				Totals	
	2		5			
1	0.392	0.238	0.427	0.246	0.406	0.240
6	0.142	0.073	0.183	0.105	0.163	0.090
Totals	0.271	0.158	0.278	0.151	0.274	0.155

*Panel B: Buyers Receiving No Advertisement (first non-trivial search decision)*

Search Cost	Advertising Cost				Totals	
	2		5			
1	0.406	0.348	0.414	0.200	0.410	0.264
6	0.127	0.176	0.164	0.141	0.153	0.155
Totals	0.324	0.288	0.302	0.177	0.311	0.224

The first entry in each cell denotes the search frequency observed in the first 10 periods and the second entry denotes the search frequency observed in the last 15 periods of each treatment run.

**Table 6: Comparison of Buyer Search Choices to Optimal Search Rule Based on Empirical Reservation Price**

Panel A: Search Cost = 1, Buyers Receiving No Advertisement:  $853/1046 = 81.5\%$  of search decisions are optimal

	Search Not Optimal	Search Is Optimal
Did Not Search	713	28 (17% undersearch)
Did Actually Search	165 (19% oversearch)	140

Panel B: Search Cost = 1, Buyers Receiving at least one Advertisement:  $1227/1603 = 76.5\%$  of search decisions are optimal

	Search Not Optimal	Search Is Optimal
Did Not Search	1060	76 (31% undersearch)
Did Actually Search	300 (22% oversearch)	167

Panel C: Search Cost = 6, Buyers Receiving No Advertisement:  $503/555 = 90.6\%$  of search decisions are optimal

	Search Not Optimal	Search Is Optimal
Did Not Search	466	9 (20% undersearch)
Did Actually Search	43 (8% oversearch)	37

Panel D: Search Cost = 6, Buyers Receiving at least one Advertisement:  $1538/1757 = 87.5\%$  of search decisions are optimal

	Search Not Optimal	Search Is Optimal
Did Not Search	1440	135 (58% undersearch)
Did Actually Search	84 (6% oversearch)	98

Note: Data are displayed for the first two search decisions in each period, after excluding the trivial initial search decision for the case of buyers receiving no advertisement.

**Table 7: Seller Best Responses and Observed Average Prices and Advertising Rates**

Experimental Parameters	Best Response		Observed Averages		
	Advertising strategy	Price	Advertising propensity	Average Advertised Price	Average Unadvertised Price
$A = 2 \quad c = 1$	Advertise	4.65	0.61	5.68	8.59
$A = 2 \quad c = 6$	Advertise	4.45	0.83	5.61	16.45
$A = 5 \quad c = 1$	Not advertise	5.95	0.38	5.30	3.94
$A = 5 \quad c = 6$	Advertise	8.35	0.70	9.12	12.31

**Table 8: Frequency of observing more than one price at the time of purchase**

[*First 10 periods    Last 15 Periods    (Equilibrium Prediction)*]

Search Cost	Advertising Cost						Totals	
	2			5				
1	0.568	0.427	(0.134)	0.465	0.277	(0.078)	0.522	0.36
6	0.510	0.463	(0.265)	0.424	0.369	(0.206)	0.462	0.411
Totals	0.542	0.443		0.442	0.328		0.492	0.386

The first entry in each cell denotes the frequency of observing more than one price in the first 10 periods and the second entry denotes the frequency of observing more than one price in the last 15 periods of each treatment run. The third entry in parenthesis indicates the corresponding frequency as implied by the equilibrium advertising rate.

