An Experimental Study of Price Dispersion in an Optimal Search Model with Advertising*

Timothy N. Cason and Shakun Datta

Department of Economics
Krannert School of Management
Purdue University
West Lafayette, IN 47907

September 2004

Abstract

This paper reports a laboratory experiment to study pricing and advertising behavior in a market with costly buyer search. Sellers simultaneously post prices and decide whether or not to incur an exogenous cost to advertise this price. Sellers are not capacity constrained, and each buyer demands one unit per period. In the unique symmetric equilibrium, sellers either charge a high unadvertised price or randomize in an interval of lower advertised prices. Theory predicts that increases in either search or advertising costs raise equilibrium prices, and that equilibrium advertising intensity decreases with lower search costs and higher advertising costs. To test the predictions regarding the level and dispersion of prices and advertising intensity, we vary the costs of search and advertising across different experimental treatments. Our results support the model's comparative static predictions, and sellers also post high unadvertised prices as predicted. In all treatments, however, sellers advertise more intensely than in equilibrium.

JEL Classification: D43; D83; L13

Keywords: Laboratory; Posted offer; Market power; Mixed strategy; Uncertainty; Shopping

*We thank Jacques Robert for very helpful suggestions, Emmanuel Dechenaux for valuable comments, Jeff Bayer for research assistance, and participants at Econometric Society and Economic Science Association conferences for useful feedback. The Purdue University Faculty Scholar program and the Purdue Research Foundation provided financial support.

> Traditional models of competition with perfect information obviously cannot explain the widely observed phenomena of price distributions…..; nor can they explain advertising…….Attempts to characterize equilibrium in product markets in which information is costly can provide considerable insight into these phenomena. (Stiglitz, 1979, pg. 339).

I. Introduction

Costly information acquisition has remained an important topic of economic research since Stigler (1961). One principal goal of this literature has been to explain nontrivial wage and price dispersion as a stable equilibrium outcome when one or both sides of the market have imperfect information. Economists have developed numerous versions of equilibrium search models citing the role of search frictions (Reinganum, 1979), information asymmetries (Varian, 1980), differing production costs (Salop, 1973), differing consumer search costs (Stahl, 1989, 1996) and *ex post* consumer heterogeneity (Burdett and Judd, 1983) and other reasons for the failure of the "law of one price."

Search models provide an equilibrium explanation for the persistent price dispersion observed in essentially homogenous product markets (Baye and Morgan, 2001; Brynjolfsson and Smith, 2000).[1] Search models also provide guidance to help answer important public policy questions, both for formulating the basic principles of the policy and for allocating resources efficiently to implement them. For instance, various consumer protection regulations stipulated by the Federal Trade Commission are aimed towards curbing the harms of imperfect information.

Despite the normative and academic significance of these models, however, their application in actual policy resolutions has been somewhat restricted. The reason is twofold (Grether, Schwartz and Wilde, 1988). First, these models are highly sensitive to their assumptions of information acquisition and dissemination. As with many models in Industrial Organization, their assumptions tend to be quite stylized and often unrealistic. Second, the predictive power of many of these models has not been tested directly. The lack of suitable field data impairs traditional empirical analysis. Experimental methods, on the other hand, can provide

[1] Baye, Morgan and Scholten (2004) document that price dispersion exists even on price comparison sites on the Internet. For instance, the highest price for a consumer electronics product is on average 57 percent above the lowest available price.

some direct empirical evidence. They isolate the relevant parameters to assess their impact and therefore provide clear tests of the predictive properties of these models. Moreover, laboratory microeconomies are "real" economic systems that are behaviorally much richer than those parameterized in theory. Therefore, although a theory that performs well in the lab may not have complete external validity, it does pass what Smith (1982) refers to as a "nontrivial test." Laboratory data are also untainted from the various complicating factors that plague field data such as reputation formation and brand proliferation.

This paper reports a laboratory study of price advertising when consumers can engage in costly search. The basic framework for the study is derived from Robert and Stahl (1993), who introduced optimal search to Butters's (1977) advertising model. Our results support the model's comparative static predictions; for example, increases in either search costs or advertising costs are reflected in higher equilibrium prices.

Robert and Stahl's advertising model with buyer search belongs to an important stream of literature on price-setting games with incomplete information. Theoretical analyses of markets with incomplete information can be traced back to Diamond's (1971) paradoxical finding that even infinitesimal search costs can lead to the monopoly price as the unique equilibrium. Following Diamond, many researchers have employed models with costly buyer search to generate seller market power or dispersed prices. For example, Salop and Stiglitz (1977) derive equilibrium price dispersion in a monopolistic competition model where the consumers are assumed to differ in their costs of search. Stahl (1989) employs a similar framework to show that if some buyers have zero search costs while others have identical positive search costs, then there is a unique symmetric Nash Equilibrium price distribution that ranges from marginal cost pricing to monopoly pricing. In both of these models, heterogeneous search costs led to dispersed prices. Salop and Stiglitz (1982), however, show that differences in the cost of gathering information are not a prerequisite for price dispersion. Their "theory of sales" model has identical firms and consumers but is still characterized by price dispersion. If all firms charged the same price, it would pay for some firm to lower its price to persuade consumers to purchase for future consumption (storage); in equilibrium, the extra sales will compensate for the lower price charged on other sales.[2] Burdett and Judd (1983) also find that ex ante heterogeneity in costs or

[2] In Varian's (1980) model of temporal price dispersion, a larger proportion of informed consumers means that lower prices would be charged a higher percentage of the time. Because of the intentional price fluctuations, the

preferences is not a prerequisite for price dispersion to occur; what is crucial is ex post heterogeneity in consumer information. A positive but not certain probability that consumers sample two stores will yield dispersed equilibrium pricing.

Firms can, of course, influence the consumers' purchase decision by advertising. Firms can use advertising to attract customers away from other firms. Stigler (1961), for instance, observes that advertising is a substitute for consumer search. Like search costs, advertising also yields a paradox. Since it is profitable for the firm to advertise a slightly lower price and capture the entire demand, the advertised price continues to be undercut until it reaches the minimum average cost and firms suffer a loss equivalent to their advertising cost. Again like search costs, the resolution of the advertising paradox lies in establishing the existence of a continuous equilibrium price distribution. In Butters's (1977) model, the firms randomly distribute their advertisements among consumers informing them about their prices. Butters (1977) was also the first to study the interaction *between advertising and search costs*. He finds that as either search or advertising become more expensive, buyers pay higher prices. Robert and Stahl (1993) introduce optimal search to Butters's advertising model. They also provide comparative statics for the effectiveness of the two informational channels.[3]

Experimental research on this class of incomplete information models was first conducted by Grether, Schwartz and Wilde (1988). They report laboratory results of 3 models that make similar assumptions about the sellers but differ in search strategies available to the consumers. Predictions about the equilibrium price range from competitive equilibrium to monopoly pricing, and these were largely consistent with the experimental outcomes. Davis and Holt (1996) find that in the absence of public information about prices, search costs tend to raise average prices, but monopoly prices as implied by the Diamond paradox are not consistently observed. Abrams, Sefton and Yavas (2000) examine cases predicted to have unified prices at the Bertrand and Diamond equilibria in a posted offer market with search. They find that the prices are closer to the midpoint between these predictions than to either of the two extremes.

The above-cited studies assess the sensitivity of the *unique* price predictions to the cost and intensity of buyer search. Cason and Friedman (2003) test the effect of noisy buyer search on

---

consumer cannot learn by experience about the sellers that consistently charge a lower price and hence the price dispersion is expected to persist.

[3] Bester (1994) and Caminal (1996) conduct a similar analysis in a monopoly framework and find comparable results – the monopolist advertises only low prices.

price dispersion in experimental posted offer markets. They find that the laboratory results conform closely to the theoretical predictions, particularly when sellers face automated ("robot") buyers who are programmed to search optimally. Morgan, Orzen and Sefton (2004a) examine equilibrium price dispersion in the clearinghouse model as opposed to the posted offer market. Additionally, they assume ex ante consumer heterogeneity; i.e., there are some consumers who are "informed" in the sense that they costlessly consult the price listings in the central clearinghouse and make purchases from the lowest priced seller. The other consumers are "captive" consumers—who buy on considerations other than price—that are distributed among the various sellers. Like Cason and Friedman, their laboratory data support the theoretical comparative static predictions.

Finally, in a recent experimental study on advertising and price competition, Morgan, Orzen and Sefton (2004b) examine the impact of costly advertising on sellers' advertising and pricing behavior in a clearinghouse setting. The sellers have to incur a cost—an advertising fee set by the gatekeeper—in order to list their price in the clearinghouse. They find that an increase in advertising costs reduces the sellers' propensity to advertise and results in higher posted prices, as predicted. The present study adds optimal consumer search in a non-clearinghouse advertising environment on the lines modeled by Robert and Stahl (1993). In this two-sided search model, costly information about prices is both gathered by the buyers and disseminated by the sellers. Robert and Stahl characterize a unique and symmetric price-dispersion equilibrium, in which firms either charge a high unadvertised price or advertise a price selected from an interval of lower prices. The unique feature of this model is that it does not resort to *ex ante* consumer heterogeneity to generate price dispersion. Endogenous advertising generates heterogeneously informed consumers. The completely uninformed consumers search among sellers using an optimal search strategy while the other consumers choose among sellers whose ads they have received.

As we outline in Section II, considering optimal consumer search in an advertising model yields a rich set of comparative static predictions. Increases in either search or advertising costs are reflected in higher equilibrium prices and profit, and equilibrium advertising intensity decreases with lower search costs and higher advertising costs. We test these comparative statics predictions using advertising cost and search cost as the primary treatment variables. Section III presents the testable hypotheses, and Section IV describes the experimental design and procedures. Section V presents the results, which generally support the model's comparative static predictions. Moreover, as predicted the unadvertised prices are significantly higher and less dispersed than advertised prices. In all treatments, however, we find that sellers advertise more intensely than the model predicts. Section VI concludes.

II. Theoretical Model

Consider a market where n identical sellers compete to supply a homogenous product. 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 consumers about their price through advertising at a cost A. We assume that if sellers choose to advertise then they reach a fixed proportion α of the consumers.[4]

On the demand side of the market, a continuum of consumers (normalized to a mass of one) have an identical valuation v for one unit of the good. Consumers are *a priori* uninformed about the prices in the market but can obtain price information either through receiving an advertisement from sellers or by conducting search at a cost c per price quote. This search is without replacement and with perfect recall. Each consumer has an independent probability of being informed of seller j's price. The ads are assumed to be randomly distributed across consumers; i.e., sellers cannot target their advertising nor can the consumers influence the probability of receiving any advertisements.

At the beginning of each period, the sellers simultaneously choose 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, buyers make their search decision. Optimal consumer search endogenously determines a unique reservation price, r, which equates the marginal benefits of search to the cost of search. According to the reservation price strategy, each consumer buys one unit of the good from the seller offering the lowest advertised price, p_j, only if $p_j + c \leq \min\{r, v\}$. This follows from the fact that a consumer who decides to buy at the advertised price will still have to incur a one-time transportation cost of c to procure the good

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

from the seller.[5] The consumer can also choose to ignore the advertised price and conduct a costly search to obtain additional price quotes from other sellers. According to the optimal search rule, the consumers will continue search until they find a price that is less than or equal to r, at which time they make the purchase.

