A Laboratory Study of Customer Markets

Timothy N. Cason
Department of Economics, Purdue University
and
Daniel Friedman
Department of Economics, UCSC

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Abstract:

In our laboratory customer markets, sellers post price and buyers incur cost (controlled at zero, low and high values) when they switch to a new seller. Sellers' production costs follow various random walks in 28 sessions, each with 50-100 trading periods.

We find that prices are sticky, and sellers absorb almost half of their cost shocks. Transaction prices are about 10 percent higher when buyers face positive switch costs, and trading efficiency is slightly impaired. Experienced buyers switch about 10 percent of the time with either high or low switch costs. Buyers switch more often when they face a higher posted price, have a lower valuation for the good, face lower switch costs, have more time remaining, and have more favorable information on alternative prices. Sellers price higher when they have more attached buyers, when buyers have less information on rivals' prices, when rivals post higher prices, and when less time remains.

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Timothy N. Cason
Professor of Economics
Krannert School of Management
Purdue University
West Lafayette, IN 47907-1310
cason@mgmt.purdue.edu
http://www.mgmt.purdue.edu/faculty/cason/
voice: (765) 494-1737
fax: (765) 494-9658

Daniel Friedman
Professor of Economics
212 Social Sciences I
University of California, Santa Cruz 95064
dan@cats.ucsc.edu
http://cash.ucsc.edu/Friedman/
voice: (831) 459-4981
fax: (831) 459-5900

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1. Introduction

A definitive feature of auction markets is that buyers and sellers seek the best price without regard for counterparty identity. Homogeneous durable goods in agriculture, industry and finance (e.g., hard red winter wheat, cold-rolled steel, Microsoft shares) trade predominantly in auction markets.

By contrast, transactors care as much about counterparty as about price in markets ranging from airframe construction to zoo visits. Buyers and sellers form long-term attachments because it is costly to switch to a new counterparty. For example, in labor markets (particularly for full time jobs and for professional services) the switch costs include the expense of job search and relocation as well as investments in training by both the firm and the worker. Even a retail shopper faces switch costs: in an unfamiliar store it takes longer to find desired items and perhaps only less desirable substitutes are available.

Markets with switch costs and consequent buyer-seller attachments are called customer markets, following Okun (1981). Customer markets are interesting for three complementary reasons. First, they are pervasive in modern economies, with a major share of wholesale and intermediate transactions as well as labor and retail. Second, their performance characteristics may differ from auction markets. Third, they are not yet well understood, either theoretically or empirically.

Our goal is to expand empirical knowledge of customer markets. We conduct a controlled laboratory experiment using profit-motivated human buyers and sellers who transact in 50 to 100 trading periods each session. As in most modern customer markets, one side (the sellers) is more concentrated and posts prices while the other side (buyers) chooses how much to transact and whether to switch. The experiment varies explicit switch costs across sessions from zero to an amount comparable to the surplus split between buyer and seller each period. Our interest is in long-term but impermanent attachments, in which switching occasionally is advantageous.[1] For this reason the experiment induces changes in buyer-seller surplus each period via small permanent shocks to each seller's production cost.

We seek evidence on customer markets' performance characteristics. For example, are prices sticky, i.e., less responsive to cost shocks than in competitive equilibrium? Are sellers able to maintain prices above the competitive level? Do buyers switch very often?

Diverse strands of existing literature highlight the importance of these questions and point to possible answers. Macroeconomists widely (though not universally) believe that wage and price stickiness play crucial roles in macroeconomic dynamics, at least in the short run for nominal variables and arguably for medium run real outcomes. The leading theoretical explanation for sticky prices is menu cost, an exogenous fixed cost associated with changing a posted price (Akerlof and Yellen, 1985; Mankiw, 1985; survey in Romer, 1996, Chapter 6). Despite some favorable evidence for supermarkets (Levy *et al*., 1997), explicit menu costs (and variants such as staggered labor contracts) seem empirically implausible as a major source of wage and price stickiness according to recent texts such as Walsh (1998, p. 202).

Scitovsky (1952, p272-81) seems to have been the first to argue that switch costs and attachments lead to sticky prices, using a variant of the kinked demand curve model. The idea is that attached customers respond immediately to a price increase but potential new customers take a while to respond to a price decrease, so within some range of marginal production costs the

[1] Lindsey, Polak and Zeckhauser (2000) model such attachments in a nonmarket setting. They find equilibria with ongoing attachments even with zero explicit switch costs and with no intrinsic advantage to staying with the current partner.

seller keeps price constant. Thus customer markets may create implicit endogenous menu costs that account for observed stickiness, as Okun (1981) so eloquently argued. See Tobin (1993) and McDonald (1995) for surveys, and Corbae and Ritter (1998), Sibley (2001) and Kranton (1996) for recent theoretical contributions.

An important strand of industrial organization theory beginning with Klemperer (1987) studies oligopoly models with switch costs. The setting is rather different from ours – for example, switch costs are heterogeneous (e.g., old vs. new consumers) or stochastic, while production cost and buyer values are identical and constant – but the models have interesting testable implications that we will examine later.

Direct field evidence is slim because it is difficult to gather individual firm data on short run production cost shocks and attachments. Perhaps the best example is the Neumark and Sharpe (1992) study of consumer bank deposits, which finds downward price rigidity and upward price flexibility in concentrated markets. Peltzman (2000) presents more comprehensive evidence of this same asymmetry for 77 consumer and 165 producer goods. He observes only a fraction of the total input cost, however. For example, in his sample of producer goods he observes an average of about 40 percent of the total input costs. Evidence from the laboratory, where cost and other key variables are observable (and controllable) complements field evidence by demonstrating empirical links between field-observable variables.

Our laboratory study builds on numerous earlier studies of posted price markets, surveyed in Davis and Holt (1993). Wilson (1998) studies Mankiw-style explicit menu costs with mixed results in an individual choice setting of a monopolist facing simulated demand. Jamison and Plott (1997) introduce parallel shifts in production costs and buyer values as well as a form of menu cost into continuous double auction markets, but find little evidence of price stickiness. Our study seems to be the first to examine either switch costs (as opposed to menu costs or static search costs) or persistent shocks to production cost (as opposed to constant or identically distributed random production cost).

The next section describes our laboratory procedures. Using available theory and well-known conjectures, the following section develops a list of hypotheses to be tested. Section 4 summarizes the results. In our experiment prices indeed are sticky, and sellers absorb almost half of their cost shocks. Transaction prices are about 10 percent higher when buyers face either high or low switch costs, and trading efficiency is slightly impaired. Experienced buyers switch about 10 percent of the time with either high or low switch costs, versus about 60 percent when explicit switch cost is zero. Buyers switch more often when they face a higher posted price, have a lower valuation of the good, have more time remaining, and have more favorable information on alternative prices. Sellers price higher when they have more attached buyers, when buyers have less information on rivals' prices, when rivals post higher prices, and when less time remains. Section 5 offers a summary and discussion. Instructions to subjects appear in Appendix A. Theoretical notes are collected in Appendix B, available on request from the second author (attached to the current draft as a courtesy to referees). Appendix C contains additional details for the empirical models of the buyer switch and the seller price decisions.

2. The experiment

The basic market institution is seller posted offer. Each period each seller enters a single take-it-or-leave-it price, and each buyer purchases at most one indivisible unit from one seller at that seller's posted price.

To create a customer market, we introduce attachments and switch costs. Each buyer begins each period attached to some seller, whose posted price she observes costlessly. In order to see other sellers' prices she must sink a switch cost $C \geq 0$. If she does so she observes the prices currently charged by all sellers (who are not further identified) and then can accept any of them. She enters the next period attached to the seller she purchased from most recently. Thus the switch decision is a more inclusive version of search. Switch cost C is constant across buyers and periods, and is publicly announced before the first period. It is varied across sessions at three levels: zero (a baseline for comparison), low (usually 20 cents) and high (50 cents, well over half the median surplus in a transaction).

Customer markets feature long term but impermanent attachments. To discourage permanent attachments, the experiment introduces random production cost innovations. In each session the production costs follow one of four alternative processes.

- Constant: each seller has constant marginal cost (160 cents for one seller, 180 cents for a second seller, and 200 cents for the third seller) for each run of 25 periods.
- Independent: each seller receives a random, additive innovation to marginal production cost each period, so seller j's cost in period t evolves randomly according to $c_{jt} = c_{jt-1} + e_{jt}$, where the innovations e_{jt} are drawn independently from the uniform distribution U(-m, m).[2] The maximum shock amplitude m is 20 cents in the sessions reported here.
- Correlated: the innovation e_{jt} above is the sum of two components, one common to all sellers drawn from U(-15, 15) and one independent component drawn from U(-5, 5). The larger correlated component keeps sellers' costs closer together in later periods.

[2] Although theoretical and empirical work usually assumes that random shocks are normally distributed, we use a uniform distribution because it is much easier to explain to subjects.

- Mean reverting: seller *j*'s cost evolves according to $\ln c_{jt} = 0.03 + 0.95 \ln c_{jt-1} + e_{jt}$, where e_{jt} are drawn from U(-10, 10). With these parameters the costs revert toward $1.67.[3]

The timeline below for each period summarizes our laboratory implementation of customer markets. Buyers' values typically don't change from one period to the next and so

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>-----|----------------|---------------|-----------------|-----------------|-------------------|----------------|-->
Sellers learn  Sellers   Buyers         Buyers may   Buyers         *Price         *Buyers
own cost c     post      observe        choose to    accept or      distribution    forecast
               prices    own seller's   switch       reject seller  announced       upcoming
                         price          (cost C)     offers         to all          median price
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are not mentioned in the first step. The asterisks on the final two steps indicate that they apply only to some sessions. The period is over after each buyer has either rejected available price(s) or else accepted one of the posted prices she sees (that of "her seller" if she did not switch, or all prices if she chose to switch). Then the sellers and buyers view interim screens that summarize their own activity in that period and their own cumulative profit. The first asterisk refers to sessions that use the "Full" information condition, in which each trader also sees the entire distribution of posted prices (but not sellers' identity) from the previous period. In some sessions we reveal only the median transaction price in the interim screen, and in other sessions we provide no price information between periods. The final asterisk refers to sessions in which we ask buyers to forecast the next period's median transaction price. The buyer with smallest absolute forecast error totaled over all periods earns a modest prize ($5.00).