**Figure 1 : Equilibrium price distributions for various parameter values.**

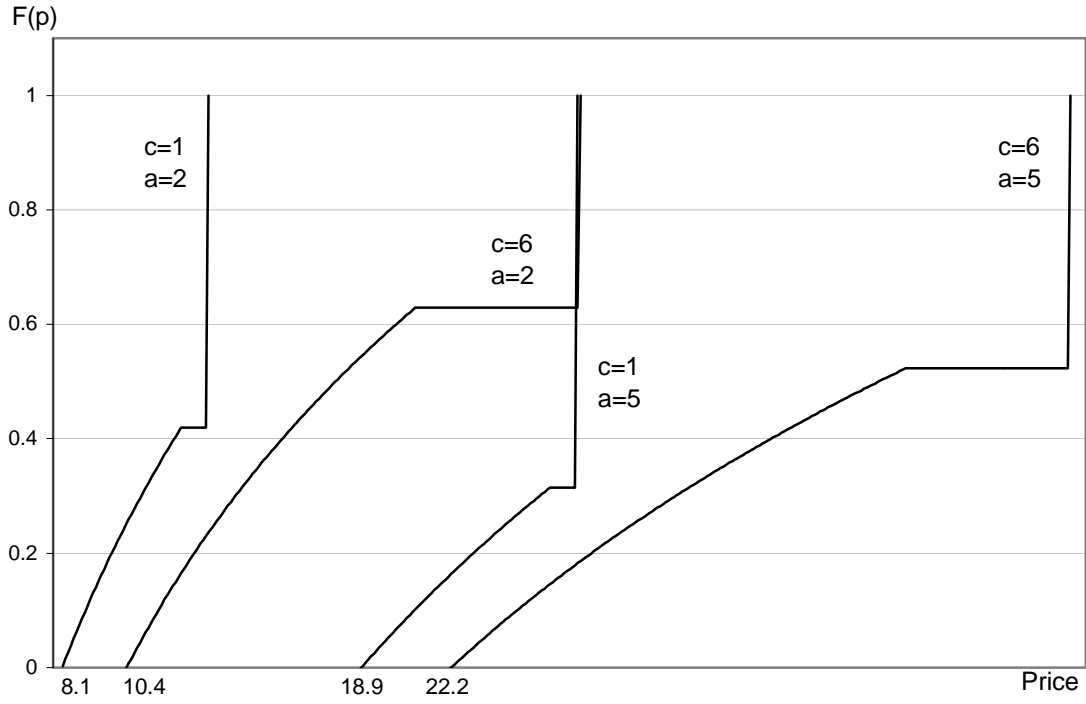


Figure 2: Prices for full information feedback session with buyer search cost=1, advertising cost=2, 5, 2