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 $F(.)$ with support contained in $(0, v)$. More specifically, the support of the distribution is the union of the interval $[p_l, r\text{-}c]$ and the reservation price $\{r\}$, where p_l is the lower bound of the equilibrium distribution. Since consumers 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 $r\text{-}c$.[6] Finally, there is no atom in the distribution at or below $r\text{-}c$ since it is always profitable to decrease marginally the advertised price to break a potential tie.

The specific functional forms and the optimal consumer search behavior are summarized in the following proposition, with technical details and the proof contained in Appendix A.

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 symmetric mixed strategy equilibrium wherein firms set price according to the following distribution function:

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

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

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

[5] Stahl (1990) examines a model where the consumer incurs a cost only when searching for price quotes and not when he decides to purchase an advertised good. This distinction is crucial only to the extent the resulting price distribution in Stahl's model is without a gap between the reservation price and the highest advertised price.

[6] The choice of a price less than r is justified only if the seller decides to advertise the price, but given the consumer's search/transportation cost c to purchase at the advertised price, this price must be at most $r\text{-}c$.

Figure 1 illustrates the equilibrium price distributions for parameter values used in the experiment.

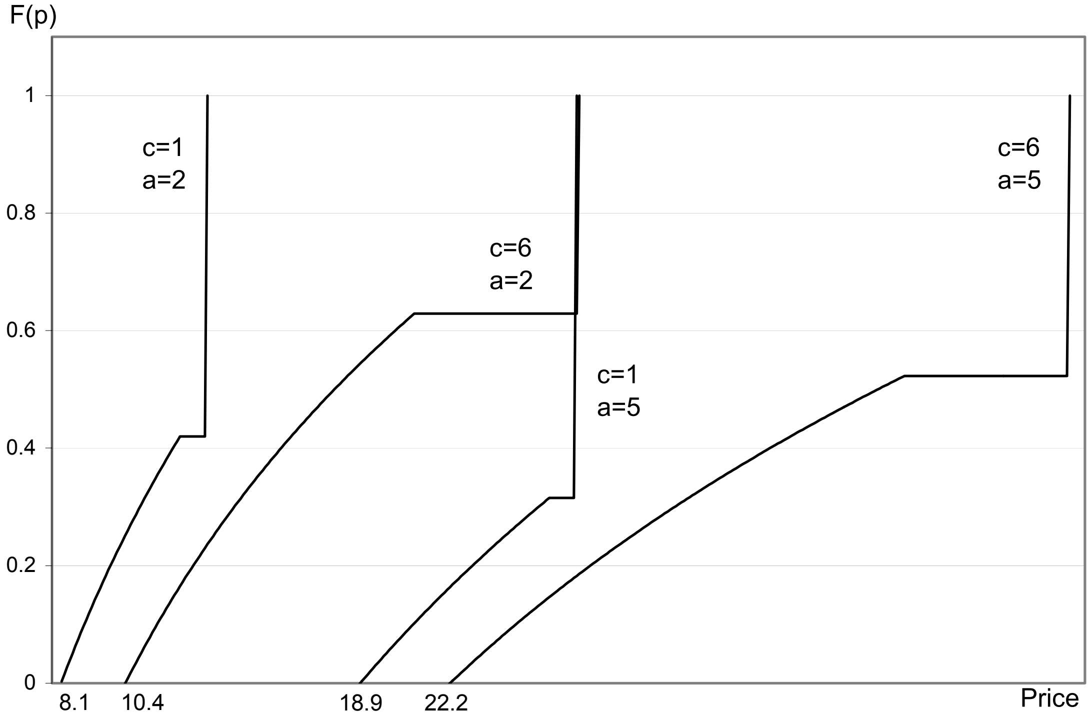


Fig.1 : Equilibrium price distribution for various parameter values.

Within this framework, we consider issues such as the strategic role of advertising and the seller market power arising due to costly buyer search. We also compare the advertising and search information channels and their impact on the level and dispersion of prices. The comparative static results are summarized in the following propositions, with proofs relegated to Appendix A.

Proposition 2: For a fixed number of sellers and fixed advertising cost and intensity for which (1) is an equilibrium distribution,

2.A $\lim_{c\to 0} F(r-c) = 0$, $\lim_{c\to 0} p_l = r$ and $\lim_{c\to 0} r = \frac{An}{(n-1)\alpha}$.

2.B The probability that sellers advertise is increasing in the search cost iff the elasticity of r with respect to c is greater than $\frac{(n\alpha+1-\alpha)c}{An}$.

If in equilibrium the elasticity of r with respect to c is less than 1 then

2.C The lower bound of the equilibrium price distribution p_l is increasing in the search cost.

2.D The equilibrium expected profit is increasing in search cost.

Proposition 3: For a fixed number of sellers and fixed advertising cost and intensity for which (1) is an equilibrium distribution,

3.A $\lim_{A \to 0} r = \frac{c(\alpha n + 1 - \alpha)}{(n-1)\alpha}$. Moreover in the limit as A goes to zero, the equilibrium expected profit and p_l remain strictly positive as long as c remains positive.

If in equilibrium the elasticity of r with respect to A is less than $1 - \frac{(n\alpha + 1 - \alpha)c}{An}$ then

3.B The probability that sellers advertise is decreasing in the advertising cost.

3.C The equilibrium expected profit is increasing in advertising cost.

3.D The lower bound of the equilibrium price distribution p_l is increasing in the advertising cost.

3.E The distribution of equilibrium posted prices is increasing in advertising cost.

In the limit as search cost goes to zero, the probability of advertising is zero in both our exogenous advertising intensity framework and in Robert and Stahl's endogenous advertising intensity case. Furthermore, the values of r and p_l are also comparable across the two models. The main difference is that since the advertising intensity is fixed at α in our version, the equilibrium outcome does not converge to the Bertrand equilibrium as advertising cost goes to zero. Note that the elasticity of r condition with respect to both c and A is satisfied for a wide range of parameters, including the parameters used in the experiment.[7]

III. Theoretical Predictions and Testable Hypotheses

Table 1 summarizes the parameter values used in the experiment and the theoretical predictions for the various treatments. We shall compare our laboratory market outcomes to the quantitative

[7] The elasticity of r with respect to c depends on the ratio of search cost to advertising cost. Numerical computations show that for n=4 and α=0.4 this elasticity is less than 1 whenever $c:A$ < 100:1. The elasticity of r with respect to A condition is satisfied for all c and A such that $c:A$ < 150:1. Therefore, the elasticity conditions are satisfied unless the two information costs differ by at least two orders of magnitude. 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.

predictions shown in this table, but based on previous experimental results we do not expect such strong, quantitative equilibrium predictions to hold very precisely. Much of our empirical analysis will therefore focus on the weaker, comparative static predictions summarized by the following hypotheses.

Table 1: Summary of Parameter Values and Theoretical Predictions

Advertising intensity (α) = 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 (simulated) = 1000

Experimental Parameters		$[p_l, r\text{-}c]$	r	Prob. Of Advertising	Expected Price	Expected Profit
$A = 2$	$c = 1$	[8.08, 12.37]	13.37	0.42	11.99	1931
$A = 2$	$c = 6$	[10.41, 20.87]	26.87	0.63	19.38	2822
$A = 5$	$c = 1$	[18.94, 25.79]	26.79	0.31	25.34	4473
$A = 5$	$c = 6$	[22.2, 38.69]	44.69	0.52	36.79	5527

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

One common feature in all search models is that equilibrium prices are increasing in the search costs. As the cost rises, consumers are more likely to buy from the first seller they sample. This gives the sellers more market power, which manifests itself in higher prices. Consumers are therefore clearly better off with lower search costs. Numerous experimental studies on search models, cited in the introduction, have found that in the absence of public information about the prices, search costs do tend to raise prices although monopoly prices as implied by the Diamond paradox are not consistently observed. [8]

Hypothesis 2: An increase in search cost results in increased incentives for the sellers to advertise, and higher seller profits.

[8] Grether, Schwartz and Wilde (1988), Davis and Holt (1996), Dufwenberg and Gneezy (2000), Abrams, Sefton and Yavas (2000), Morgan, Orzen and Sefton (2004a), Cason and Friedman (2003).

As the search cost increases, search intensity decreases. This creates increased incentives for the sellers to inform the consumers about their prices. The impact of search cost on seller profit would therefore appear to be ambiguous since the benefit of higher prices may be offset by increased advertising. However, if the elasticity of r with respect to c is less than 1 then the price effect dominates the increased advertising expenditure effect so that the profit increases as c increases. In the experiment, the parameters satisfy this restriction so that expected profit is increasing in search cost.

Hypothesis 3: An increase in advertising cost results in higher posted prices.

As outlined in Proposition 3, increasing advertising cost shifts the support of the equilibrium price distribution to the right and results in more weight being placed on higher prices. Morgan, Orzen and Sefton (2004b) also examine this comparative statics prediction and find support for this hypothesis. However, instead of using their "clearinghouse" institutional setting, we examine equilibrium price dispersion in the posted offer market.[9] But more importantly, we examine whether the comparative statics predictions on sellers' advertising and pricing behavior are supported even in the presence of buyer search costs.

Hypothesis 4: 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. However, the indirect effect of such an increase is that all sellers place a greater weight on higher prices (hypothesis 3), which reduces consumer search intensity. This in turn induces sellers to invest in advertising. The condition on the elasticity of r with respect to A ensures that the decrease in advertising incentives outweighs the effect arising from an increase the reservation price, leading to an overall lower propensity to advertise. However, note that although the advertising propensity decreases, the expected advertising expenditure may still increase. But even in this case, the increase in expected price set by each seller is sufficient to offset the increased advertising expenditure, ultimately resulting in higher profit. More specifically, the

[9] The clearinghouse model matches many of the institutional characteristics of internet price comparison sites such as Shoppers.com. Sellers have to incur a cost – an advertising fee set by the gatekeeper – in order to list their price in the clearinghouse. The posted offer institution studied here, on the other hand, resembles conventional retail markets.

increase in profit results directly from a downward shift in the cumulative price distribution. This establishes the role of advertising cost as a "facilitating device" to raise prices, as noted by Morgan et al. (2004b) in a model with a very different advertising technology.

IV. Experimental Design and Procedures

Experimental Design: The experiment modifies the standard posted-offer environment by incorporating two treatment variables – seller advertising and costly consumer search. We assume that sellers can reach a fixed proportion α (set equal to 0.4) of the consumers by incurring an advertising cost A. The buyers then have the option to engage in search at a cost c to obtain additional price quotes from other sellers. The experimental design is summarized in Table 2.

Table 2: Experimental Design

	Seller Advertising Cost High-Low-High	**Seller Advertising Cost Low- High-Low**
Low Buyer Search Cost	16 subjects –Robot Buyers (2 independent groups of 8 subjects)	16 subjects –Robot Buyers (2 independent groups of 8 subjects)
High Buyer Search Cost	16 subjects –Robot Buyers (2 independent groups of 8 subjects)	16 subjects –Robot Buyers (2 independent groups of 8 subjects)

Advertising costs enter the sellers' price and advertising decision directly and therefore have a pronounced effect on the equilibrium. On the other hand, the impact of the buyer search costs on the pricing behavior is indirect, since it operates through changing buyer behavior. This is the primary reason why we chose to manipulate advertising costs within sessions and search costs across sessions.[10] In four of the sessions, 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 'Low-High-Low' sessions. The two levels of search cost used in the experiments are c =1 and c = 6. The data identify the effect of a change in search costs by making the relevant across-sessions comparisons while within-session comparisons assess the effect of change in advertising cost A.