Each session is divided into runs of 25 periods, and (except in a few of the earliest sessions) buyers and sellers are randomly re-matched to new trading partners at the beginning of each run. Each session has three sellers who produce to demand (i.e., no inventories) at a uniform

[3] This choice of parameters produces cost sequences that to the naked eye are hard to distinguish from those produced in the independent and correlated random walk treatments. See Figure 2 below. The mean reverting

(constant) marginal cost each period and no fixed cost. Each seller's capacity is 3 units, so the maximum quantity that sellers can supply in total is 9 units per period. Five buyers each demand only one unit per period.[4] Buyer values are constant over each session at 300, 275, 250, 225, and 200 cents; assignments of buyers to these values are rotated at the end of each 25 period run. Figure 1 displays the supply and demand for the constant cost sessions (top panel) and for an example period in a random cost session (bottom panel). The reader can verify that the competitive equilibrium (CE) price (set by the intersection of induced supply and demand curves) usually coincides with the median marginal cost, but not always. The competitive equilibrium often gives buyers more than half the surplus, but in some periods the low cost seller gets the lion's share.

Table 1 summarizes the 28 sessions. Identical software was used at both sites (USC and UCSC). To sharpen comparisons across switch cost treatments, we used the same sequence of random shocks e_{jt} for all sessions with the same experience and cost process conditions. Experienced subjects participated in an earlier session listed in the table, usually at the same site and with the same switch cost and production cost process (but, of course, a different cost sequence). The realized cost sequences are shown in Figures 2a – 2e. See Appendix A for the complete instructions to subjects.

3. Testable Hypotheses

No fully articulated theory of customer markets is yet available, but some predictions can

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treatment has the theoretical advantage that it has a non-trivial steady state.

[4] If buyers try to accept more units than a specific seller has offered, then buyers who transacted most recently with that seller receive priority. Any remaining units are awarded first come first served. Occasionally a buyer is "rationed out"; since she has already paid the switch cost, she can accept another seller's price offer that period without incurring further switch cost.

be extracted from pieces of existing theory. Appendix B collects theoretical notes supporting the discussion below.

Consider first the decision problem of a single buyer with value v for a single indivisible unit. The buyer's profit in a given period is 0 if she doesn't transact, and is v-p if she accepts posted price p. Her optimization problem is to maximize the (undiscounted) stream of profits over the time $T \leq 25$ remaining until the market reinitializes.[5] If she chooses not to switch, then her value function is max{0, v-p} plus the continuation value with the current seller. If she chooses to switch and believes the lowest posted price q has distribution G, then her value function is $-C$ + $E_G$max{0, v-q} plus the continuation value with the new seller. Very mild technical assumptions ensure that the difference (value if not switch – value if switch) is a monotone decreasing function of posted price p. Hence there is a reservation price $b = B(v, C, G, T) \leq \infty$ such that she will optimally choose to switch iff $b \leq p$. With additional assumptions one can establish the following properties:

1. When $v \leq v_o(C, G, T)$ then the buyer is "discouraged" because the potential gains from switching won't cover the switch cost C in the time remaining. In this case the buyer should never switch, i.e., $b = \infty$. Under simplifying assumptions, the threshold v_o is the solution to the equation [C amortized over the time remaining] = $E_G$max{0,v-q} $\equiv \int_0^v (v-q)dG(q)$.
2. For buyers who are not discouraged, the reservation price is monotone increasing in v and C, and is decreasing in T. It also is increasing in G when the distributions of minimum prices are partially ordered by first order stochastic dominance.

[5]Sometimes it is more theoretically convenient to refer to a discount factor δ rather than to the number T of periods remaining. To find a correspondence between the two, note that the duration of a perpetuity is $D = \delta/(1-\delta)$, and the duration of an annuity for T periods with no discounting is $D = T/2$. Equating the expressions for D and solving yields the discount factor proxy $\delta \approx T/(2+T)$, which we will use later.

Now consider the seller's choice problem. Each period he knows the number of attached buyers n_o inherited from the previous period, and has an estimate H of the distribution of their reservation prices as well as an estimate G of the distribution of his rivals' lowest current price. From these estimates he can derive the distribution of the number n of purchases (and hence next period's inherited attachments) for each choice of posted price p. He also knows his current marginal production cost c and the distribution of future costs he faces given the cost innovation process. His choice problem is to maximize the expectation of current profit $n(p-c)$ plus the continuation value, which depends on n, c, T and H as well as his rivals' subsequent posted prices. Under simplifying assumptions one can derive an optimal pricing function $p = P(c, n_o, T; G, H)$ that applies to all sellers. The function P is increasing in c and n_o. It also appears (but is not yet theoretically verified) that P is increasing (in the sense of first order stochastic dominance) in rivals' price G and in reservation price H. The dependence on H and the reservation price rule B then induce the properties of increasing in switch cost C and decreasing in time remaining T.

Of course, individual buyers and sellers interact through the market, and their interactions must be accounted for in predicting observed behavior. It is a bit tricky to define equilibrium for customer markets with long-lived but impermanent attachments. To our knowledge, no one has yet analyzed market equilibrium when the surplus follows any sort of random walk in a posted offer market with switch costs. Some insights nevertheless may be gleaned from the most closely related theoretical articles.

There is a well-known theoretical literature starting with Diamond (1971) on equilibrium with search cost, assuming identical constant cost c=0 sellers, identical constant value v>0 buyers and no ongoing attachments. The striking result is that the unique Nash equilibrium is the same for any positive level of search cost: all sellers post the monopoly price, and buyers do not bother to search. Burdett and Coles (1997) extend this literature with an attachment model in which sellers disappear at a constant rate and are replaced by new sellers with no attached buyers. They derive an equilibrium pricing rule $p = P(n_o; C)$ that (due to the need for newer sellers to build up their customer base) is increasing in the current number of customers n_o and also (now comparing across economies rather than across sellers) increasing in the switch cost C and presumably also in marginal production cost c. Mortensen and Pissarides (1994) analyze a model where the surplus v-c in an attachment is subject to random change. Unfortunately it is difficult to apply the model to our experiment because the surplus itself (rather than a shock to surplus) is drawn randomly each period, and two separate processes govern attachment formation and attachment dissolution (so there are spells of unemployment but no switching *per se*).

Klemperer (1987, 1995) studies oligopoly models where firms choose price to attract unattached new customers and to retain attached customers, who can switch to a rival at cost C. Unlike our setup, firms' production costs are identical and constant and customers observe all prices before deciding whether to switch. Klemperer generally finds that higher switch cost implies higher equilibrium prices. Taylor (1999) considers the impact of price discrimination between old attached customers and new customers (or those attached to other firms). He finds that firms will offer a lower price to new customers but that the equilibrium prices are independent of the number of attached customers and of the time remaining. Taylor assumes identical constant production cost, but introduces stochastic switch cost (independent and identically distributed for each buyer each period).

Table 2 lists the hypotheses we shall test using the laboratory data. The absence of a fully articulated equilibrium model for our setup is felt most acutely in the market-level predictions MH1-3. As noted in the introduction, price stickiness (MH1) has motivated macroeconomists' interest in customer markets at least since Okun (1981) but has not yet been theoretically demonstrated in market equilibrium. We shall compare outcomes with positive switch costs to the more competitive zero switch cost baseline to evaluate MH2 and MH3. Burdett and Coles and Klemperer predict supra-competitive transaction prices as in MH2, albeit in somewhat different market environments. Since they assume all buyers have the same known value *v*, their models predict efficient market outcomes (apart from new customers' adaptation costs in Klemperer), but Diamond (1971) and later articles that assume a sloped demand curve predict inefficiency via the usual deadweight loss. MH3 predicts inefficiencies in our laboratory markets due to deadweight losses (demand slopes downward due to diverse buyer values) and also because we expect to see switch costs incurred in equilibrium when sellers' costs are subject to shocks.

The predictions for buyer behavior BH1-6 come from the preceding discussion of the buyer choice problem. Recall that these predictions do not apply to "discouraged" buyers or to sessions with *C*=0, so we develop procedures to exclude these cases. BH1 relaxes the reservation price property in order to take behavioral noise into account. The sharp threshold between switch probability=0 and switch probability=1 might be smoothed by errorless decision in the presence of unobservable small random payoff components, or by decision errors that decrease in their expected cost. Either way, the result is that the observed switch frequency is increasing continuous function of posted price, *ceteris paribus*. Recent discussions, e.g., Fudenberg and Levine (1998, Chapter 4) or Friedman and Massaro (1998), point to a logit or probit specification for switch behavior in the presence of behavioral noise. BH2-4 directly reflect the monotonicity of reservation prices in *v*, *C*, and *T*. BH5 has two sources. First, buyers' beliefs about the distribution of lowest price *G* this period should be monotone increasing in their observations of recent prices, because (even if prices are not sticky) sellers' costs are persistent. Second, the reservation price should be monotonic in *G* in the sense of first order stochastic dominance. BH6 has similar sources, but applies when interim screen information on last period's price is unavailable. Then the best available information is what the buyer observed herself the last time she switched, and uncertainty (or variance in the perceived price distribution *F*) increases in the time elapsed since the observation. In turn, this implies a higher value for the search option.