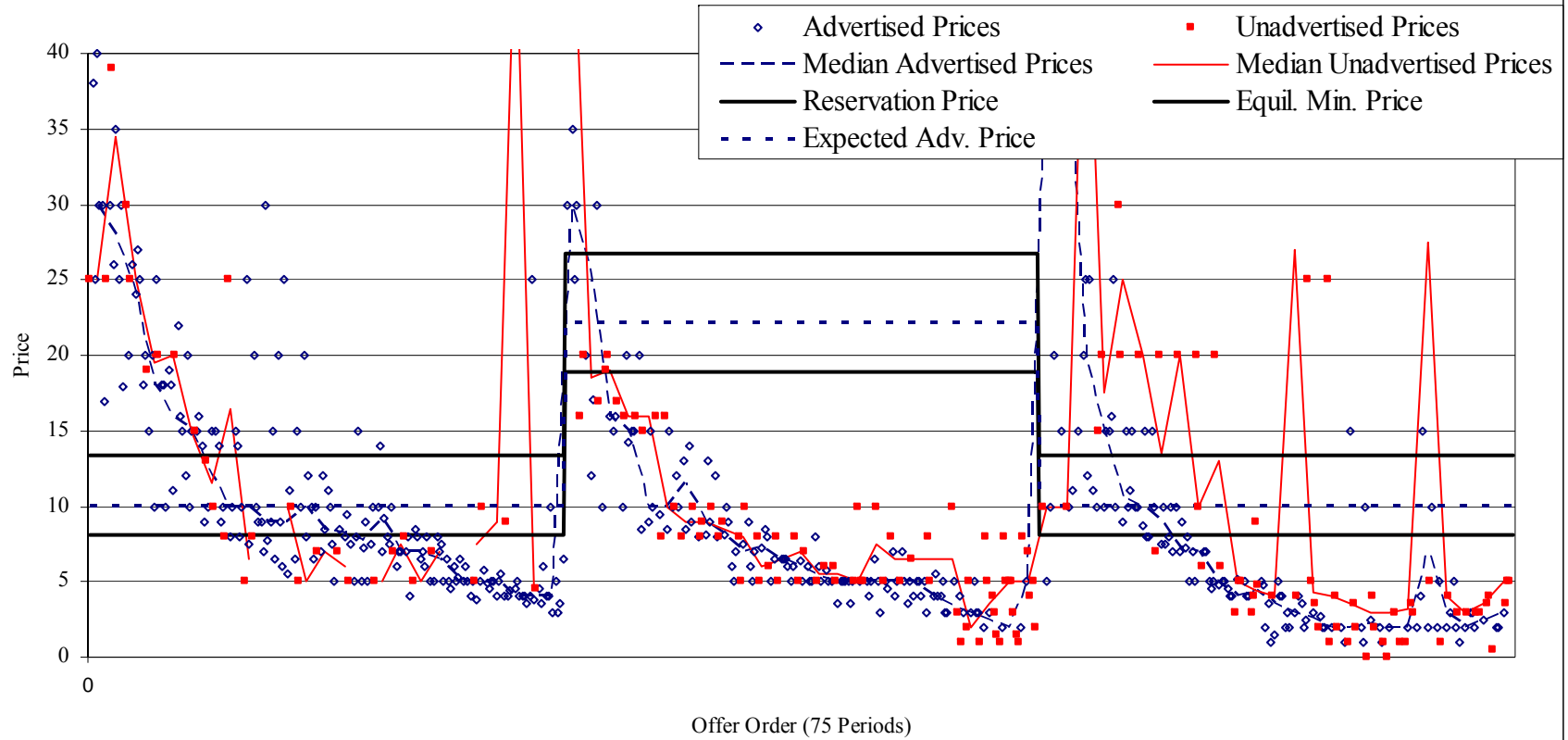
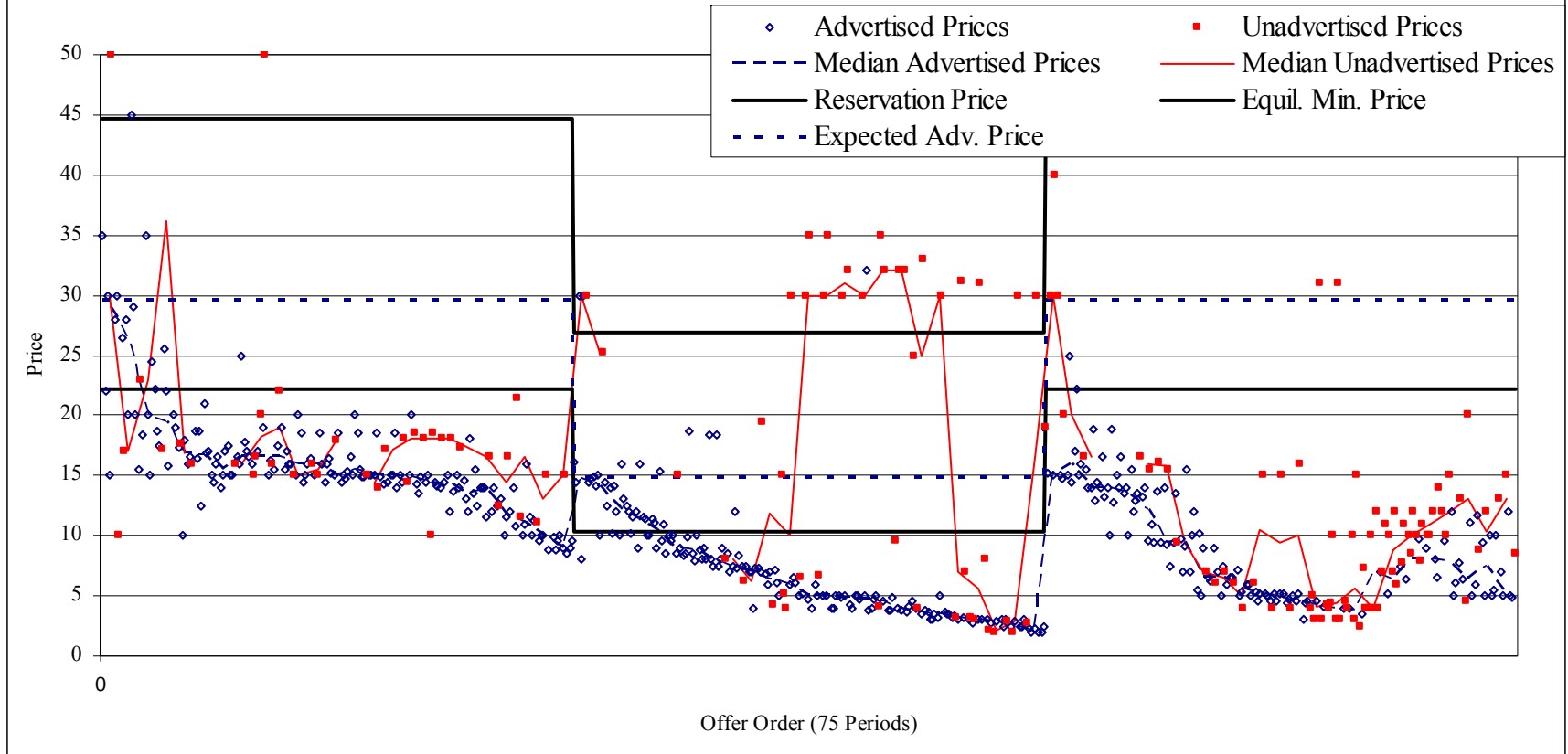
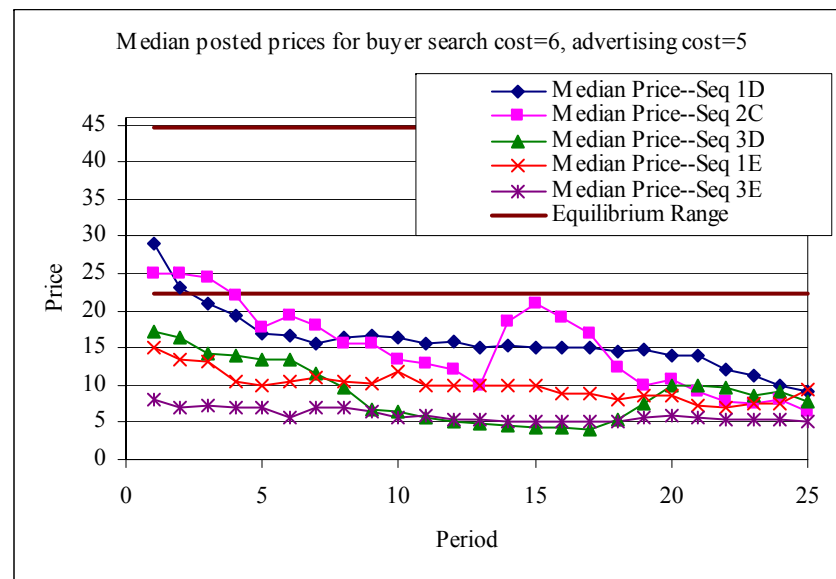