[10] Morgan et al. (2004b) also vary advertising cost within session.

To mitigate repeated game effects and reduce the incentives for collusive behavior, we randomly re-match subjects each period.[11] We made this design choice because we are testing a static model.

In order to focus on the strategic interactions among sellers, we adopt the robot buyer procedure used in Cason and Friedman (2003) and Morgan, Orzen and Sefton (2004 a,b).[12] Each of the four markets is comprised of 4 sellers and 1000 simulated computer buyers. The automated buyers always follow the equilibrium search strategy. This has the advantage of eliminating non-optimal search behavior and sharpens the focus on the theoretical mixed strategy predictions. To simplify the sellers' problem further, we inform all sellers of the buyers' reservation value r and did not allow sellers to price above r. Note, however, that we chose the parameters such that the reservation value r in the A=2 / c=6 treatment is the same as in the A=5 / c=1 treatment. It is important to verify that the differences in price distributions we observe are not driven by differences in reservation prices alone. In this key A=2 / c=6 versus A=5 / c=1 comparison, the reservation prices remain the same while the mean and minimum prices differ across treatments. Of course, other predictions such as the advertising intensity also differ across all treatments and do not depend on the announced reservation price.

Experimental Procedures: The experiment consisted of four 120-minute sessions containing eight independent subject cohorts, all conducted in the Vernon Smith Experimental Economics Laboratory at Purdue University. The subjects were recruited from undergraduate economics classes and no one participated in more than one session. Upon arrival, the subjects were seated at separate, visually isolated computer terminals and no communication was permitted throughout the session. Each subject received a set of instructions and record sheets. Appendix B contains the instructions for the sessions. Since the instructions were read aloud, we assume that the information contained in them was common knowledge.

Each session proceeded through a sequence of 75 trading periods. All sellers have the same homogenous good whose cost of production is normalized to zero. The sellers do not face any

[11] The 16 sellers in the experimental session were divided into two equal sized groups of 8 sellers each and the random matching took place within each group. This allowed us to obtain two statistically independent observations per session.

[12] Cason and Friedman (2003, page 239) note that, "Human buyers might not follow strictly a reservation price strategy, much less (an) identical reservation strategy." The differing human behavior may then influence the sellers' pricing strategy. Moreover, the model calls for a continuum of consumers. In the experimental setting, this is can be approximated by simulating them with computer algorithms (or robots).

capacity constraint i.e. they can sell as many units as are demanded. At the start of a trading period, each seller decides the price he wants to charge and also whether or not he wants to advertise this price. If he chooses to advertise then he must pay the advertising cost. The price advertisement reaches forty percent of the buyers.

After all sellers make their advertising and pricing decision, some of the buyers receive a price advertisement. Every period, each advertising seller's price is equally likely to be shown to each buyer and which of the buyers actually receive the advertisements is determined randomly. Note that a buyer may receive multiple ads or may not receive any ad at all. Buyers then make their search decision. The buyers who receive advertisements decide whether to search for other prices or to buy a single unit at an advertised price. If a buyer decides to search for other sellers then he has to pay the transportation cost for each different price quote. If he decides to buy at the advertised price, he has to pay a one-time transportation cost to obtain the good from the seller. The buyers are programmed to follow the reservation price strategy; i.e., each robot buyer will search only once if it receives no ad or else will purchase at the advertised price if it is less than r.

Following Cason and Friedman (2003) and Morgan, Orzen and Sefton (2004b), at the end of each period the seller is informed about the number of units he or she has sold, the prices, quantities and advertising decisions of other sellers in the market. These prices were displayed from the lowest to the highest and did not reveal the identities of the individual sellers.[13]

All transactions were in experimental francs, which were converted to dollars at the end of the experiment using a known but private dollar conversion rate. The earnings typically ranged between \$15 and \$35 per subject.

V. Experimental Results

We divide the results into four subsections. Section V.1 presents an overview of the time series of prices in the late periods of the sessions. Sections V.2 and V.3 report results on the search cost and advertising cost comparative statics, respectively. Section V.4 focuses on price distributions.

[13] 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.

V.1 Overview of Late Periods

Figures 2 through 5 present the time series of prices for four of the twelve 25-period "runs." Each figure presents a different buyer search cost and seller advertising cost combination. All the figures display the final 25 periods in the sessions since the results are somewhat more erratic in the early periods when subjects are learning about the market and the incentives they face.[14] Open diamonds display individual advertised prices and solid squares represent unadvertised prices. The figures show the mean advertised and unadvertised prices with the dashed and solid lines, respectively. The perfectly horizontal lines display the theoretical price predictions, with the reservation price the higher thick, solid line and the equilibrium minimum prices the lower thick, solid line.

In these later periods, nearly all unadvertised prices are at the buyers' reservation price as predicted by the model. Although not all sellers immediately recognize the incentive to post unadvertised prices at the reservation price, most unadvertised prices are within 10 percent of this maximum price after the initial 25-period run. In fact, in some cases *all* unadvertised prices are at the reservation price (Figure 4). Advertised prices, on the other hand, are clearly dispersed in all four figures. Some advertised prices are below the equilibrium minimum price, but these appear to be offset by sufficiently high prices so that the mean advertised price ranges both above and below the equilibrium expected advertised price. Overall, these figures give the impression that the price predictions of the model receive considerable support. The next two subsections provide formal documentation consistent with this impression.

V.2 Search Cost Comparative Statics

As mentioned above, sellers' behavior is more erratic in the initial periods of the sessions when they are learning the trading mechanism as well as their advertising and pricing incentives. Moreover, the results in the first several periods after a treatment change sometimes exhibit a hysteresis effect arising from the conditions of the previous treatment. Since we are interested in testing the *equilibrium* predictions of the model, in the formal tests we exclude the initial 25-period "learning" run and the first 5 periods of each run following a treatment switchover. We

[14] Morgan et al. (2004b) also note that "substantial and systematic adjustment in behavior" seems to occur during the early phase of their experiment.

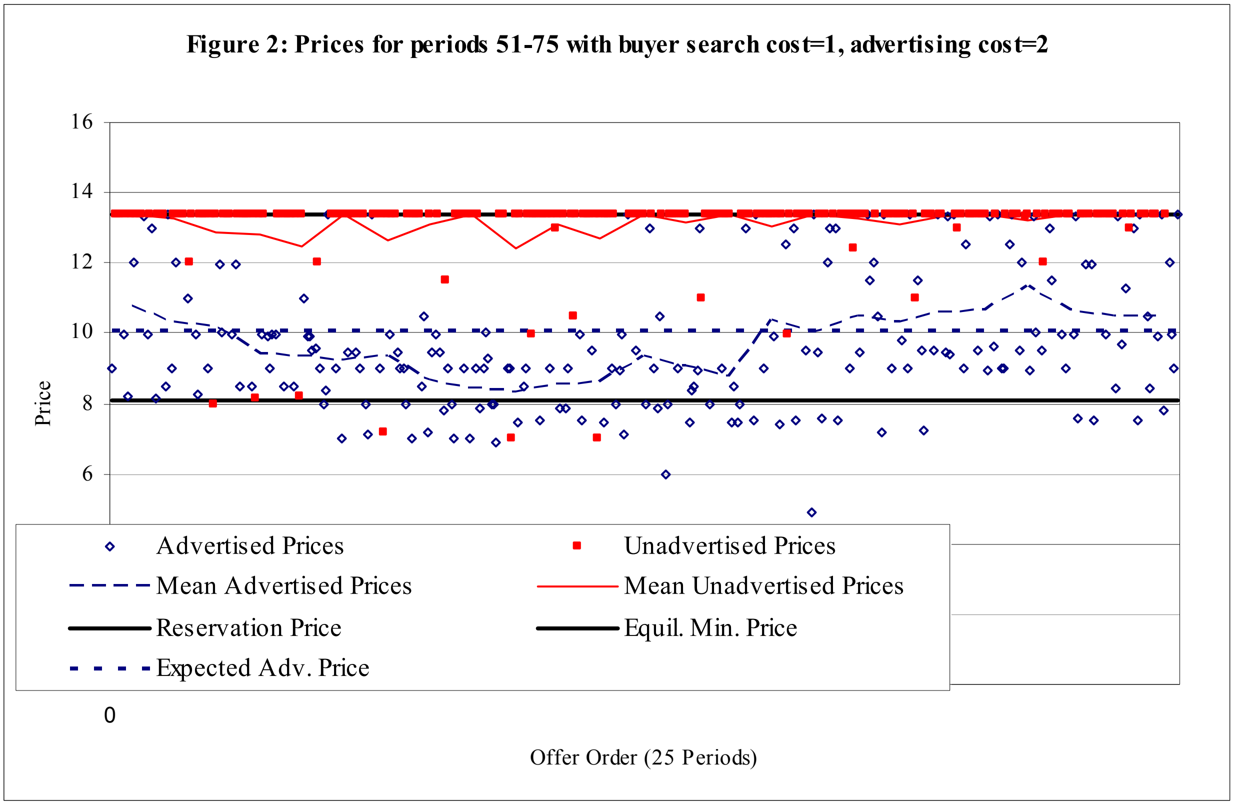


Figure 2: Prices for periods 51-75 with buyer search cost=1, advertising cost=2
16
14
12
10
8
6
Price
Advertised Prices
Unadvertised Prices
Mean Advertised Prices
Mean Unadvertised Prices
Reservation Price
Equil. Min. Price
Expected Adv. Price
0
Offer Order (25 Periods)