The seller prediction SH1 is the individual-level version of sticky prices: in order to keep the customer base, sellers will often absorb some or all of their cost changes. (Unfortunately we do not have a sharp theoretical statement of the conditions or degree.) SH2-3 reflect directly the monotonicity of the pricing function *P* in *c* and n_o, and SH4 reflects the effect of rivals' price *G* mentioned earlier. SH5-7 reflect the dependence on the distribution *H* of buyer's reservation prices and the dependence of reservation price on switch costs, time remaining and the availability of information.[6] The model of Burdett and Coles (1997) provides an alternative theoretical basis (with looser ties to the laboratory environment) for SH2-3 and SH5-6. Similarly, Taylor (1999) is consistent with SH4-5 (but not SH3 and SH6), and Klemperer (1995) is consistent with SH3-5.

It bears repeating that the BH and SH predictions are conditioned on arbitrary subjective distributions of lowest posted prices *G* and reservation prices *H*. For testing purposes, these distributions can be proxied nicely by empirical distributions. Sharper predictions would arise from an equilibrium theory that pins down *G* and *H*, but as yet such a theory is unavailable.

[6] SH7 may be the most problematic. The logic is that with more interim price information, buyers will find the switch option less valuable and will switch less often (as in the BH6 prediction), hence sellers can price higher without losing so many customers. On the other hand, more interim price information may directly increase buyers' price elasticity, hence induce sellers to price lower, contrary to SH7. It is an empirical question which effect is stronger.

4. Results

We begin with a qualitative overview of the data. Later subsections present test results for the market level predictions MH1-3 and for the buyer and seller behavior predictions BH1-6 and SH1-7.

Figure 3 summarizes the market outcomes in the initial periods of session USC501c, which features inexperienced traders, a high (C = 50 cents) switch cost, and correlated random seller production costs. Within each period column the highest cost sellers' offers and transactions are shown at the left, the middle cost sellers' offers in the middle and the low cost seller's offers on the right. Open circles represent unsold offer prices, closed circles represent accepted offers, and the horizontal lines display the CE price. In all but one of the periods shown (period 10), the CE price equals the middle seller production cost, so it is somewhat less volatile than individual seller costs. In general mean transaction prices seem to exceed but roughly track the CE price, and hence they reflect the marginal cost with an upward bias. As documented later, sessions with C=0 switch cost have lower transaction prices that are closer to marginal cost.[7]

Figure 4 shows the last part of experienced session UC506ix, with high switch cost and independent random production costs. Mean transaction prices here seem less closely linked to the CE price. For example, the low cost (rightmost) seller raises her price quite often in the later periods, eventually exceeding the CE price by about 80 cents, yet manages to retain her customers. [This seller earned over $54 in trading profit over the entire session.] Figure 5 displays some final experienced periods with 20-cent switch costs and correlated random seller costs. The prices here (and in several other sessions with non-zero switch costs) seem quite sticky.

[7] Session UC003 is closest to standard laboratory posted offer markets, since it has zero switch costs and stationary supply and demand conditions. Prices in this session approached the CE price from above, as is typically observed in posted offer experiments. The convergence process was rather slow, however, and most of the 50 trading periods

4.1 Overall Market Performance

The first question is whether the price changes simply reflect cost changes, or whether prices really are sticky. Define price volatility as the median of absolute period-to-period price changes $|Price_t - Price_{t-1}|$. Prediction MH1 is that prices are sticky in the sense that the volatility of mean transaction (actual) price is less than the volatility of competitive equilibrium price.[8] The left columns of Table 3 compare volatility using data from all 23 sessions with random production costs. (We exclude the 5 constant cost sessions because there the CE price changes are always 0.) Consistent with MH1, the typical CE price change of 7 cents far exceeds the actual median price change of 4 cents.

The contrast is even sharper in the nine experienced sessions, where the actual volatility of 3.75 cents is less than half the CE volatility of 8 cents. The production cost and information treatments generally have a small effect, and MH1 in all cases is supported by actual price volatility 2.5 to 3.3 cents below CE volatility. Switch cost also seems to have a small effect on the MH1 tests, as the actual price volatility ranges from 3.4 cents (for zero switch costs) to 4.4 (for low switch costs).

One possible objection to this test is that there is a single CE price each period but transaction prices typically are dispersed. Different conventions are possible in computing transaction price changes across periods. For example, instead of the mean each period one could use the maximum or minimum transaction price, or the average of the two, or the median. We tried a few alternatives and saw no real difference in conclusions. Perhaps the most informative

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were complete before prices were within 10 cents of the CE.

[8] Using the median absolute price change as volatility rather than the standard deviation allows us to regard prices as sticky even when the actual price level is tied closely to the competitive equilibrium level in the long run. Occasional large jumps in transaction prices that restore the long run tie would dominate a standard deviation measure but don't much affect the median.

way to deal with the problem is to go to the individual level data. In the right two columns of Table 3 we compare individual sellers' posted price volatility to cost volatility (defined as the median of $|cost_t - cost_{t-1}|$). Cost volatility is always 1 to 3 cents higher than the corresponding CE price volatility, not surprisingly since CE is usually the period-median cost. Likewise the mean transaction price each period is a weighted average (with time varying weights) of the posted prices, so it is not surprising that the posted price volatility is 0.75 to 3.5 cents higher than the transaction price volatility. The main point regarding MH1, however, is that prices are about as sticky at the individual seller level as they are at the market level: price volatilities are again about 3 cents lower than the corresponding cost volatilities.

The most unexpected result in Table 3 is that posted price volatility and transaction price volatility are slightly higher in the 20 cent switch cost treatment than in either the zero or 50 cent switch cost treatment. As a robustness check, we classified individual sellers as "sticky" if their absolute cost changes exceed their absolute price changes in at least half of all periods. In zero, 20 cent and 50 cent treatments of sessions with random costs, we found respectively 11/18 = 61%, 17/30 = 57% and 16/21 = 76% sticky sellers. In Fisher's exact test all *p*-values exceed 0.2, and we conclude that the stickiness difference is not robust. That is, the data clearly exhibit sticky prices but do not exhibit any clear relation between the level of switch cost and the degree of stickiness.

Now consider evidence on MH2, that price level is higher in customer markets than in CE. Figures 6 and 7 show that the mean actual prices are almost always above the CE price in correlated cost sessions, particularly for the positive switch cost sessions. In most periods the mean price for zero switch cost sessions tracks the CE fairly closely, but with a small, positive bias. Consistent with most previous research in laboratory markets (see Holt, 1995, for a survey), for these competitive conditions prices are much closer to CE than to an alternative "fairness" prediction that price equally splits the available exchange surplus. Consistent with MH2, mean prices are higher in the positive switch cost sessions, but there is no clear difference between prices in the low and high switch cost sessions. Similar impressions arise from examining figures for sessions using other cost process treatments.

Table 4 tests MH2 more systematically. The dependent variable is the mean transaction price minus the CE price, and (in view of the findings on sticky prices) the regression estimates account for an autocorrelated error structure. The insignificant intercept estimate in the first line indicates that transaction prices do not systematically differ from CE for the baseline case of zero switch costs and constant production costs. The very significant point estimates in the second and fourth lines indicate that transaction prices tend to be 18 (or 20) cents above the CE level with positive low (or high) switch costs in late periods, strongly supporting MH2. The significant negative interaction estimates in the third and fifth lines indicate that switch costs have a smaller impact in earlier periods. For example, the –0.39 estimate indicates that $25 \times -0.39 = -9.75$, or almost half of the 20 cent impact for high switch costs, is offset at the beginning of a 25 period run. The seventh and ninth lines indicate that prices tend to be higher in early periods in sessions with non-mean reverting random cost. Is the impact of high switch cost significantly greater than low switch cost? A standard F-test cannot tell them apart ($F_{2,1794} = 0.33$), consistent with the Diamond (1971) prediction that any positive switch cost offers the same boost to transaction prices.

Table 5 presents evidence on MH3. Gross efficiency is measured each period in the usual fashion as realized earnings by all traders as a percent of the maximum possible. Inexperienced traders with zero switch cost are less efficient at extracting surplus than in most posted offer laboratory markets (perhaps because of the complex, dynamic cost environment), but experienced traders achieve a very respectable efficiency averaging over 95 percent. Experienced traders achieve only 91 percent efficiency with low positive switch costs and only 87 percent with high switch costs, consistent with MH3. The regressions in the lower part of Table 5 indicate that efficiency significantly increases with experience, and is significantly lower for high switch costs—particularly for experienced sessions.

A novel source of inefficiency in customer markets is the direct cost of switching. For comparative purposes, the right side of Table 5 presents trading efficiency *per se*, netting out incurred switch costs when C>0. For example, sellers with high production costs may sell more units in the high switch cost sessions because buyers are less able to search for lower prices, and such production misallocation would lower trading efficiency. The table indicates that for experienced subjects, trading efficiency is still highest with zero switch costs, but declines less precipitously (to about 93 percent) with positive switch costs.

4.2 Buyer Switching Behavior

Figure 8 presents overall switch rates for the 28 sessions. Buyers switch more than half the time when switch costs are zero.[9] It appears that switch rates fall as switch costs increase when subjects are inexperienced, but experienced subjects switch at about the same rate when switch costs are 20 cents and 50 cents.

In testing predictions BH1-6, a natural empirical model for noisy reservation price behavior is probit with random subject effects. The dependent variable is binary, with value 1 for

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[9] But why not search every period when it is free? It turns out that the priority rule explained in footnote 4 introduces a tiny opportunity cost even when *C*=0. Suppose your current seller turns out to have the lowest price this period. If you did not switch you are assured a unit when you accept his price. If you switch you can still order a unit from him but now you run the risk of being rationed out. Because of this risk the perceived switch cost will slightly exceed the explicit 0, 20 or 50 cent switch cost.

each buyer in each period she incurred the switch cost and 0 in other periods. Independent variables include those listed in BH1-6 together with appropriate controls. Recall that "discouraged" buyers are excluded because their reservation price is infinite and not responsive to the variables cited in BH1-6. Appendix C explains the procedure for identifying discouraged buyers, and the instrumental variables approach for the price distribution summary statistics.