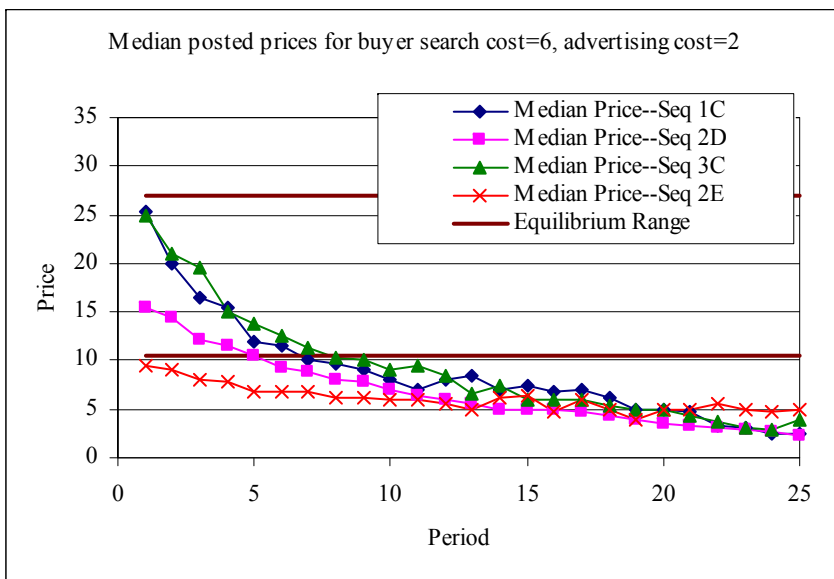
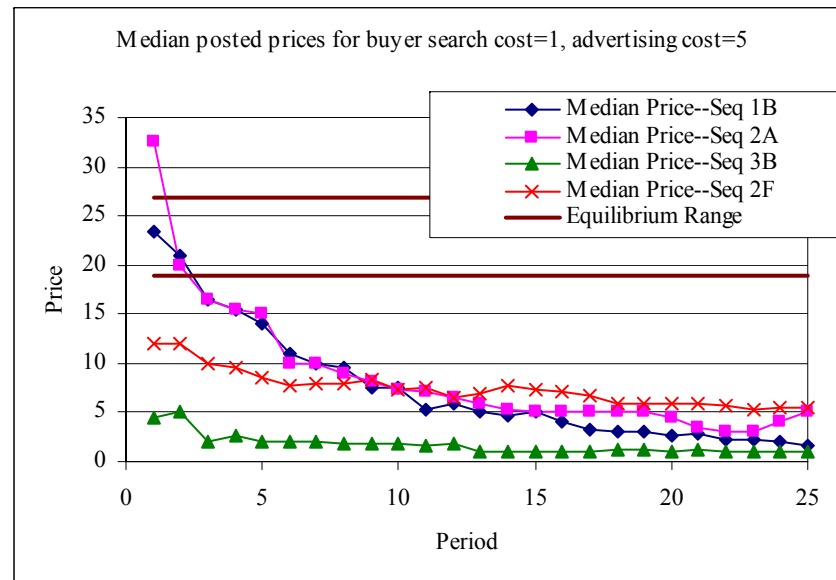
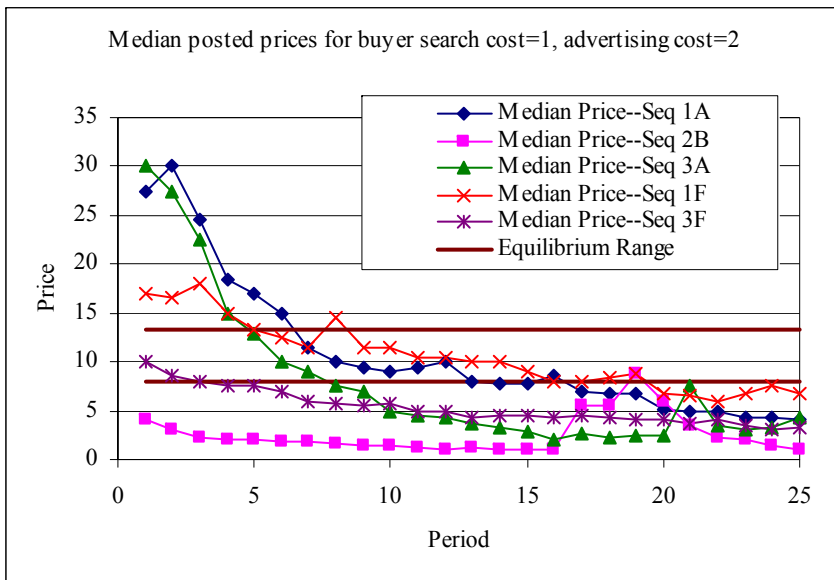