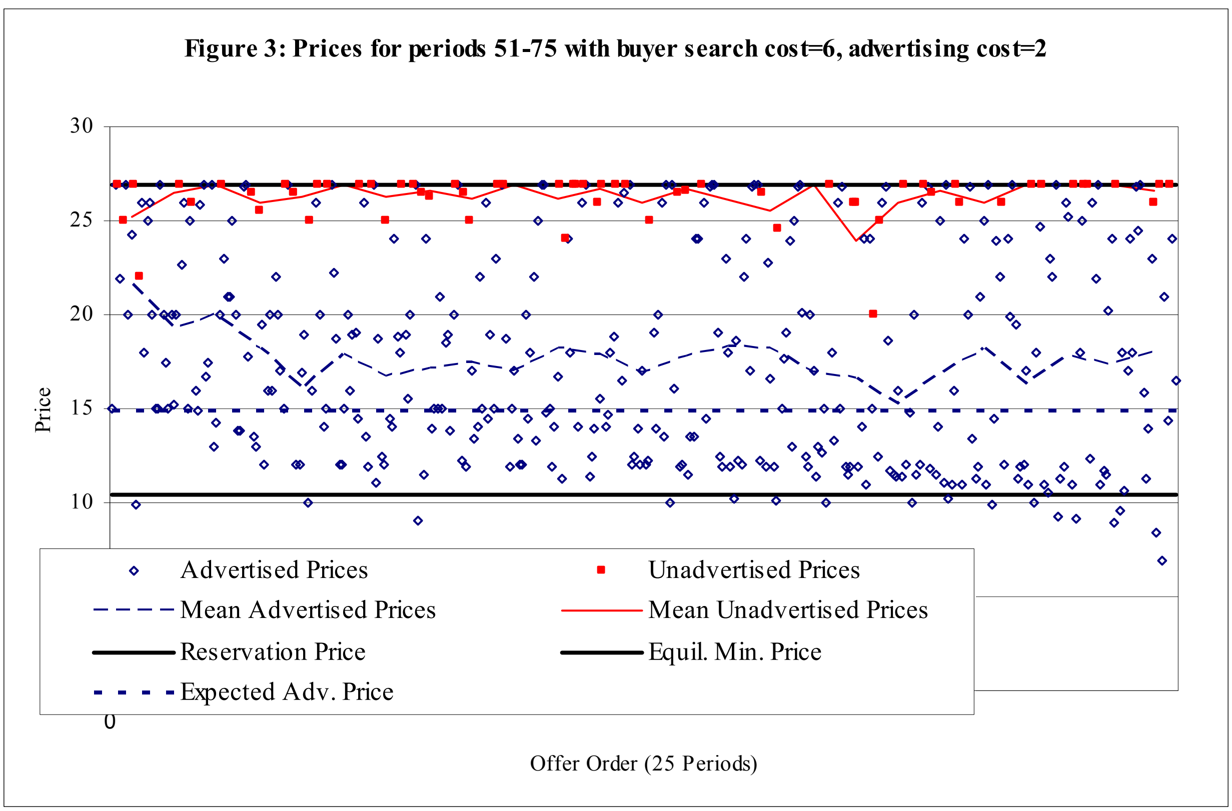


Figure 3: Prices for periods 51-75 with buyer search cost=6, advertising cost=2
30
25
20
15
10
Price
Advertised Prices
Unadvertised Prices
Mean Advertised Prices
Mean Unadvertised Prices
Reservation Price
Equil. Min. Price
Expected Adv. Price
0
Offer Order (25 Periods)

Figure 4: Prices for periods 51-75 with buyer search cost=1, advertising cost=5

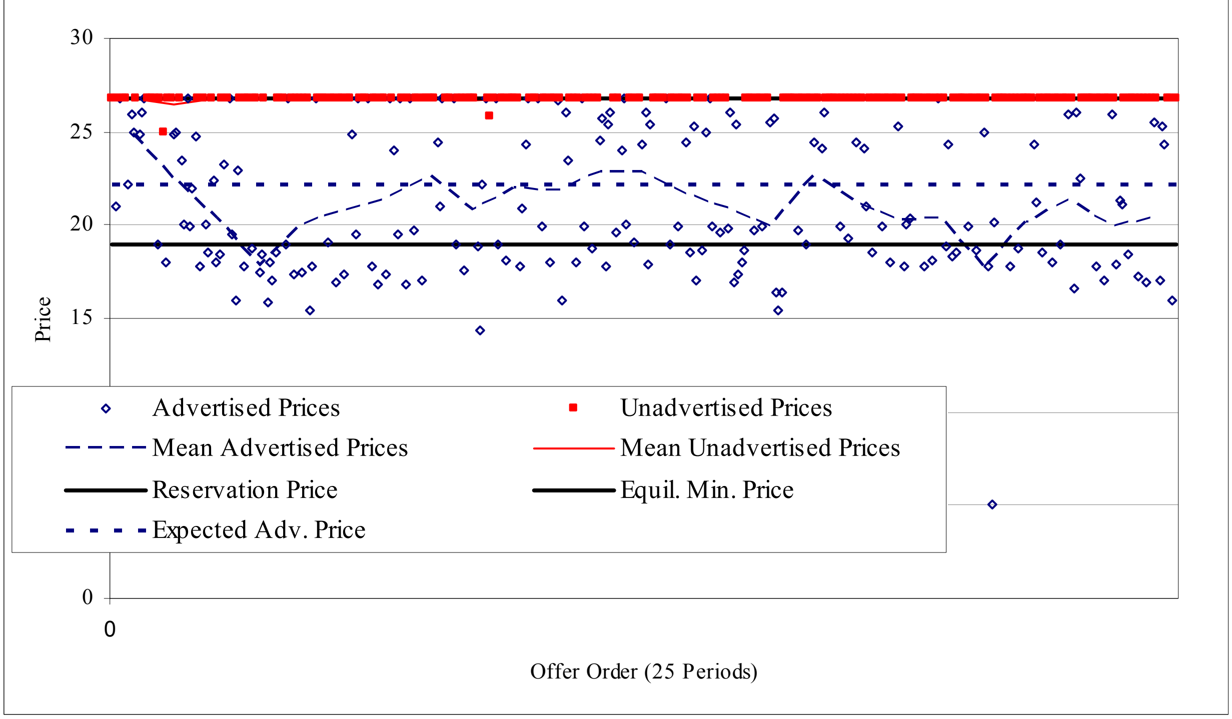
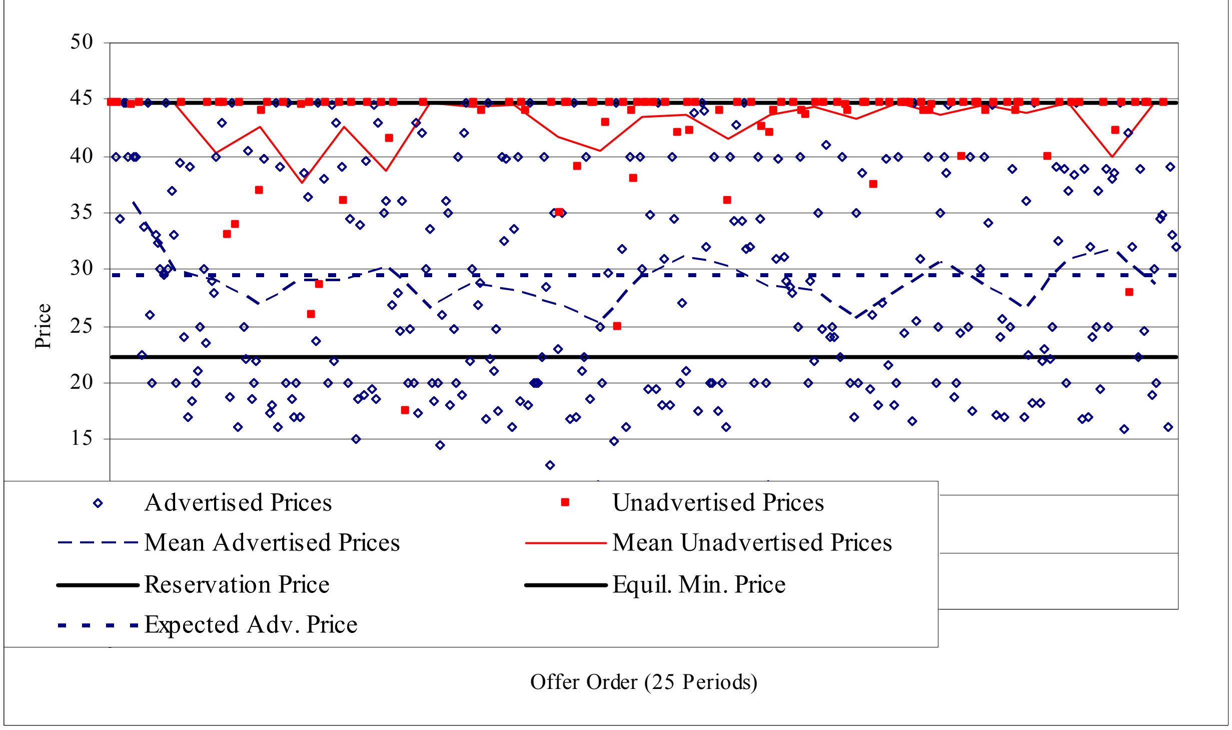


Figure 5: Prices for periods 51-75 with buyer search cost=6, advertising cost=5



therefore employ 40 of the 75 total periods in the following analysis: periods 31-50 (run 2) and periods 56-75 (run 3).

Result 1: An increase in search costs leads to higher prices (support for Hypothesis 1).

Support: Table 3 reports the summary statistics for each session, separately for each independent matching group. When the advertising cost is 2, shown in the top half of the table, the highest mean overall price (column 7) when the search cost = 1 is lower than the lowest mean overall price when the search cost = 6. Consequently, a conservative, nonparametric Mann-Whitney test based on one observation from each of these 8 statistically independent sessions rejects the null hypothesis that search costs do not affect the mean prices at the 5-percent significance level. The mean advertised price in column 4 and the median advertised price in column 5 also give the same result. Similar statements and identical conclusions also hold for advertising cost = 5 in the lower half of the table.

The lower end of the advertised price distribution also varies as predicted with the search costs. The minimum price is less informative since it depends on the outliers of the distribution. Therefore, for a formal comparison of the lowest prices we use the 10^{th} percentile of the advertised price distribution, shown in column 6. The highest 10^{th} percentile in the advertising cost = 2, search cost = 1 treatment (8.48) is less than the lowest 10^{th} percentile in the advertising cost = 2, search cost = 6 treatment (9.99), so the Mann-Whitney test strongly rejects the null hypothesis of equal distributions for these summary statistics. There is a slight overlap between the distributions of the 10^{th} percentiles when advertising cost = 5, but the Mann-Whitney U statistic only rises to 1 so the null hypothesis is still rejected at the 5-percent significance level (one-tailed test). Qualitatively similar results can be obtained when using other measures of the low prices, such as the 5^{th} percentile of the price distribution.

These conservative, nonparametric tests are valuable because they require a minimal number of statistical assumptions, and are based on only statistically independent observations. However, they do not control for other factors that could influence results, such as possibly significant time trends in the prices. To control for any time trends and check the robustness of our conclusions we also conducted multivariate, random effects regression models, where individual subjects represented the random effects. The regressions also include session dummies to capture fixed session effects, and they provide the same conclusions irrespective of whether ln(period) or 1/period is used to control for time trends. They corroborate with the conclusions from the nonparametric tests; in particular, prices are significantly higher with higher search costs both when advertising cost = 2 (*t*-statistic = 4.03) and when advertising cost = 5 (*t*-statistic = 5.33).

Table 3: Summary Statistics for Later 40 Periods 31-50 and 56-75

(1) Session ID	(2) Adver-tising Cost	(3) Buyer Search Cost	(4) Mean Advertised Price	(5) Median Advertised Price	(6) Advertised Price 10th Percentile	(7) Mean Overall Price	(8) # of Advertised Prices	(9) Frequency of Advertising	(10) Mean Seller Profit
1	2	1	9.38	8.99	7.00	11.82	58	0.36	1920
2	2	1	9.91	9.46	7.80	11.06	102	0.64	1251
3	2	1	10.11	9.95	8.48	11.93	70	0.44	1872
4	2	1	9.84	10.00	6.33	11.01	106	0.66	1140
Treatment Summary			9.84	9.49	7.25	11.45		0.53	1546
Treatment Predictions			10.05	9.97	8.42	11.99		0.42	1931
5	2	6	18.58	17.00	11.48	19.70	137	0.86	2489
6	2	6	16.04	14.69	10.68	17.64	135	0.84	2101
7	2	6	19.01	19.99	10.50	19.63	143	0.89	2536
8	2	6	18.21	19.22	9.99	18.75	136	0.85	2444
Treatment Summary			17.98	17.50	10.69	18.93		0.86	2392
Treatment Predictions			14.94	14.59	11.12	19.38		0.63	2822
1	5	1	19.20	21.95	12.15	22.53	65	0.41	3090
2	5	1	19.56	17.99	15.98	22.62	87	0.54	2464
3	5	1	21.11	19.75	17.34	24.49	65	0.41	3608
4	5	1	21.14	20.96	16.62	24.10	76	0.48	3159
Treatment Summary			20.23	19.74	15.79	23.44		0.46	3080
Treatment Predictions			22.17	22.07	19.52	25.34		0.31	4473
5	5	6	30.10	28.99	19.94	33.63	107	0.67	4071
6	5	6	30.36	29.00	19.96	34.44	112	0.70	4058
7	5	6	28.41	24.99	17.50	32.75	115	0.72	3329
8	5	6	28.89	28.00	17.00	32.46	117	0.73	3402
Treatment Summary			29.42	28.00	18.14	33.32		0.70	3715
Treatment Predictions			29.57	29.13	23.41	36.79		0.52	5527

Result 2: An increase in buyer search costs leads to a higher seller advertising rate (support for Hypothesis 2).