Table 6 reports the results. The significantly positive coefficient estimates in the first line indicate, consistent with BH1, that a buyer is more likely to switch when her seller offers a higher price. Evaluated at the sample means of the explanatory variables, the estimates imply that an increase in the offered price from \$1.80 to \$2.20 raises the probability of buyer switch from 1 percent to 10 percent. The next line strongly supports BH2, since the coefficient estimate for the buyer value is significantly negative. This indicates that lower-valued buyers are more likely to switch to a new seller. The estimates imply an overall switch rate of 9 percent for a buyer with a \$2.00 value, compared to an overall switch rate of 3 percent for a buyer with a \$3.00 value.

The data fully support BH3—less switching when switch costs are higher—as the significant and negative high switch cost dummy variable in line 3 indicates a reduction in switch probability relative to the (omitted dummy) of low switch costs. The fourth line of the table offers support for BH4, that switch likelihood declines with the number of periods T remaining in a run. Recall that we proxy the discount factor d by $T/(2+T)$. The significantly positive coefficient estimate for this variable indicates that the model implies a switch rate of about 5 percent in the first period of a 25-period run, compared to 1 percent in the last period.

Recall that BH5 predicts that buyers are less likely to switch when they observe higher prices on the interim screen. The relevant variable is the interaction of median transaction price from the previous period with a dummy variable for the treatments that display interim price information. The coefficient estimate for this interaction on line 5 is negative and highly significant, supporting BH5. Evaluated at the sample means of the explanatory variables, the model estimates imply that an increase in the previous period median price from $1.50 to $2.00 lowers the probability of buyer switching from about 6 percent to about 1 percent.

Finally, we examine the evidence for BH6. Contrary to that prediction, the coefficient estimate is negative in line 6, indicating that with no interim screen price information, switching is less likely the longer it has been since the last switch.[10] The logic behind BH6 also suggests that buyers with less price information should more likely to switch: with less information, buyer beliefs have more variance, which increases the value of searching (or switching). The negative estimates on the two information dummy coefficients in lines 7 and 8 provide conflicting evidence on this conjecture. The negative coefficient in line 7 indicates that, as predicted, switching is less likely when the full price distribution is shown on the interim screen. However, the negative coefficient in line 8 indicates that switching is also less likely (relative to the omitted case of median price information only) when no price information is shown on the interim screen.

Lines 9-12 of Table 6 report estimates for control variables for the seller production cost process and for subject experience. The negative estimates indicate that switch rates tend to be lower in the random production cost and experienced treatments, relative to the omitted baseline case of constant production costs and inexperienced subjects. Lines 13 and 14 report estimates for the instrumental variables—fitted mean and variance of the session's posted price distribution.

[10] It is unlikely that this result is an artifact of the differential switch rates across individual buyers not captured by our explanatory variables. Since the model is estimated with random subject effects, these unmodeled subject differences should be picked up by the error term.

Consistent with intuition, the estimates indicate that buyer switching is less likely in sessions with higher posted prices and with lower price variance.[11]

4.3 Seller Pricing Behavior

Tests of the seller predictions are relatively straightforward. We regress individual sellers' posted prices (in cents) each period on the experimental treatments and on predetermined prices and sales quantities. A random effects error structure, with the seller as the random effect, takes into account for the panel nature of the price sequences.

Table 7 reports the results. The positive estimate on the production cost variable is significantly different both from zero and from one, which provides strong support for Hypotheses SH1 and SH2. The coefficient estimate implies a less than proportionate change in price in response to cost innovations; a typical 10-cent cost change, for example, results in an estimated 6-cent price change, confirming the earlier analysis of price stickiness. The next line of the table indicates that sellers with more customers charge a significantly higher price, as predicted in SH3. The economic impact is rather small, however. For example, increasing the number of customers from 0 (the minimum) to 3 (the maximum) only leads to an estimated six-cent increase in price.

Prediction SH4 is that a seller will charge a higher price when the other two sellers in the market chose a higher price in the previous period. The relevant variable is the mean price posted by rivals last period, interacted with a dummy variable equal to one when that price information is observable on the interim screen. The positive and significant coefficient estimate on line 3 supports the prediction, but again the economic impact is small.

The remaining predictions are for higher posted prices when buyers switch less, due to higher switch cost (SH5), less time remaining (SH6), or better information on last period's posted

[11] Appendix C summarizes the results of several alternative model specifications. These alternative specifications

prices (SH7). The positive but insignificant coefficient estimate for the high switch cost dummy in line 4 provides surprisingly weak support for SH5. Recall that buyers indeed switch less with higher switch costs (BH3), but it seems that sellers do not fully exploit the opportunity by systematically pricing higher. The significantly negative coefficient estimate for the discount factor proxy $d = T/2+T$ in the next line supports SH6, and indicates higher prices when fewer periods remain in the run. The extremely significant 55-cent price increase with no interim price information in line 7 is contrary to SH7 as stated, but it is consistent with the underlying reasoning. Recall that earlier results indicate buyers actually switch less in this treatment, and the estimate indicates that sellers exploit this opportunity. The remaining lines indicate that the usual control variables do not significantly shift posted prices.[12]

5. Discussion

Our customer markets perform quite differently than the auction markets featured in countless earlier studies. We observed systematic departures from competitive equilibrium, notably sticky prices, persistently supra-competitive prices, and slightly depressed trading efficiency.

The differences in market performance can be traced to regularities in buyer and seller behavior. Buyers' behavior is explained rather well by noisy reservation price strategies, in which switching is more likely when posted price is higher, own value is lower, switch cost is lower, more time remains, and when available information indicates lower alternative posted prices. Sellers' pricing decisions generally conform to prediction: they post higher prices when they have higher costs (but they typically pass on less than 60 percent of incremental cost), more attached

indicate that the conclusions are generally robust.

buyers and less time remaining, when buyers have less information on rivals' prices, and when their rivals post higher prices.

The finding on sticky prices should interest a variety of readers. Our laboratory findings boost the longstanding conjecture that customer market structure is a major reason for sticky prices, due to endogenous implicit menu costs that are rooted in the costs of forming new buyer-seller attachments. At the same time our findings underline the need for a solid theory of customer markets. At one point we hoped that recent advances in real option theory (also known as irreversible investment theory; e.g., Dixit and Pindyck, 1994) would fill the gap. Unfortunately it seems difficult to reconcile steady state market equilibrium with the underlying assumption of that theory, that costs are governed by geometric Brownian motion and hence diffuse away from each other (and from buyer values). We leave as a challenge to theorists how to properly formalize equilibrium in customer markets.

Much empirical work remains. Even the current data set is not yet fully mined; for example, there is some weak evidence for asymmetries between price increases and price decreases. In particular, in some datasets the median price increase was smaller than the median price decrease, but in most cases the price changes were close to symmetric. Peltzman (2000) observed an asymmetry in upward versus downward price adjustment speed for about two-thirds of the goods in his sample, and in future research we hope to apply his empirical methodology to investigate the speed of price adjustments in our data. At some point we also hope to investigate how buyers and sellers learn from experience, and whether other-regarding behavior affects attachment and pricing decisions as suggested by Akerlof (1982), Blanchard (1990) and

[12] Again, see Appendix C for a discussion of alternative specifications.

Kahneman, Knetsch and Thaler (1986) among others. The forecast data should be useful for these purposes.

More laboratory work is also called for. At this point it is not clear whether mean-reverting random walk costs induce sticky prices in other market institutions, or whether stickiness is due entirely to switch costs and attachments. A relevant experiment (which we do not yet have plans to run) is to introduce random walk costs into an otherwise orthodox auction market, e.g., the continuous double auction. We do plan to investigate the opposite combination, switch costs and attachments in a continuous bilateral negotiation market institution that we call haggling. We also plan to investigate pure search costs in a simple posted offer market with no attachments or cost shocks, to better test existing theory in the tradition of Diamond (1971).

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Table 1:
Summary of 28 Sessions

Session Name	Seller Production Costs	Switch Costs	Experience Level	Interim Screen Price Information?	Trading Periods
UC101i	Indep. Random Walk	$0.10	Inexperienced	Full	38
UC202i	Indep. Random Walk	$0.20	Inexperienced	Full (+ forecasting)	50
USC503i	Indep. Random Walk	$0.50	Inexperienced	None	50
USC204i	Indep. Random Walk	$0.20	Inexperienced	None	50
UC205ix	Indep. Random Walk	$0.20	Experienced	Full (+ forecasting)	80
USC005ix	Indep. Random Walk	$0.00	Experienced	None	100
UC506ix	Indep. Random Walk	$0.50	Experienced	None	100
UC003	Constant	$0.00	Inexperienced	Full	50
USC201	Constant	$0.20	Inexperienced	Full (+ forecasting)	50
USC202	Constant	$0.20	Inexperienced	None	50
UC504	Constant	$0.50	Inexperienced	Full (+ forecasting)	50
UC507	Constant	$0.50	Inexperienced	None	50
USC206c	Corr. Random Walk	$0.20	Inexperienced	None	50
USC001c	Corr. Random Walk	$0.00	Inexperienced	Median (+ forecasting)	50
UC002c	Corr. Random Walk	$0.00	Inexperienced	Median (+ forecasting)	50
USC201c	Corr. Random Walk	$0.20	Inexperienced	Median (+ forecasting)	50
UC202c	Corr. Random Walk	$0.20	Inexperienced	Median (+ forecasting)	50
USC501c	Corr. Random Walk	$0.50	Inexperienced	Median (+ forecasting)	50
UC502c	Corr. Random Walk	$0.50	Inexperienced	Median (+ forecasting)	50
USC003cx	Corr. Random Walk	$0.00	Experienced	Median (+ forecasting)	100
UC004cx	Corr. Random Walk	$0.00	Experienced	Median (+ forecasting)	100
USC203cx	Corr. Random Walk	$0.20	Experienced	Median (+ forecasting)	100
UC204cx	Corr. Random Walk	$0.20	Experienced	Median (+ forecasting)	100
USC503cx	Corr. Random Walk	$0.50	Experienced	Median (+ forecasting)	100
UC504cx	Corr. Random Walk	$0.50	Experienced	Median (+ forecasting)	100
UC001r	Mean-Reverting Random Walk	$0.00	Inexperienced	Median (+ forecasting)	50
UC201r	Mean-Reverting Random Walk	$0.20	Inexperienced	Median (+ forecasting)	50
UC501r	Mean-Reverting Random Walk	$0.50	Inexperienced	Median (+ forecasting)	50

In the independent random walk sessions, the sellers' cost shock was drawn independently from U(-.20,.20). In the correlated costs sessions, the sellers' cost shock had both a common component (drawn from U(-.15,.15)) and an independent component (drawn from U(-.05,.05)). In the mean-reverting random walk sessions, the sellers' cost evolved according to $\ln c_{jt} = 0.03 + 0.95 \ln c_{jt-1} + e_{jt}$, where e_{jt} are drawn from U(-10,.10). "UC" in the session name denotes sessions conducted at UC-Santa Cruz; "USC" denotes sessions conducted at the University of Southern California.