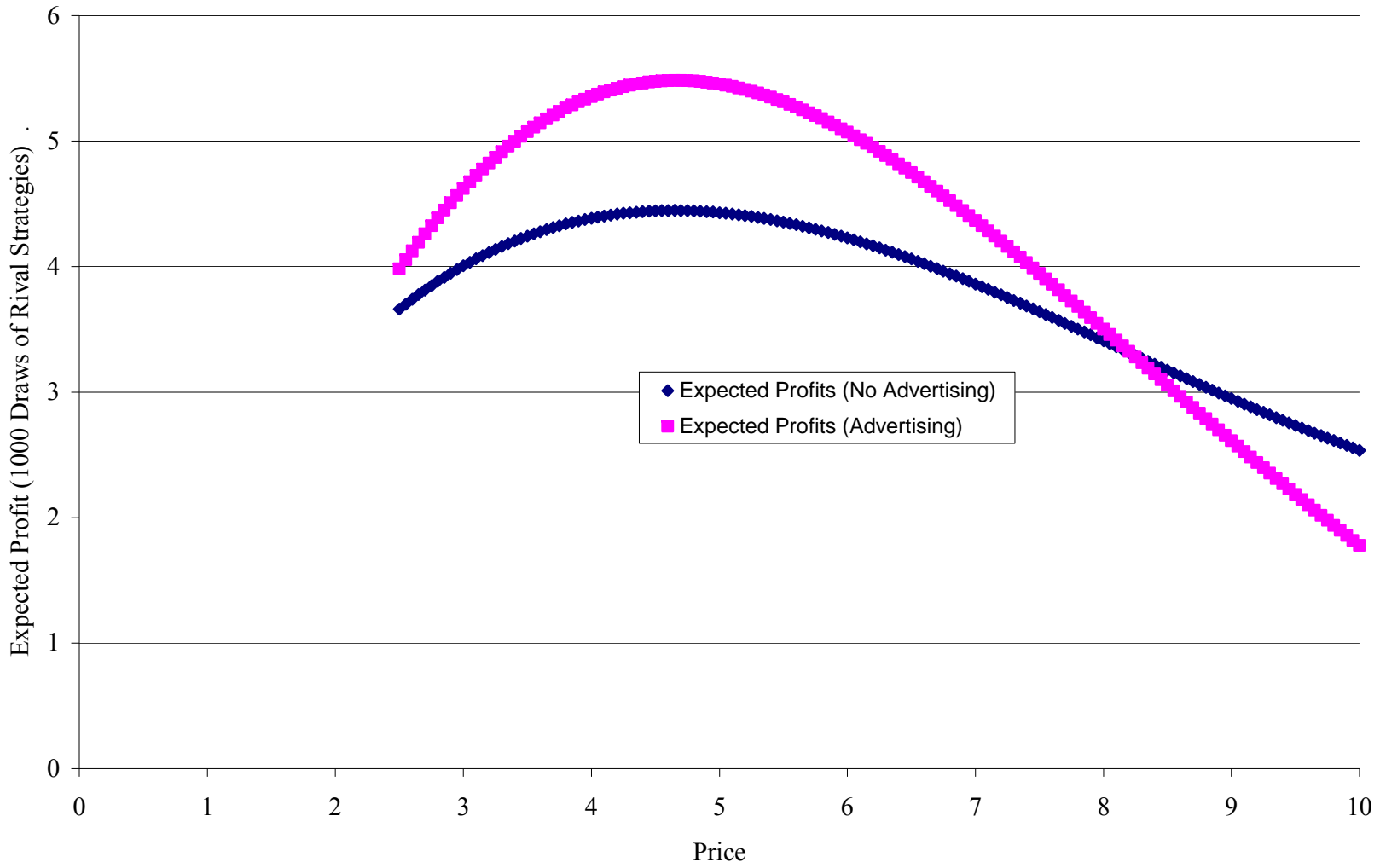
Figure 3: Prices for full information feedback session with buyer search cost=6, advertising cost=5, 2, 5