Support: A higher search cost creates increased incentives for sellers to inform the consumers about their prices through advertising. Column 9 of Table 3 provides strong support for this prediction. In both advertising cost treatments, all the advertising rates for the independent sessions are higher with the higher search costs than with the lower search costs, so the Mann-Whitney test rejects the null of no search cost treatment effect at the 5-percent level. Probit models for the seller advertising choice that control for a time trend and use random subject effects and fixed session effects also support this conclusion both for advertising cost = 2 (*t*-statistic = 4.17) and for advertising cost = 5 (*t*-statistic = 2.25). It is important to note, however, that in all four treatment conditions the overall advertising rate exceeds the model's prediction.

Result 3: An increase in buyer search costs leads to higher seller profits (support for profit component of Hypothesis 2).

Support: An increase in search costs results both in higher prices (result 1) and higher advertising expenditure (result 2). The model predicts that in equilibrium the price effect dominates the advertising expenditure effect, thereby raising the overall profits. Column 10 of Table 3 provides strong support for this prediction. In both advertising cost treatments, all the mean seller profits for the independent sessions, are higher with the higher search costs than with the lower search costs, so the Mann-Whitney test rejects the null of no search cost treatment effect at 5-percent level. Regression models for the individual seller profits that control for a time trend and use random subject effects and fixed session effects support this conclusion for advertising cost = 2 (*t*-statistic = 3.01) but not for advertising cost = 5 (*t*-statistic = 1.01).[15] Importantly, however, note that average profits fall below the predicted profits in all four treatment conditions, especially when advertising costs are high. Since average prices are similar to the predictions (columns 4, 5 and 7), these lower-than-expected profits may be attributed to the higher-than-predicted advertising rate.

[15] This insignificant difference in profits when advertising cost = 5 could be due to the significantly increasing profits over time in this treatment (ln(period) variable *t*-statistic = 2.38) and the highly significant session fixed effects ($\chi^2_{6\,d.f.}$ = 20.53).

Result 4: Minimum and mean advertised prices are lower in the advertising cost = 2 / search cost = 6 treatment than in the advertising cost = 5 / search cost = 1 treatment, as predicted.

Support: Recall from Table 1 that the buyers' reservation price, which is provided to sellers and is a constraint on the permissible price offers, is virtually identical in these two treatments. We deliberately aligned the reservation prices in these two treatments because we were concerned that the price and profit results documented above could be arising from differences in the reservation prices across treatments. These two treatments, therefore, provide a more demanding test of the model, since although the maximum (reservation) price is the same in both treatments, the minimum and mean advertised prices are different. Consistent with the equilibrium predictions, column 6 of Table 3 shows that the highest 10^{th} percentile in the ad cost = 2, search cost = 6 treatment (11.48) is less than the lowest 10^{th} percentile in the ad cost = 5, search cost = 1 treatment (12.15), so the Mann-Whitney test rejects the null hypothesis of equal minimum price for these two treatments. Similarly, column 4 shows that the highest mean advertised price in the ad cost = 2, search cost = 6 treatment (19.01) is less than the lowest mean advertised price in the ad cost = 5, search cost = 1 treatment (19.20). Therefore, the Mann-Whitney test also indicates that mean prices are significantly different for these two key treatments. Advertising rates (column 9) also differ across these two treatments as predicted by the theory.

V.3 Advertising Cost Comparative Statics

Recall that our design varied advertising costs within sessions. The Mann-Whitney test is based on two independent samples, so it is not appropriate for the within-session advertising cost comparison. Since each group of subjects made choices in both low and high advertising cost treatments, with the treatment order varied, our design generates statistically independent *pairwise differences* for conservative nonparametric sign tests and Wilcoxon tests. The power of these tests is limited when considering only a single buyer search cost because they are based on only 4 sessions. The power increases considerably when pooling across the search costs and using all 8 sessions. As in the previous subsection, we also report parametric regressions that verify the robustness of our conclusions to the inclusion of time trends. In all cases, the tests agree and provide strong support for the model's comparative static predictions regarding advertising cost. These findings are consistent with the view of advertising costs as a "facilitating device" that allows the sellers to set higher prices, which translates into higher profit despite their increased advertising expenditures.

Result 5: An increase in advertising costs leads to higher prices (support for Hypothesis 3).
Support: We construct the relevant pairwise differences from the results shown in Table 3. For example, in session ID 1 the mean price is 11.82 when advertising cost is 2 and it is equal to 22.53 when advertising cost is 5. The difference of 10.71 is one of four statistically independent differences with buyer search cost = 1, all of which are positive as predicted by the model. The probability of four positive differences under the null hypothesis that positive and negative differences are equally likely is the same as the probability of flipping a fair coin as four consecutive heads, and gives a *p*-value=0.0625 according to the sign test. In fact, a similar pairwise comparison of any prices shown in Table 3 (mean, median or 10^{th} percentile of advertised prices, or the mean overall price) for both buyer search cost treatments *always* indicates higher prices when advertising costs are higher. The sign test therefore always supports Hypothesis 3. Pooling observations in the two buyer search cost treatments increases the sample size to 8 sessions, which is sufficient to conduct nonparametric Wilcoxon signed rank tests. The 8 positive differences for each price summary statistic leads to a test statistic value of 0, which is significant at the 1-percent significance level.

Result 6: An increase in advertising costs reduces the sellers' propensity to advertise (support for Hypothesis 4).
Support: When search cost = 6, the advertising rate is always lower with higher advertising costs (0.67 to 0.73) than with lower advertising costs (0.84 to 0.89). Since all the four pairwise differences are negative we can reject the null of no difference using a sign test. A random effects probit model with subject random effects, session fixed effects and a time trend also strongly rejects the null hypothesis of no advertising cost treatment effect (*t*-statistic = 6.94). When search cost = 1, in one of the four sessions (session 1) the advertising rate is lower with lower advertising costs (0.36) than with higher advertising costs (0.41), so the sign test does not reject the null hypothesis for this search cost. The random effects probit model has more power, however, and strongly rejects the null hypothesis of no advertising cost treatment effect even for this low buyer search cost (*t*-statistic = 2.76). Applying the Wilcoxon signed rank test to the

pooled data for all 8 sessions across both search cost treatments also rejects the null at the 1-percent significance level with a test statistic value of 1.

Result 7: An increase in advertising costs leads to higher seller profits (support for Hypothesis 4).

Support: The overall advertising rate only declines by about 15 to 20 percent when advertising costs rise by 150 percent from 2 to 5, so advertising expenditures clearly increase as we increase the advertising cost. However, an increase in advertising costs also results in higher prices (Result 5) which raises seller profits. In theory, the positive indirect price effect exceeds the negative direct advertising expenditure effect, leading to a somewhat counterintuitive conclusion that the sellers benefit from increased advertising costs. Column 10 of Table 3 provides strong support for this prediction. In both search cost treatments all the pairwise differences in mean seller profits indicate higher profits with the higher advertising costs than with the lower advertising costs, so the sign test rejects the null of no advertising treatment effect. Regression models for individual seller profits that control for a time trend and use random subject effects and fixed session effects also support this conclusion both for search cost = 1 (*t*-statistic = 17.78) and for search cost = 6 (*t*-statistic = 10.43). This result stands in sharp contrast to Morgan et al.'s finding that increased advertising costs have no significant impact on profits. We discuss a possible explanation in the next subsection.

V.4 Price Distributions

The analysis to this point has focused on average prices and profits. However, the model predicts price dispersion as the outcome of a mixed strategy equilibrium. To complete the analysis, we therefore construct an empirical price distribution using aggregate session level data.

Figures 6 and 7 illustrate the theoretical and empirical cumulative price distributions for both levels of search cost. While the changes in the distribution are in the predicted directions and the dispersion of prices is clearly evident, in three of the four cases, observed prices tend to be lower than the predicted levels. Indeed, in these cases the equilibrium distribution first order stochastically dominates the empirical distribution. Moreover, in all cases, the lower bound of the empirical distribution is below that predicted by the model.

Figure 6: Empirical and Equilibrium Price CDF for Search Cost=1, for late 40 periods 31-50 and 56-75

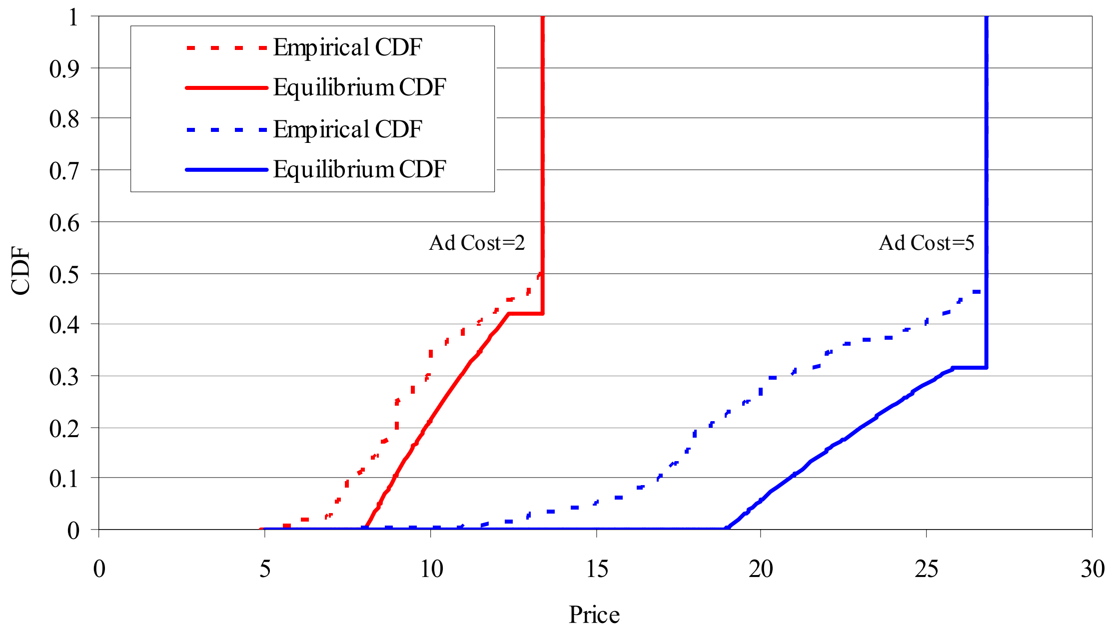
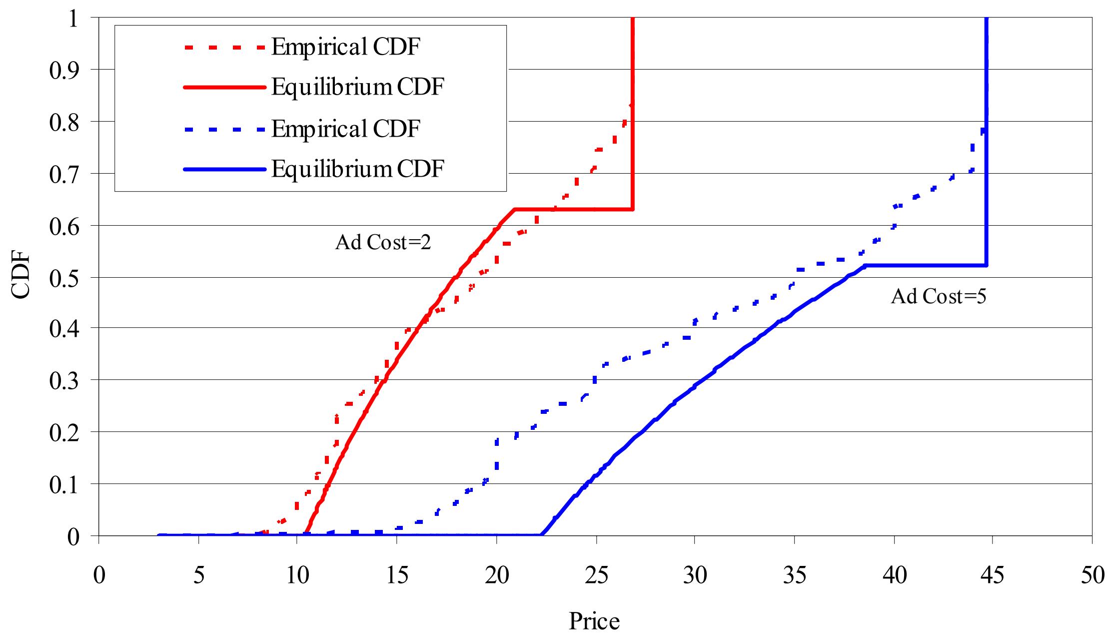