Table 2:
Summary of Testable Hypotheses

Code	Hypothesis	Theoretical Basis
	Market Hypotheses apply to sessions with varying CE price and *C*>0	
MH1	Sticky prices: |Transaction price change| typically less than |CE price change|	Motivates Customer Markets, but not yet demonstrated theoretically
MH2	Market power: Mean transaction price is higher than CE price	Diamond (1971) and later articles
MH3	Market power: Mean efficiency is lower than in CE	Diamond (1971) and later articles specialized to our setting
	Buyer Hypotheses apply to non-discouraged buyers in sessions with *C*>0	
BH1	Switch frequency increases in posted price *p*	Reservation price definition (with noisy threshold)
BH2	Switch frequency decreases in buyer value *v*	Reservation price comparative statics
BH3	Switch frequency decreases in switch cost *C*	Reservation price comparative statics
BH4	Switch frequency increases in time remaining *T*	Reservation price comparative statics
BH5	Switch frequency decreases when interim info indicates higher prices	Reservation price comparative statics for *G*
BH6	Switch frequency increases in time since previous switch when no interim info	Indirect consequence of reservation price comparative statics for *G*
	Seller Hypotheses apply to sessions with *C*>0	
SH1	Sticky posted prices: |price change| less than |cost change|	Individual level counterpart of MH1
SH2	Posted price increases in own cost c	Pricing function comparative statics
SH3	Posted price increases in #attached buyers n	Pricing function comparative statics
SH4	Posted price increases in rivals' previous prices	Pricing function comparative statics for *G*
SH5	Posted price increases in switch cost *C*	Pricing function comparative statics for *H* + BH3
SH6	Posted price decreases in time remaining *T*	Pricing function comparative statics for *H* + BH4
SH7	Posted price increases with more interim information on prices	Pricing function comparative statics for *H* + BH6

Table 3:
Median Absolute Posted Price and Cost Changes, and Median Absolute Changes in Mean Transaction Price and Competitive Equilibrium Price for Random Cost Sessions (cents)

Treatment	Median Absolute Change in Mean Transaction Price	Median Absolute Change in Competitive Equilibrium Price	Median Absolute Posted Price Change	Median Absolute Cost Change
All Data	4	7	5	9
Inexperienced	4.7	7	6	9
Experienced	3.75	8	5	9
Zero Switch Cost	3.4	7	5	9
20¢ Switch Cost[a]	4.4	7	6	9
50¢ Switch Cost	4.25	7	5	9
No Interim Price Info or only Median Interim Price Info	4	7	5	9
Full Interim Price Info	4.5	7	8	10
Uncorrelated Random Costs	3.75	7	6	10
Correlated Random Costs	4.4	7.5	5	8
Mean Reverting Random Costs	3.68	7	6	8
Low-Cost Seller	----	----	5	9
Middle-Cost Seller	----	----	5	9
High-Cost Seller	----	----	8	9

[a]Includes one session with 10¢ switch costs.

Table 4:
Mean Transaction Price Regression Model
(Dependent Variable = Mean Transaction Price – CE Price (in cents))

	Variable	Coefficient	Std. Error
(1)	Intercept	5.74	5.46
(2)	=1 if Switch Cost=$0.20	17.93**	3.43
(3)	=1 if Switch Cost=$0.20 × Periods Left	-0.30**	0.12
(4)	=1 if Switch Cost=$0.50	20.39**	3.89
(5)	=1 if Switch Cost=$0.50 × Periods Left	-0.39**	0.12
(6)	=1 if Uncorrelated Random Walk	5.61	5.46
(7)	=1 if Uncorrelated Random Walk*Periods Left	0.43**	0.16
(8)	=1 if Correlated Random Walk	-0.45	5.91
(9)	=1 if Correlated Random Walk × Periods Left	0.29*	0.13
(10)	=1 if Mean Reverting	-0.03	7.90
(11)	=1 if Mean Reverting *Periods Left	0.14	0.19
(12)	=1 if Experienced	-0.51	3.20
(13)	=1 if Experienced × Periods Left	-0.03	0.11
(14)	=1 if Full Information	-4.94	4.32
(15)	Periods Left	-0.19	0.13
Observations: 1824			
R^2: 0.721			

Note: ** denotes significantly different from zero at 1 percent; * denotes significantly different from zero at 5 percent (all two-tailed tests). Estimates are corrected for autocorrelation.

Table 5:

Average Efficiency

Switch Cost	Gross Efficiency (including switch costs) Inexperienced Sessions	Gross Efficiency (including switch costs) Experienced Sessions	Trading Efficiency (net of switch costs) Inexperienced Sessions	Trading Efficiency (net of switch costs) Experienced Sessions
Zero	0.877	0.955	0.877	0.955
Low	0.881	0.907	0.923	0.930
High	0.826	0.867	0.873	0.925

Gross Efficiency Regression Model

(Dependent Variable = Gross Efficiency (including switch costs))

Cross-Sectional OLS Regression (one observation per session)

	All Sessions	Inexperienced Sessions	Experienced Sessions
Variable	Coefficient (Std. Error)	Coefficient (Std. Error)	Coefficient (Std. Error)
Intercept	0.873** (0.033)	0.864** (0.033)	0.964** (0.023)
=1 if Switch Cost=$0.20	-0.008 (0.024)	0.018 (0.032)	-0.049 (0.030)
=1 if Switch Cost=$0.50	-0.060* (0.025)	-0.043 (0.034)	-0.086* (0.030)
=1 if Uncorrelated Random Walk	-0.016 (0.031)	-0.022 (0.035)	-0.027 (0.026)
=1 if Correlated Random Walk	0.089 (0.058)	0.004 (0.030)	
=1 if Mean Reverting Random Walk	0.045 (0.067)	0.043 (0.038)	
=1 if Experienced	0.055* (0.022)		
=1 if Full Information	0.015 (0.030)		
=1 if Median Information	0.005 (0.053)		
Observations	28	19	9
Adjusted R^2	0.267	0.104	0.452

Note: ** denotes significantly different from zero at 1 percent; * denotes significantly different from zero at 5 percent (all two-tailed tests).

Table 6:
Probit Model of Buyers' Switch Decision for Positive Switch Cost Sessions Only
(Dependent Variable = 1 if Switch; = 0 otherwise)

		Periods with discouraged buyers excluded		Within 5 periods of discouraged buyers excluded	
	Variable	Coefficient	Std. Error	Coefficient	Std. Error
(1)	Offer Price ($)	2.47**	0.10	2.50**	0.12
(2)	Value ($)	-0.60**	0.13	-0.67**	0.14
(3)	Dummy=1 iff switch cost is high	-1.64**	0.58	-1.74**	0.62
(4)	(Periods remaining)/(2+periods remaining)	0.68**	0.23	0.55*	0.26
(5)	Previous period median price×dummy=1 iff median price is displayed on interim screen	-1.68**	0.15	-1.63**	0.15
(6)	Periods since last switch×dummy=1 iff no price info on interim screen	-0.023*	0.010	-0.024*	0.011
(7)	Dummy=1 iff complete transaction price info is displayed on interim screen	-6.69*	2.82	-7.15*	3.00
(8)	Dummy=1 iff no transaction price info is displayed on interim screen	-9.58**	2.73	-9.89**	2.90
(9)	Dummy=1 iff seller costs follow (non-mean reverting) independent random walk	-2.51*	1.27	-2.74*	1.36
(10)	Dummy=1 iff seller costs follow (non-mean reverting) correlated random walk	-6.38*	2.70	-6.81*	2.88
(11)	Dummy=1 iff seller costs follow mean reverting independent random walk	-6.16*	2.68	-6.59*	2.86
(12)	Dummy=1 if subjects are experienced	-2.08*	0.89	-2.21*	0.95
(13)	Fitted mean posted price (instrumental variable)	-4.15*	1.80	-4.50*	1.91
(14)	Fitted posted price variance (instrumental variable)	108.02*	53.33	116.53*	56.91
(15)	Intercept	8.79*	4.30	9.76*	4.55
(16)	Rho (random effects)	0.20**	0.03	0.22**	0.03
	Observations	5927		5509	
	Log-Likelihood	-1731.9		-1637.8	
	Restricted Log-Likelihood	-1792.6		-1700.4	