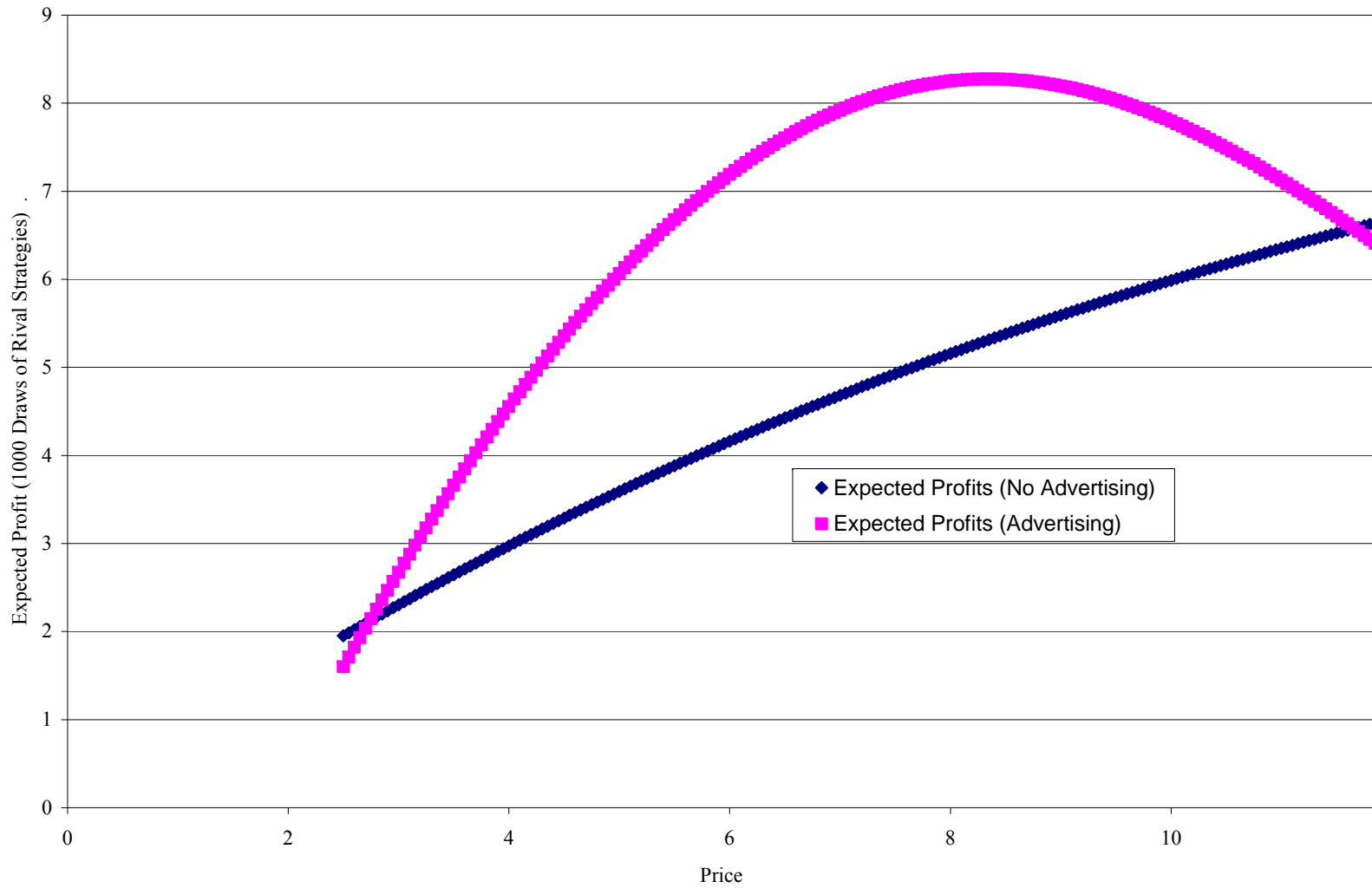
**Figure 4: Median posted prices in all treatment runs**