Figure 7: Empirical and Equilibrium Price CDF for Search Cost=6, for late 40 periods 31-50 and 56-75



Morgan et al. (2004b) also observe that prices are lower than predicted. They argue that these lower prices combined with the tendency to over advertise explain the failure of profits to increase as advertising cost increases. This result is not replicated in our study despite prices that are also observed below theoretical predictions. While in both studies prices and advertising expenditures rise with increases in the advertising cost, only in our experiment is the price increase sufficient to offset the greater advertising expenditure, resulting in higher profit. This discrepancy may arise from a fundamental difference in the mechanism by which buyers obtain price information in the two models. In Morgan et al.'s clearinghouse model the "bargain-hunters" always pay the lowest advertised price, intensifying competition compared to our posted offer environment with search in which buyers purchase at the lowest price among the ads that they receive. For this reason we conjecture that the positive effect of increased advertising cost on prices is less pronounced in Morgan et al.'s clearinghouse environment.

VI. Conclusion

In this study we analyze the effect of two types of informational costs on pricing and advertising behavior in posted offer markets. The experiment is based on a variant of Robert and Stahl's (1993) influential model of seller advertising with costly buyer search. The laboratory data provide almost uniformly positive support for the theoretical model. The data support all of the model's comparative static predictions for prices and profits, and the only major systematic deviation from the quantitative prediction is that observed advertising rates exceed the predicted rates. Prices are also a bit lower than predicted.

The distinguishing feature of our environment is that the information can both be disseminated by the sellers and acquired by the buyers. This is more realistic than the more simplified posted offer market often studied in the laboratory, and it allows us to draw important parallels between our results and behavior observed in the field. For instance, the aggressive advertising strategies adopted by sellers in our experiment are reminiscent of many 'real world' price advertising campaigns adopted by firms in markets in which price information could also be gathered by buyers. Our study suggests that this type of aggressive advertising may not be the product of "irrational exuberance" but in fact be deeply rooted in strategic profit considerations.

The next obvious question to be addressed is whether these findings are robust to inclusion of more erratic human buyer behavior. Morgan et al. (2004b) note that "complexity of computing [two levels of] equilibrium [mixed] strategies make it far from obvious that human decision makers will use equilibrium strategies". Cason and Friedman (2003) use similar reasoning to justify employing robot buyers as an additional treatment variable in their markets with costly buyer search but no seller advertising. The results were more variable in Cason and Friedman's (2003) human buyer sessions than in their robot buyer sessions, but the price dispersion model's comparative statics were generally supported even with human buyers. By contrast, in a companion paper (Cason and Datta, 2004) we show that the current model's equilibrium predictions are grossly violated when we replace the robot buyers' pre-programmed and observable reservation price strategies with human buyers that make costly search and purchase decisions. The human buyer sessions illustrate that the equilibrium price predictions of this incomplete information model are very sensitive to deviations from equilibrium advertising and search decisions. In particular, the overly aggressive advertising observed in the robot buyer sessions reported here, which is similar to the aggressive advertising documented in the robot buyer sessions of Morgan, Orzen and Sefton (2004b), appears to cause large deviations from equilibrium with human buyers.

REFERENCES

1. Abrams, Eric, Martin Sefton and Abdullah Yavas (2000), An Experimental comparison of two search models, *Economic Theory*, Vol. 16, 735-749.

2. Baye, Michael and John Morgan (2001), Information gatekeepers on the internet and the competitiveness of homogeneous product markets, *American Economic Review*, Vol. 91, 454-474.

3. Baye, Michael, John Morgan and Patrick Scholten (2004), Price dispersion in the small and in the large: Evidence from an Internet price comparison site, *Journal of Industrial Economics*, forthcoming.

4. Brynjolfsson, Eric and Michael Smith, (2000) "Frictionless commerce? A Comparison of Internet and Conventional Retailers," *Management Science*, Vol. 46, 563-585.

5. Bester, Helmut (1994), Random Advertising and Monopolistic Price Dispersion, *Journal of Economics and Management Strategy*, Vol. 3, 545-60.

6. Burdett, Kenneth and Kenneth Judd (1983), Equilibrium Price Dispersion, *Econometrica*, Vol. 51, 955-970.

7. Butters, Gerard (1977), Equilibrium Distributions of Sales and Advertising Prices, *Review of Economic Studies*, Vol. 44, 465-492.

8. Caminal, Ramon (1996), Price Advertising and Coupons in a Monopoly Model, *Journal of Industrial Economics*, Vol. 44, 33-52.

9. Cason, Timothy and Shakun Datta (2004), Costly Buyer Search in Laboratory Markets with Seller Advertising, working paper, Purdue University.

10. Cason, Timothy and Daniel Friedman (2003), Buyer Search and Price Dispersion: A Laboratory Study, *Journal of Economic Theory,* Vol. 112, 232-260.

11. Davis, Douglas and Charles Holt (1996), Consumer Search Costs and Market Performance, *Economic Inquiry*, Vol. 34, 133-151.

12. Diamond, Peter (1971), A Model of Price Adjustment, *Journal of Economic Theory*, Vol. 3, 156-168.

13. Dufwenberg, Martin and Uri Gneezy (2000), Price competition and market concentration: An experimental study, *International Journal of Industrial Organization,* Vol. 18, 7-22.

14. Grether, David M., Alan Schwartz, and Louis L. Wilde (1988), Uncertainty and Shopping Behavior: An Experimental Analysis, *Review of Economic Studie*s, Vol. 55, 323-342.

15. Morgan, John, Henrik Orzen, and Martin Sefton (2004a), An Experimental Study of Price Dispersion, *Games and Economic Behavior*, forthcoming..

16. Morgan, John, Henrik Orzen, and Martin Sefton (2004b), An Experimental Study of Advertising and Price Competition, *European Economic Review*, forthcoming.

17. Reinganum, Jennifer (1979), A Simple Model of Equilibrium Price Dispersion, *Journal of Political Economy*, Vol. 87, 851-858.

18. Robert, Jacques and Dale O. Stahl (1993), Informative Price Advertising in a Sequential Search Model, *Econometrica*, Vol. 61, 657-686.

19. Salop, Steven (1973), Wage Differentials in a Dynamic Theory of the Firm, *Journal of Economic Theory*, Vol. 6, 321-344.

20. Salop, Steven and Joseph Stiglitz (1977), Bargains and Ripoffs: A Model of Monopolistically Competitive Price Dispersion, *Review of Economic Studies*, Vol. 44, 493-510.

21. Salop, Steven and Joseph Stiglitz (1982), The Theory of Sales: A Simple Model of Equilibrium Price Dispersion with Identical Agents, *American Economic Review*, Vol. 72, 1121-1130.

22. Smith, Vernon (1982), Microeconomic System as an Experimental Science, *American Economic Review,* Vol. 72, 923-55.

23. Stahl, Dale O. (1989), Oligopolistic Pricing with Sequential Consumer Search, *American Economic Review*, Vol. 79, 700-712.

24. Stahl, Dale O. (1990), Strategic Advertising and Pricing with Sequential Buyer Search, Center for Economic Research, University of Texas, Discussion Paper 90-04.

25. Stahl, Dale O. (1996), Oligopolistic Pricing with heterogeneous consumer search, *International Journal of Industrial Organization*, Vol. 14, 243-268.

26. Stigler, George (1961), The Economics of Information, *Journal of Political Economy*, Vol. 69, 213-225.

27. Stiglitz, Joseph (1979), Equilibrium in Product Markets with Imperfect Information, *American Economic Review*, Vol. 69, 339-345.

28. Varian, Hal (1980), A Model of Sales, *American Economic Review*, Vol. 70, 651-659.

Appendix A: Theoretical Details

We consider a simplified version of Robert and Stahl's (1993) optimal search model. The only difference is that at a cost A, the advertisers can reach a proportion $\alpha < 1$ of the population. All the other assumptions are the same. The recursive procedure for the derivation of the symmetric market equilibrium can be outlined as follows.

Proof of Proposition 1: Sellers play a mixed strategy wherein they either charge an unadvertised reservation price r or randomize in the interval $[p_l, r-c]$ where p_l is the lower bound of the equilibrium distribution. No seller sets a price between r and $(r-c)$. Sellers charging $(r-c)$ or less pay an advertising cost A in order to reach a proportion α of the population. The probability that a seller charges p or below is denoted by $F(p)$ and the equilibrium expected profit is denoted by θ. It then follows that

$$\theta = \begin{cases} p\left[\alpha\left[1-\alpha F(p)\right]^{n-1} + \dfrac{1-\alpha}{n}\left[1-\alpha F(r-c)\right]^{n-1}\right] - A, \text{ for } p \in \left[p_l, (r-c)\right] & (1) \\ p_l\left[\alpha + \dfrac{1-\alpha}{n}\left[1-\alpha F(r-c)\right]^{n-1}\right] - A \text{ for } p = p_l & (2) \\ (r-c)\left[\left(\alpha + \dfrac{1-\alpha}{n}\right)\left[1-\alpha F(r-c)\right]^{n-1}\right] - A \text{ for } p = r-c & (3) \\ \dfrac{r}{n}\left[1-\alpha F(r-c)\right]^{n-1} \text{for } p = r & (4) \end{cases}$$

where $\alpha F(p)$ is the probability that a consumer receives an ad from a given seller charging a price less than or equal to p when the seller's advertising intensity is α.
$\alpha\left[1-\alpha F(p)\right]^{n-1}$ is the probability that a consumer receives an ad from a given seller and does not receive any ad from any other sellers charging a price less than or equal to p.
$\frac{1}{n}\left[1-\alpha F(r-c)\right]^{n-1}$ is the probability that a consumer receives no ad from any of the other sellers and chooses to visit one given store at random.
$\left[\alpha\left[1-\alpha F(p)\right]^{n-1} + \frac{1}{n}\left[1-\alpha F(r-c)\right]^{n-1}\right]$ is the probability that the seller sells to a consumer at a price p.