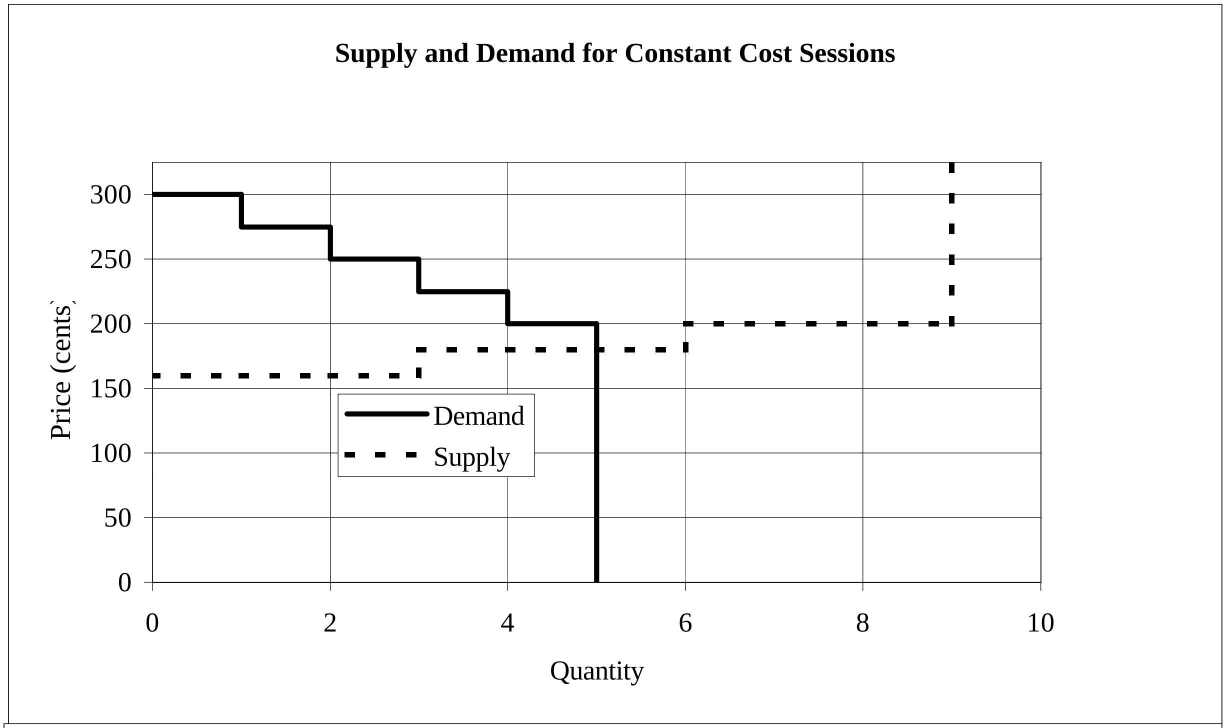
Notes: Omitted dummies correspond to low (usually $0.20) buyer switch costs, constant seller production costs, inexperienced subjects, and only median transaction prices displayed on the interim screen.
Model is estimated with each buyer in each 25-period run as a random effect.
** Denotes significantly different from zero at one-percent level.
* Denotes significantly different from zero at five-percent level.

Table 7:
Model of Individual Seller Price Choices for Positive Switch Cost Sessions Only
(Dependent Variable = Price Posted by the Seller in Cents)

	Variable	Coefficient	Std. Error
(1)	Seller Cost (cents)	0.59**	0.01
(2)	Number of customers	2.04**	0.37
(3)	Previous period mean price posted by other 2 sellers×Dummy=1 iff price info on interim screen	0.14**	0.02
(4)	Dummy=1 iff switch cost is high	4.99	3.23
(5)	(Periods remaining)/(2+periods remaining)	-6.82**	2.33
(6)	Dummy=1 iff complete transaction price info is displayed on interim screen	12.38	9.03
(7)	Dummy=1 iff no transaction price info is displayed on interim screen	55.28**	8.38
(8)	Dummy=1 iff seller costs follow (non-mean reverting) independent random walk	-0.34	4.61
(9)	Dummy=1 iff seller costs follow (non-mean reverting) correlated random walk	12.62	8.22
(10)	Dummy=1 iff seller costs follow mean reverting independent random walk	13.50	9.96
(11)	Dummy=1 if subjects are experienced	0.98	3.71
(12)	Constant	53.53**	9.97
	Observations	5164	
	Adj. R^2	0.46	

Notes: Omitted dummies correspond to low (usually $0.20) buyer switch costs, constant seller production costs, inexperienced subjects, and only median transaction prices displayed on the interim screen.
Model is estimated with each seller in each 25-period run as a random effect.
** Denotes significantly different from zero at one-percent level.
* Denotes significantly different from zero at five-percent level.

Figure 1:


Supply and Demand for Constant Cost Sessions
Price (cents)
300
250
200
150
100
50
0
Demand
Supply
0
2
4
6
8
10
Quantity

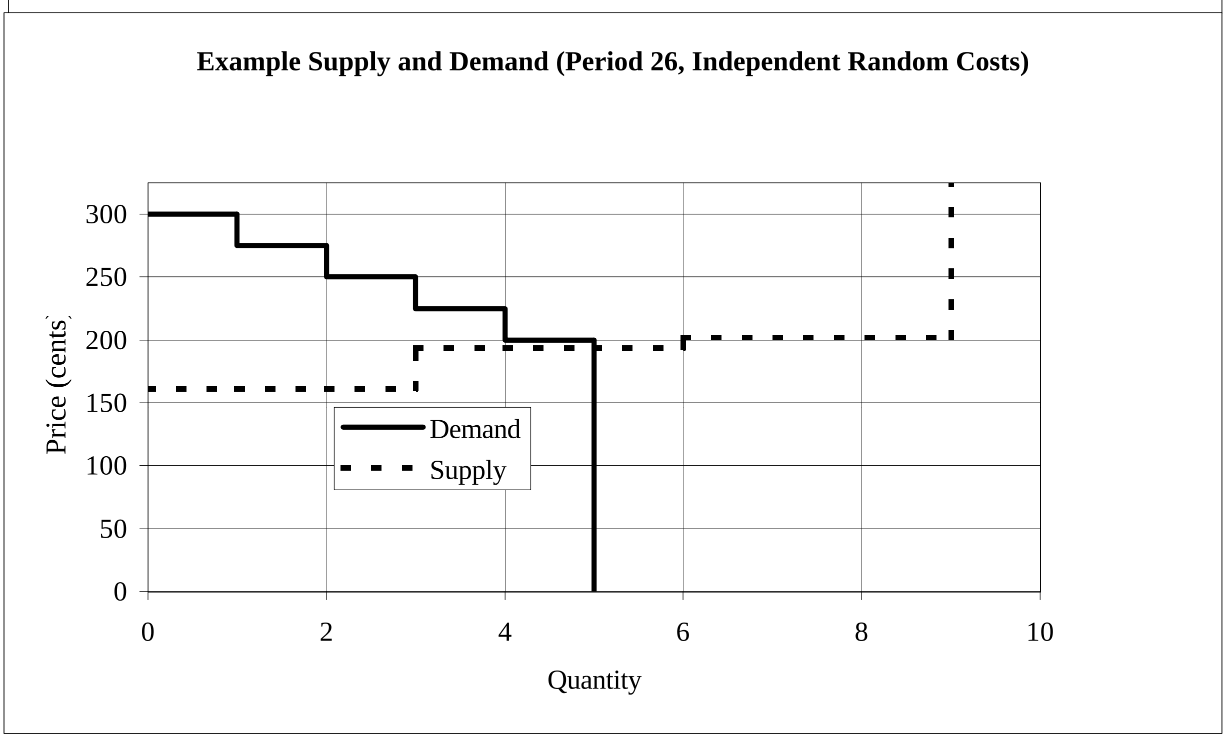
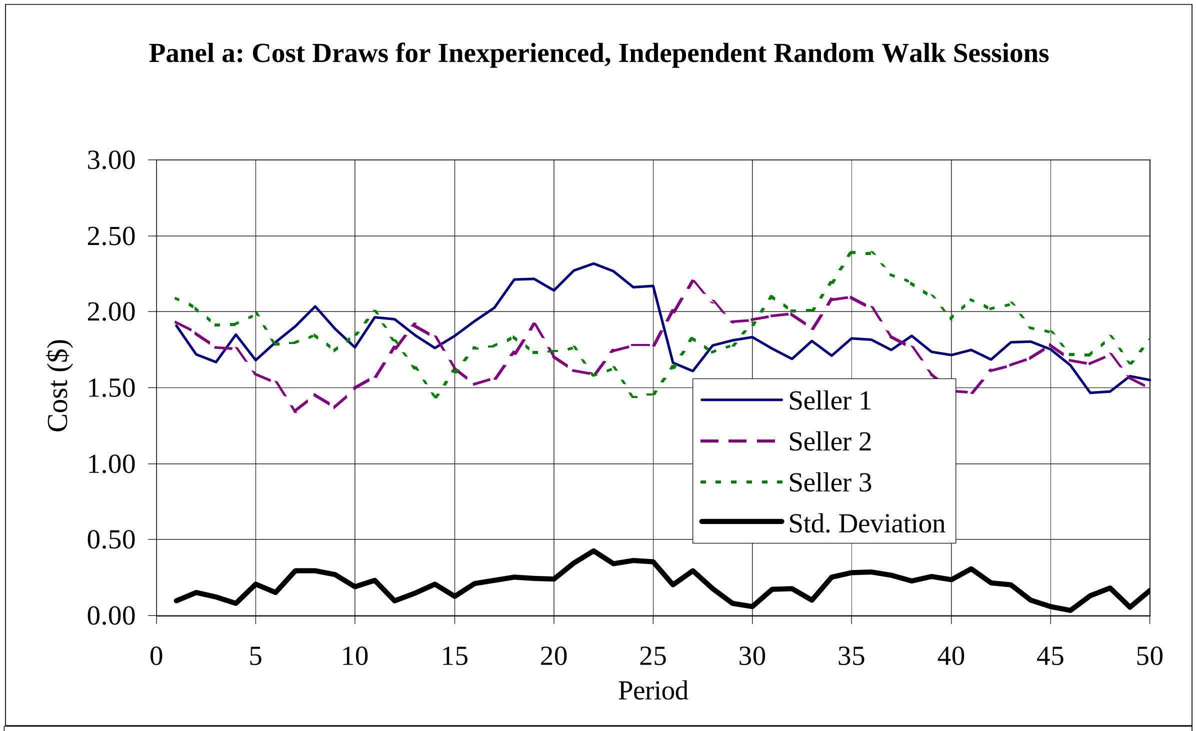
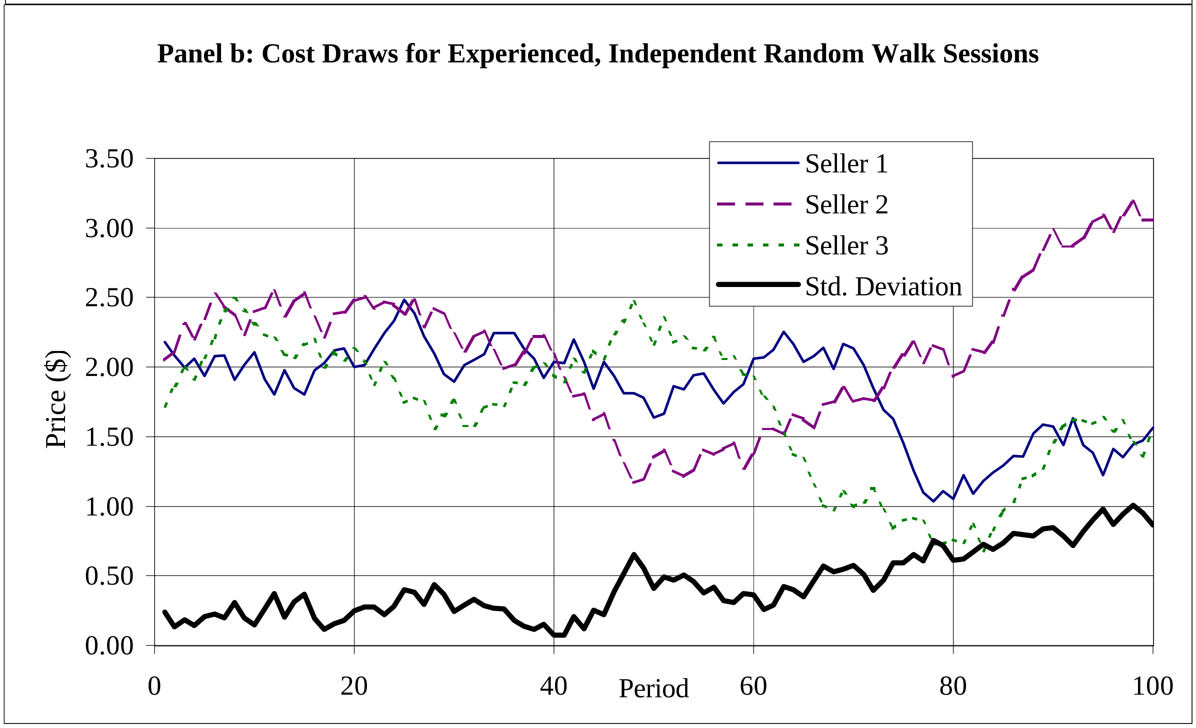