**Figure 5: Expected Profits Based on Late Period Rival Strategies and Search: Search Cost=1, Ad Cost=2**



**Figure 6: Expected Profits Based on Late Period Rival Strategies and Search: Search Cost=6, Ad Cost=5**



## **Referee's Appendix A: Experiment Instructions (not intended for publication)**

### **General**

This is an experiment in the economics of market decision-making. Various research agencies have provided funds for the conduct of this research. The instructions are simple and if you follow them carefully and make good decisions you may 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 please feel free to ask any questions at any time. It is important that you do not talk and discuss your information with other participants in the room until the session is over.

In this experiment we are going to conduct markets in which you will be a participant in a sequence of 75 separate trading periods. In every period you will be buying or selling a fictitious good X. All transactions in today's experiment will be in experimental francs. These experimental francs will be converted to real US dollars at the end of the experiment at the rate of \_\_\_\_\_ experimental francs = \$1 in the first 25 periods and the last 25 periods, and at the rate of \_\_\_\_\_ experimental francs = \$1 in the middle 25 periods. Your conversion rates are your private information. All buyers' conversion rates are equal and all sellers' conversion rates are equal, but the conversion rates are different for the buyers and for the sellers. Notice that the more francs you earn, the more dollars you earn. What you earn depends partly on your decisions and partly on the decisions of others. Everyone starts each set of 25 periods with a starting balance of 30 francs.

The 18 participants in today's experiment will be randomly re-matched each period into 2 markets with 4 sellers and 5 buyers in each market. Therefore, the specific people who are trading in your market change randomly after each period. Your Personal Record sheet indicates whether you are a buyer or seller in today's experiment and you will remain in this role throughout the experiment.

### **Instructions to the Sellers**

1. As a seller you can sell multiple units of good X every period but each buyer will purchase only one unit of the good each period. The good costs you nothing to produce.
2. At the beginning of every period, you decide on what price to charge per unit of good X and whether or not you wish to advertise this price. See Figure 1 on the next page. Click on the Continue button to submit your price and advertising decision. The computer will wait until all sellers have made their decisions before displaying anyone's price to the market.
3. If you choose to advertise the price then you must pay an advertising cost. If you choose not

to advertise, you will incur no advertising cost. This advertising cost will change for each set of 25 periods. This change will be announced by the experimenter and the new cost will be displayed on your decision screen. All sellers have the same advertising cost.

4. After all sellers have made their advertising and pricing decision, *some* of the buyers may receive the price advertisement. Each seller's advertised price will be shown to 2 buyers. Each buyer is equally likely to receive the ad, and which 2 of the 5 buyers actually receive the ad is determined randomly, as explained in more detail later.

Period 2 out of 25 Remaining time [sec]: 7

Buyers cost to visit a seller: 1.00  
The cost to advertise is: 2.00

Enter the price you wish to post:

Do you wish to advertise this price?  No  Yes

continue

**Fig. 1 Seller's Decision Screen**

5. At the end of the period, your profit is computed and displayed on the output screen as shown in Figure 2. Remember that there is no cost of producing the good in this experiment. The only cost that you have to incur is the advertising cost if you choose to advertise the price. Your profit is then calculated as follows:

$$Profit = (price \times number\ of\ units\ sold) - advertising\ cost$$

For example:

- Suppose a seller posts a price of 18.69 francs and chooses not to advertise.  
If the seller sells 1 unit, his profit is equal to  $18.69 \times 1 - 0 = 18.69$  francs.
- Suppose a seller posts a price of 15.60 francs and chooses to advertise when the advertising cost is 2 francs.  
If he sells 2 units, his profit is  $15.60 \times 2 - 2 = 29.20$  francs.

Period		Remaining time [sec]: 29	
4 out of 25			
Price	Advertised	Quantity Sold	
25.50	Yes	2	
56.00	Yes	1	
15.00	Yes	2	
174.00	No	0	
Your Price: 15.00			
Your Quantity Sold: 2			
Your Total Revenue: 30.00			
Your Advertising Cost: 2			
Your Profit This Period: 28.00			
Cumulative Profit So Far: 149.69			
<input type="button" value="continue"/>			

**Fig. 2 Seller's Example Outcome Screen**

### Instructions to the Buyers

1. Each buyer can purchase one unit of good X each period. All buyers have a resale value of \_\_\_\_\_ for the good. This is the amount that the buyer receives when “reselling” the item to the experimenter at the end of the period, as explained more in point 6 below. This value will remain unchanged throughout the experiment.
2. After all sellers have posted prices and made their advertising decisions, the computer randomly determines which seller's prices will be displayed on which buyer's screens at the

start of the buying phase of each period. That is, which price ad(s) the buyer receives is randomly determined and does not depend on the actions of the either buyers or the sellers. Note that some buyers may receive multiple ads and some may not receive any ad at all. The number of buyers who receive the ad depends on the number of sellers who advertise.