Since in equilibrium, the expected profits earned by the sellers over the support of the mixed strategy is constant, we can derive an expression for $F(p)$ as a function of the endogenously determined reservation price, r.
From Equation (4) we get $\frac{\theta n}{r} = \left[1-\alpha F(r-c)\right]^{n-1}$ (5)
Substituting equation (5) in equation (2) yields $p_l = \frac{(\theta+A)r}{\alpha r+(1-\alpha)\theta}$ (6)
Substituting equation (5) in equation (3) yields $\theta = \frac{Ar}{\left[(n\alpha+1-\alpha)(r-c)-r\right]}$ (7)

Using (6) and (7) we can obtain an expression for the lower bound of the equilibrium distribution, p_l in terms of the parameters of the model and the endogenously determined r.

$$p_l = \frac{A\left(n\alpha+1-\alpha\right)(r-c)}{\alpha[\left(n\alpha+1-\alpha\right)(r-c)-r]+(1-\alpha)A} \tag{8}$$

Rewriting equation (6) gives $F(p)=\frac{1}{\alpha}\left[1-\left[\frac{\theta+A}{p\alpha}-\frac{\theta(1-\alpha)}{\alpha r}\right]^{\frac{1}{n-1}}\right]$.

Substituting for equation (7) in the above expression gives

$$F(p)=\frac{1}{\alpha}\left[1-\left[\frac{A\left[\left(n\alpha+1-\alpha\right)(r-c)-p(1-\alpha)\right]}{p\alpha\left[\left(n\alpha+1-\alpha\right)(r-c)-r\right]}\right]^{\frac{1}{n-1}}\right]. \tag{9}$$

Finally, the probability of the consumer being uninformed about seller j's price is given by

$$1-F(r-c)=\frac{1}{\alpha}\left[\alpha-1+\left\{\frac{An}{(n\alpha+1-\alpha)(r-c)-r}\right\}^{\frac{1}{n-1}}\right]. \tag{10}$$

Next we examine the consumer's search behavior. The reservation price r equates the expected benefits from search to the cost of search. A consumer is indifferent between accepting price r and spending search cost c to explore at random another store from which he did not receive any ad.

$$r = c + r\left[1-G(r-c)\right]+\int_{p_l}^{r-c} p dG(p)$$

$$\text{where } G(p)=\frac{(1-\alpha)F(p)}{\left[1-\alpha F(r-c)\right]}, \text{ for } p \le r-c.$$

$G(p)$ is the probability that the consumer assigns to the event that seller j's price is at or below p conditional on not being informed about j's price. Below, after substituting for the expression for $G(p)$, we simplify the expression for r.

$$r = c + r\frac{[1-F(r-c)]}{\left[1-\alpha F(r-c)\right]}+\int_{p_l}^{r-c} pd\frac{(1-\alpha)F(p)}{\left[1-\alpha F(r-c)\right]}$$

$$\Leftrightarrow \left[1-\alpha F(r-c)\right]r = c\left[1-\alpha F(r-c)\right]+r[1-F(r-c)]+(1-\alpha)\left(r-c\right)F(r-c)$$
$$-\int_{p_l}^{r-c}(1-\alpha)F(p)dp$$

$$\Leftrightarrow c\left[1-F(r-c)\right]=\int_{p_l}^{r-c}(1-\alpha)F(p)dp$$

$$\Leftrightarrow c=\frac{\int_{p_l}^{r-c}(1-\alpha)F(p)dp}{\left[1-F(r-c)\right]}\equiv H(r) \tag{11}$$

Comparative Statics

Lemma 1 $\frac{dr}{dc}>1$.

Proof: Applying the Implicit Function Theorem to equation (11) we get

$$-dc+\left[\frac{1}{[1-F(r-c)]^2}\right]\left[[1-F(r-c)][\int_{p_l}^{r-c}(1-\alpha)\frac{\partial F(p)}{\partial c}-(1-\alpha)F(r-c)]\right]dc+$$
$$\left[\frac{1}{[1-F(r-c)]^2}\right]\left[\frac{\partial F(r-c)}{\partial c}\int_{p_l}^{r-c}(1-\alpha)F(p)dp\right]dc+$$
$$\left[\frac{1}{[1-F(r-c)]^2}\right]\left[[1-F(r-c)][\int_{p_l}^{r-c}(1-\alpha)\frac{\partial F(p)}{\partial r}+(1-\alpha)F(r-c)]\right]dr+$$
$$\left[\frac{1}{[1-F(r-c)]^2}\right]\left[\frac{\partial F(r-c)}{\partial r}\int_{p_l}^{r-c}(1-\alpha)F(p)dp\right]dr=0.$$

It is straightforward to show that $\frac{\partial F(p)}{\partial c}$ and $\frac{\partial F(r-c)}{\partial c}$ are negative so that the terms multiplied by dc are negative. The terms multiplied by dr can be proved to be positive. It thus follows that $\frac{dr}{dc}>0$. Finally note that $\left|\frac{\partial F(p)}{\partial c}\right|>\left|\frac{\partial F(p)}{\partial r}\right|$ and $\left|\frac{\partial F(r-c)}{\partial c}\right|>\left|\frac{\partial F(r-c)}{\partial r}\right|$, which upon observing the above expression is sufficient to prove that $dr/dc>1$.

In the remainder, we denote $\frac{dr}{dc}=r'(c)$.

Proof of Proposition 2.A: To show that $p_l\to r$ as c goes to zero, suppose $\lim_{c\to 0}p_l<r$ and let $p\in(p_l,r)$. Then

$$\lim_{c\to 0}F(p)=\frac{1}{\alpha}\left[1-\left(\frac{A[(n\alpha+1-\alpha)r-p(1-\alpha)]}{p\alpha^2(n-1)r}\right)^{\frac{1}{n-1}}\right]>0.$$

This implies that $\lim_{c\to 0}H(r)=\lim_{c\to 0}\frac{\int_{p_l}^{r-c}(1-\alpha)F(p)dp}{[1-F(r-c)]}>0=\lim_{c\to 0}c$, a contradiction to the definition of $H(r)$. Therefore, we must have $\lim_{c\to 0}p_l=r$. It then follows at once that $\lim_{c\to 0}F(r-c)=F(p_l)=0$.

Finally $\lim_{c\to 0}F(r-c)=1-\left[\frac{An}{(n-1)\alpha r}\right]^{n-1}=0$. Solving for r it is then easy to see that it must be the case that $\lim_{c\to 0}r=\frac{An}{(n-1)\alpha}$.

Proof of Proposition 2.B: The probability of advertising by a seller is given by $F(r-c)$

$$F(r-c)=\frac{1}{\alpha}\left[1-\left\{\frac{An}{(n\alpha+1-\alpha)(r-c)-r}\right\}^{\frac{1}{n-1}}\right]$$

Differentiating with respect to c, we obtain

$$\frac{dF(r-c)}{dc}=\frac{1}{(n-1)\alpha}\left[\frac{An}{(n\alpha+1-\alpha)(r-c)-r}\right]^{\frac{-n}{n-1}}\left[\frac{An[(n\alpha-\alpha)r'(c)-(n\alpha-\alpha+1)]}{[(n\alpha+1-\alpha)(r-c)-r]^2}\right]$$

Thus, if $r'(c)>\dfrac{n\alpha+1-\alpha}{n\alpha-\alpha}$ it follows that $\frac{dF(r-c)}{dc}>0$.

Proof of Proposition 2.C: Differentiating the lower bound of the equilibrium distribution, p_l, with respect to c gives

$$\frac{dp_l}{dc}=\frac{A(n+1-\alpha)\left[r\alpha-\alpha cr'(c)+A(1-\alpha)[r'(c)-1]\right]}{\left[\alpha\left[(n\alpha+1-\alpha)(r-c)-r\right]+(1-\alpha)A\right]^2}.$$

The above expression is clearly positive if $\frac{r}{c}>\frac{dr}{dc}$ or $r'(c)\dfrac{c}{r}<1$.

Proof of Proposition 2.D: A straightforward calculation yields

$$\frac{d\theta}{dc}=\frac{A[r-r'(c)c][\alpha(n-1)+1]}{\left[\left(n\alpha+1-\alpha\right)(r-c)-r\right]^2}$$

which is positive if $\frac{r}{c}>r'(c)$ or $r'(c)\dfrac{c}{r}<1$.

Lemma 2: $\frac{dr}{dA}>0$.

Proof: Following the same steps as for Lemma 1, the result follows from straightforward computations.

Proof of Proposition 3.A: Recall that $F(r-c)=\frac{1}{\alpha}\left[1-\left\{\frac{An}{(n\alpha+1-\alpha)(r-c)-r}\right\}^{\frac{1}{n-1}}\right]$.

If $\lim_{A\to 0}\left(n\alpha+1-\alpha\right)(r-c)-r\neq 0$, then $\lim_{A\to 0}F(r-c)\notin[0,1]$, which is impossible. This implies that $\lim_{A\to 0}\left(n\alpha+1-\alpha\right)(r-c)-r=0$ or $\lim_{A\to 0}r=\dfrac{c(\alpha n+1-\alpha)}{(n-1)\alpha}$. Using the above result, $\lim_{A\to 0}\theta=\frac{c(n\alpha+1-\alpha)}{(\alpha n-\alpha)n}\left(\lim_{A\to 0}\left[1-\alpha F(r-c)\right]^{n-1}\right)$. Since $\lim_{A\to 0}F(r-c)\leq 1$, it follows that $\lim_{A\to 0}\left[1-\alpha F(r-c)\right]^{n-1}\geq(1-\alpha)^{n-1}>0$. Thus, $\lim_{A\to 0}\theta=(1-\alpha)^{n-1}\frac{c(n\alpha+1-\alpha)}{(\alpha n-\alpha)n}$

> 0. Finally, since $\lim_{A\to 0}\theta$ and $\lim_{A\to 0} r$ are both strictly positive, $\lim_{A\to 0} p_l = \frac{(A+\theta)r}{\alpha r+(1-\alpha)\theta} > 0$.

Proof of Proposition 3.B: Differentiating the probability of advertising $F(r-c)$ with respect to A gives

$$\frac{dF(r-c)}{dA} = \frac{An[(n\alpha-\alpha)r'(A)] - n[(n\alpha+1-\alpha)(r-c)-r]}{\alpha(n-1)[(n\alpha+1-\alpha)(r-c)-r]^2}\left[\frac{An}{(n\alpha+1-\alpha)(r-c)-r)}\right]^{\frac{-n}{n-1}}$$

which is negative iff the elasticity of r to A is less than 1-$\frac{(n\alpha+1-\alpha)c}{An}$. This condition holds by assumption.

Proof of Proposition 3.C: Straightforward differentiation of the equilibrium expected profit θ with respect to A yields

$$\frac{d\theta}{dA} = \frac{[r[(n\alpha+1-\alpha)(r-c)-r] - Acr'(A)(n\alpha+1-\alpha)]}{[(n\alpha+1-\alpha)(r-c)-r]^2}$$

Rearranging the numerator of the above expression gives that $\frac{d\theta}{dA}$ is positive iff $\frac{r'(A)A}{r} < \frac{An}{c(n\alpha+1-\alpha)} - 1$. It is easy to show that this condition is always consistent with the elasticity assumption used in the proposition. Hence proved.

Proof of Proposition 3.D: $p_l = \frac{(\theta+A)r}{\alpha r+(1-\alpha)\theta}$. Differentiating this expression with respect to A yields

$$\frac{dp_l}{dA} = \frac{r[\alpha r+(1-\alpha)\theta] + (dr/dA)[(1-\alpha)\theta(\theta+A)] + (d\theta/dA)[r(r\alpha-(1-\alpha)A)]}{[\alpha r+(1-\alpha)\theta]^2}$$

From Lemma 2 and Proposition 3.C is follows that $\frac{dr}{dA}$ and $\frac{d\theta}{dA}$ are strictly positive. Therefore, the lower bound of the equilibrium price distribution is increasing in A if $r\alpha > (1-\alpha)A$. Since the minimum value of $r = \frac{An}{(n-1)\alpha}$ the latter inequality always holds.

Proof of Proposition 3.E: Since the expected profit is constant over the support of the mixed strategy, it follows from equations (1) and (2) that

$$[p_l - p][\frac{(1-\alpha)}{n}(1-F(r-c))^{n-1}] + \alpha[p_l - p(\alpha(1-\alpha F(p))^{n-1}] = 0$$

From Propositions 3.B and 3.C it is known that p_l is increasing in *A* and *F(r-c)* is decreasing in *A*. Therefore, for the equality to hold the price distribution must shift downwards as *A* increases. That is, $\frac{dF(p)}{dA} < 0$.

Appendix B: Experiment Instructions

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. 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. 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 5000 francs.

In every period you will be a seller of a fictitious good X. The 16 participants in today's experiment will be randomly re-matched each period into 4 markets with 4 sellers in each market. Therefore, the specific people who are sellers in your market change randomly after each period. The buyers in today's experiment are simulated by computerized "robots." There are 1000 robot buyers in each of the 4 markets.

Trading Instructions

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 400 robot buyers. Each buyer is equally likely to receive the ad, and which 400 of the 1000 buyers actually receive the ad is determined randomly. Furthermore, which price ad the buyer receives is also randomly determined and does not depend on the actions of the 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. In the next section we will explain how the robot buyers make their decisions.

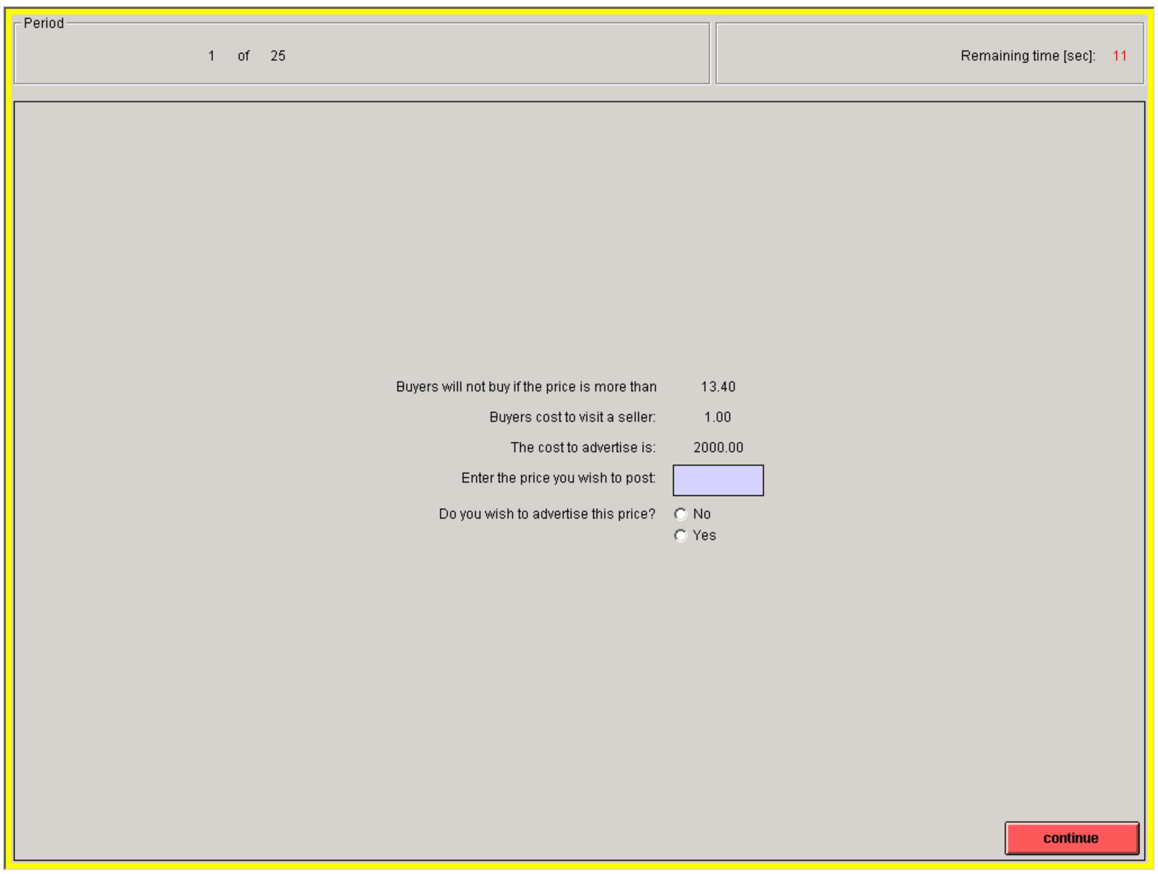


Fig. 1 Seller's Decision Screen

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 sold 54 units, his profit is equal to 18.69×54 – 0 = 1009 francs.
- Suppose a seller posts a price of 15.60 francs and chooses to advertise when the advertising cost is 2000 francs.
  If he sells 198 units, his profit is 15.60×198 - 2000 = 1089 francs.

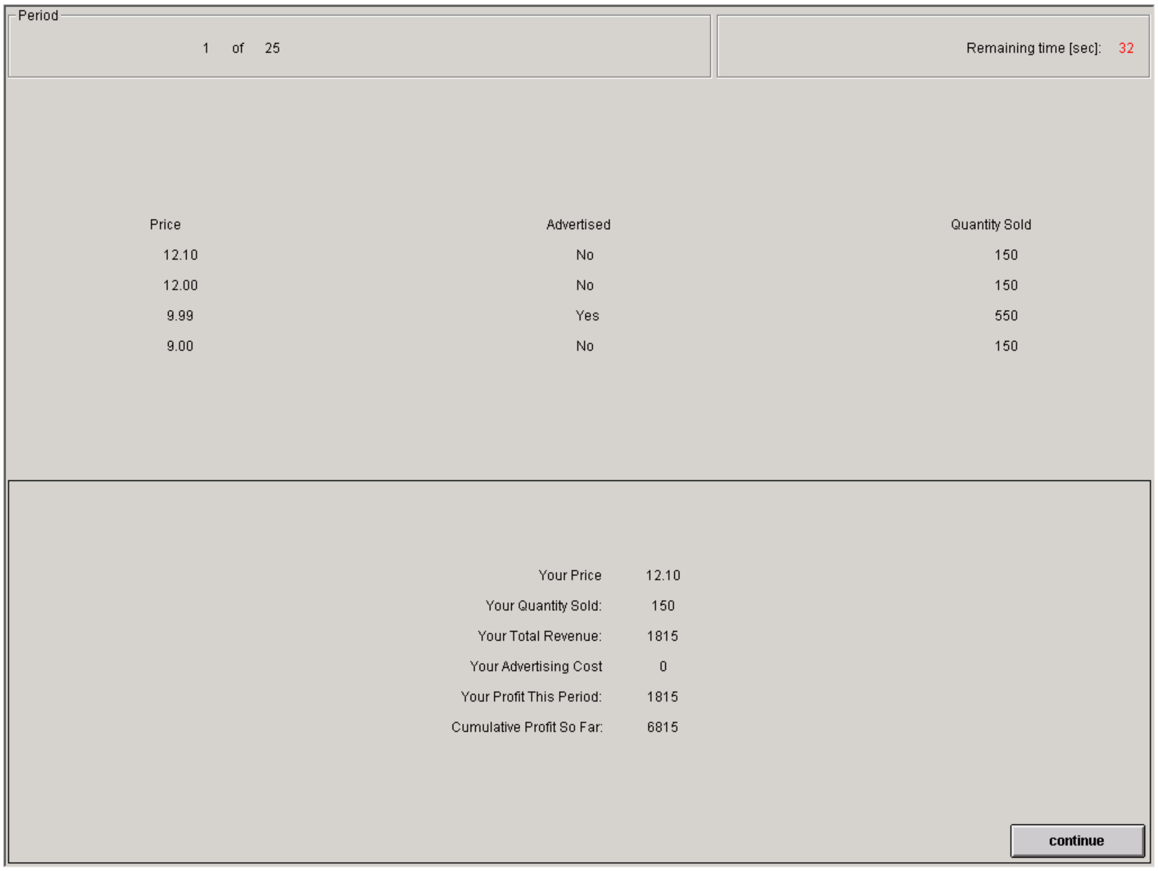


Fig. 2 Outcome Screen

6. Once the outcome screen is displayed you should record the trading information – your price, quantity sold, total revenue, advertising 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.

7. The top half of the outcome screen provides information for your market in the period just completed. All 4 sellers' price offers (including yours) are displayed, sorted from the highest price to the lowest price, as well as all the sellers' advertising decisions and quantities sold. Recall that you will be randomly re-matched with another group of sellers in each period.

Robot Buyers' Decisions

1. Each robot buyer will purchase one unit of good X each period. The maximum price that the buyers are willing to pay for the single unit will be displayed on everyone's decision screen as shown in Figure 1. This maximum price is the same for all buyers and sellers, but it will also change for each set of 25 periods. Sellers are not allowed to post a price above this maximum.

2. If a robot buyer receives advertisement(s), it visits and buys from the seller with the lowest advertised price as long as that price is less than or equal the maximum price explained above. If, on the other hand, a buyer does not receive any advertisement, it must visit sellers to obtain price quotes.

3. This cost to visit a seller is ____ experimental francs. 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. A buyer who does not receive an advertisement or who wishes to obtain price quotes not shown in the advertisement must pay this cost for each visit to obtain a price quote. The buyers receive a new quote from a different seller each time they pay this cost. For example: a buyer who makes two visits to obtain price offers from two sellers will pay a total visit cost of _____ francs. The visit cost will remain the same throughout today's experiment. 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.

4. Robot buyers who search for prices by visiting sellers will stop searching and buy as soon as they find a price that is less than or equal to the maximum price explained above.

Are there any questions before we begin?