For example, if one seller decides to advertise his price then two buyers will receive an ad. If two sellers decide to advertise, then there are 3 possibilities for the random ad distribution:

- a. Two buyers get two ads each.
  - b. One buyer gets two ads and two other buyers get one ad each.
  - c. Four buyers get one ad each.
3. A buyer's cost to visit a seller is \_\_\_\_ experimental francs. The visit cost will remain unchanged throughout today's experiment. A buyer who receives an advertisement and who buys at an advertised price must pay this cost to visit the seller and complete the purchase. Buyers who receive a price ad(s) but who wish to obtain price quotes not shown in the advertisement must pay this cost to visit different sellers. A buyer who does not receive any advertisement must visit sellers if he or she wants to obtain price quotes.

Random ID	Price	Visit Cost
1	25.00	Already paid
2		
3		
4	23.35	Not yet paid

Cost to visit a seller: 1.00

Enter the ID number you wish to purchase from:

**Fig. 3 Buyer's Decision Screen**

4. A buyer receives a new quote from a different, randomly-determined seller each time he or she pays this visit cost by clicking the **Visit Another Seller** button on Figure 3. For example: a buyer who makes two visits to obtain price offers from two sellers will pay a total visit cost of \_\_\_\_\_ francs. If a buyer pays the visit cost to obtain a price quote from a particular seller in a certain period, he can purchase from that seller at any time during that same period without paying the visit cost again.
5. The prices are displayed on buyer's computer screen as shown in Figure 3. The order of displayed prices is not related to the actual identity of the seller. The display order is randomly determined each period by the computer. To make the purchase, the buyer enters the temporary, random ID number of the seller from whom he wishes to make the purchase and then clicks on the **Buy** button. A buyer who chooses to visit another seller should click on the **Visit Another Seller** button. At any time, the buyer can choose not to purchase in the current period by clicking the **Quit** button.
6. At the end of the period, your profit is computed and displayed on an output screen similar to Figure 4. Remember that you will have to pay your visit cost irrespective of whether or not you buy the good. Your profit is then calculated as follows:

*Profit (if you purchase) = resale value of the good – price paid – total cost of visiting sellers*

*Profit (if you do not purchase) = – total cost of visiting sellers*

Note that a buyer would earn a negative profit (lose money) if she pays a price above the value of the good.

For example: Suppose the resale value of the good is 20 and the cost of visiting a seller is 1.

A buyer receives the ad from a seller with a quoted price of 10.

- If he decides not to visit any other seller before buying, he earns Profit = 20 – 10 – 1 = 9 (Note that he pays the visit cost of 1 to buy from a seller from whom he received an ad.)
- If he decides to visit another seller and obtains a price quote of 15, he can purchase at one of the two quoted prices, visit another seller or quit.
  - If he purchases at price 10, he earns Profit = 20 – 10 – 2 = 8.
  - If he decides to quit and not purchase, he must still pay the visit cost he just incurred to obtain the price quote of 15. Therefore, he earns a negative profit of –1.
  - If he visits another seller and receives a quote of 6 and decides to purchase at this price, he earns Profit = 20 – 6 – 2 = 12.

Period		Remaining time [sec]: 32	
2 out of 25			
Price	Advertised	Quantity Sold	
25.00	Yes	2	
45.00	No	0	
78.00	No	0	
23.35	Yes	2	
Your Price Paid: 23.35 Your Resale Value: 60 Your Visit Costs: 3 Your Profit This Period: 33.65 Cumulative Profit So Far: 92.70			
<input type="button" value="continue"/>			

**Fig. 4 Buyer's Example Outcome Screen**

**End of the period**

1. Once the outcome screen is displayed you should record the trading information—your price, quantity sold (for sellers), total revenue or resale value, advertising or visit cost—in your Personal Record sheet. Also record your profit from this period and from the session so far. Then click on the button on the lower right of your screen to begin the next trading period.
2. The top half of everyone's outcome screen provides information for your market in the period just completed. All four sellers' price offers in your market are displayed, sorted in random order, as well as all the sellers' advertising decisions and quantities sold. Recall that you will be randomly re-matched with another group of buyers and sellers in each period.

Are there any questions before we begin?

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