Example Supply and Demand (Period 26, Independent Random Costs)
Price (cents)
300
250
200
150
100
50
0
Demand
Supply
0
2
4
6
8
10
Quantity

Figure 2:



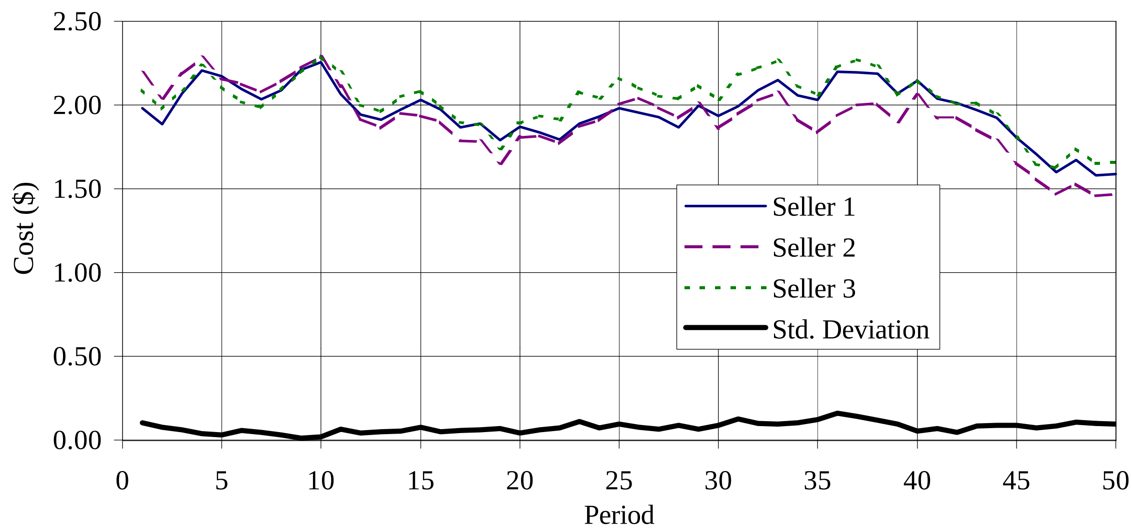
Panel a: Cost Draws for Inexperienced, Independent Random Walk Sessions
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Cost ($)
0
5
10
15
20
25
30
35
40
45
50
Period
Seller 1
Seller 2
Seller 3
Std. Deviation



Panel b: Cost Draws for Experienced, Independent Random Walk Sessions
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Price ($)
0
20
40
Period
60
80
100
Seller 1
Seller 2
Seller 3
Std. Deviation

Figure 2:

Panel c: Cost Draws for Inexperienced, Correlated Random Walk Sessions



Panel d: Cost Draws for Experienced, Correlated Random Walk Sessions

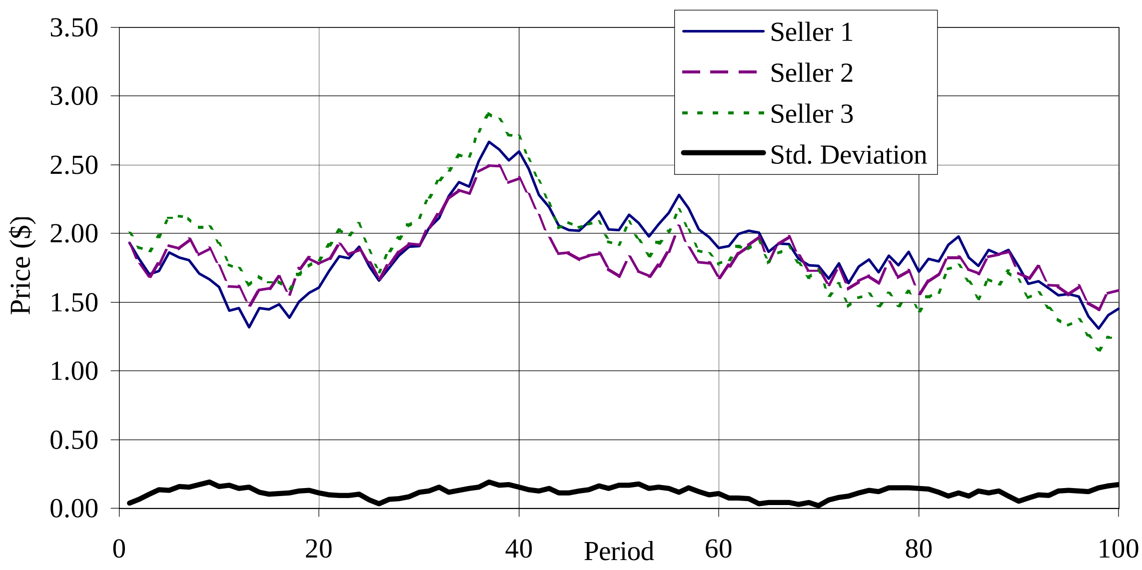
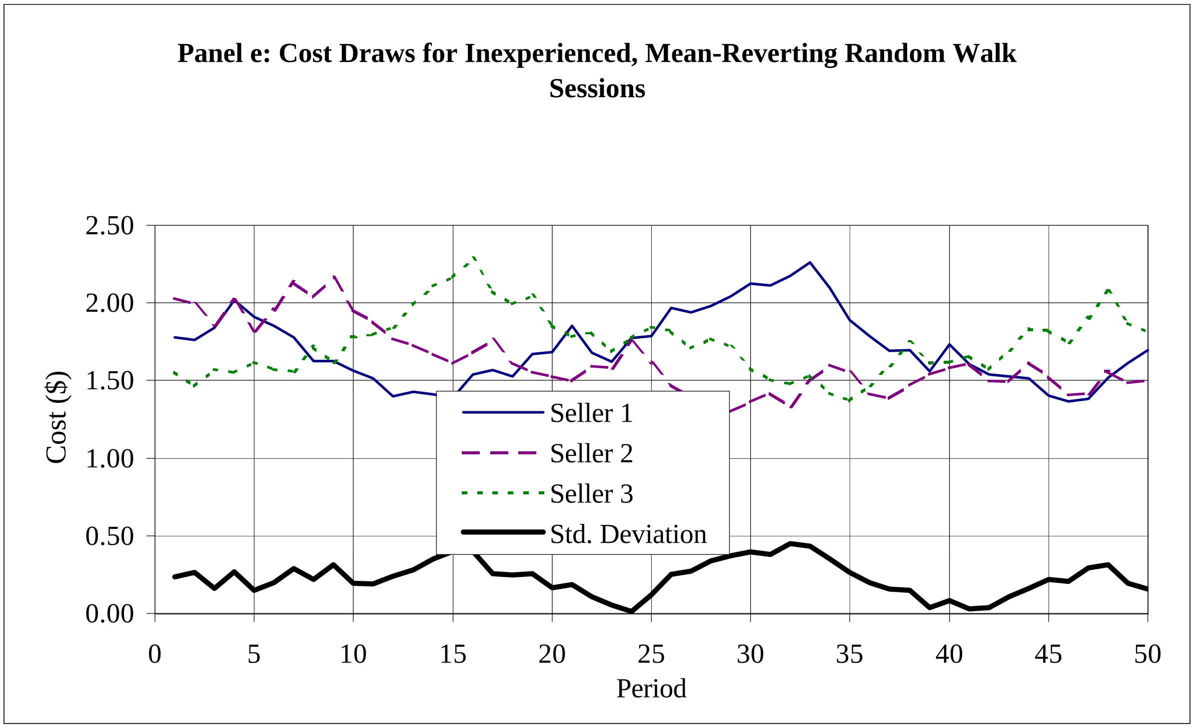
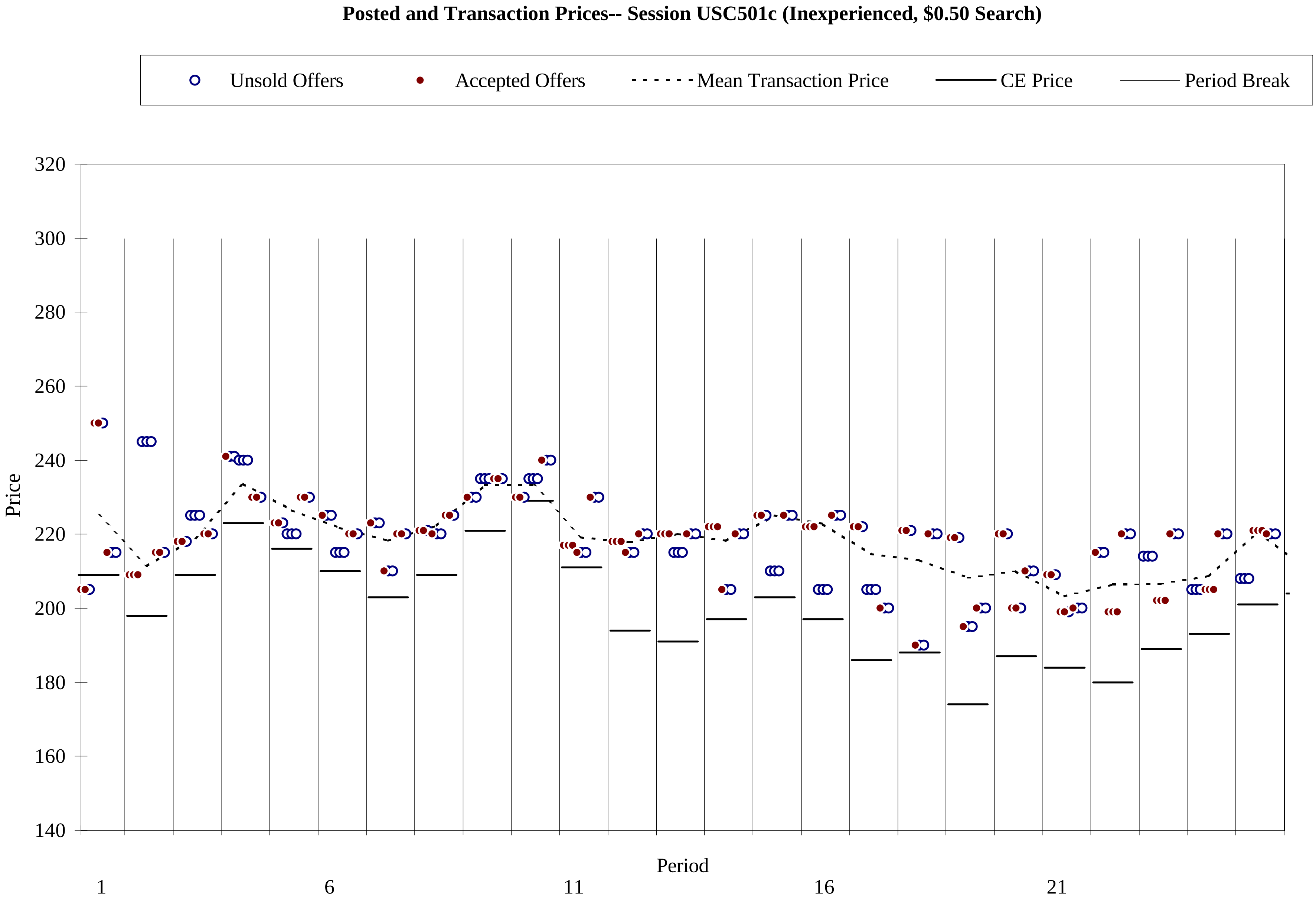


Figure 2:



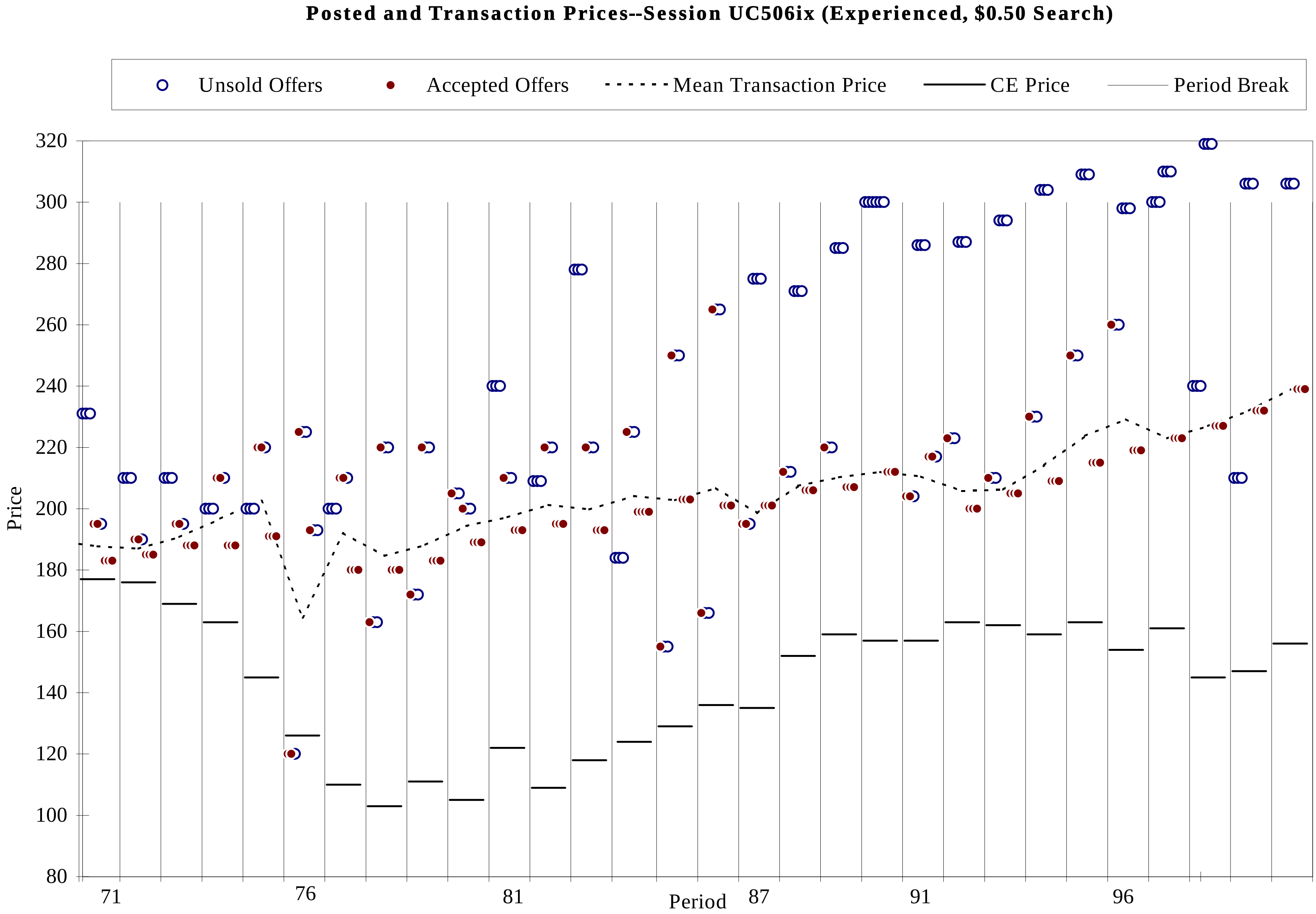
Panel e: Cost Draws for Inexperienced, Mean-Reverting Random Walk Sessions
2.50
2.00
1.50
1.00
0.50
0.00
Cost ($)
0
5
10
15
20
25
30
35
40
45
50
Period
Seller 1
Seller 2
Seller 3
Std. Deviation

Figure 3:



Posted and Transaction Prices-- Session USC501c (Inexperienced, $0.50 Search)
Unsold Offers
Accepted Offers
Mean Transaction Price
CE Price
Period Break
Price
320
300
280
260
240
220
200
180
160
140
Period
1
6
11
16
21

Figure 4:



Posted and Transaction Prices--Session UC506ix (Experienced, $0.50 Search)
Unsold Offers
Accepted Offers
Mean Transaction Price
CE Price
Period Break
320
300
280
260
240
220
200
180
160
140
120
100
80
Price
71
76
81
Period
87
91
96

Figure 5:

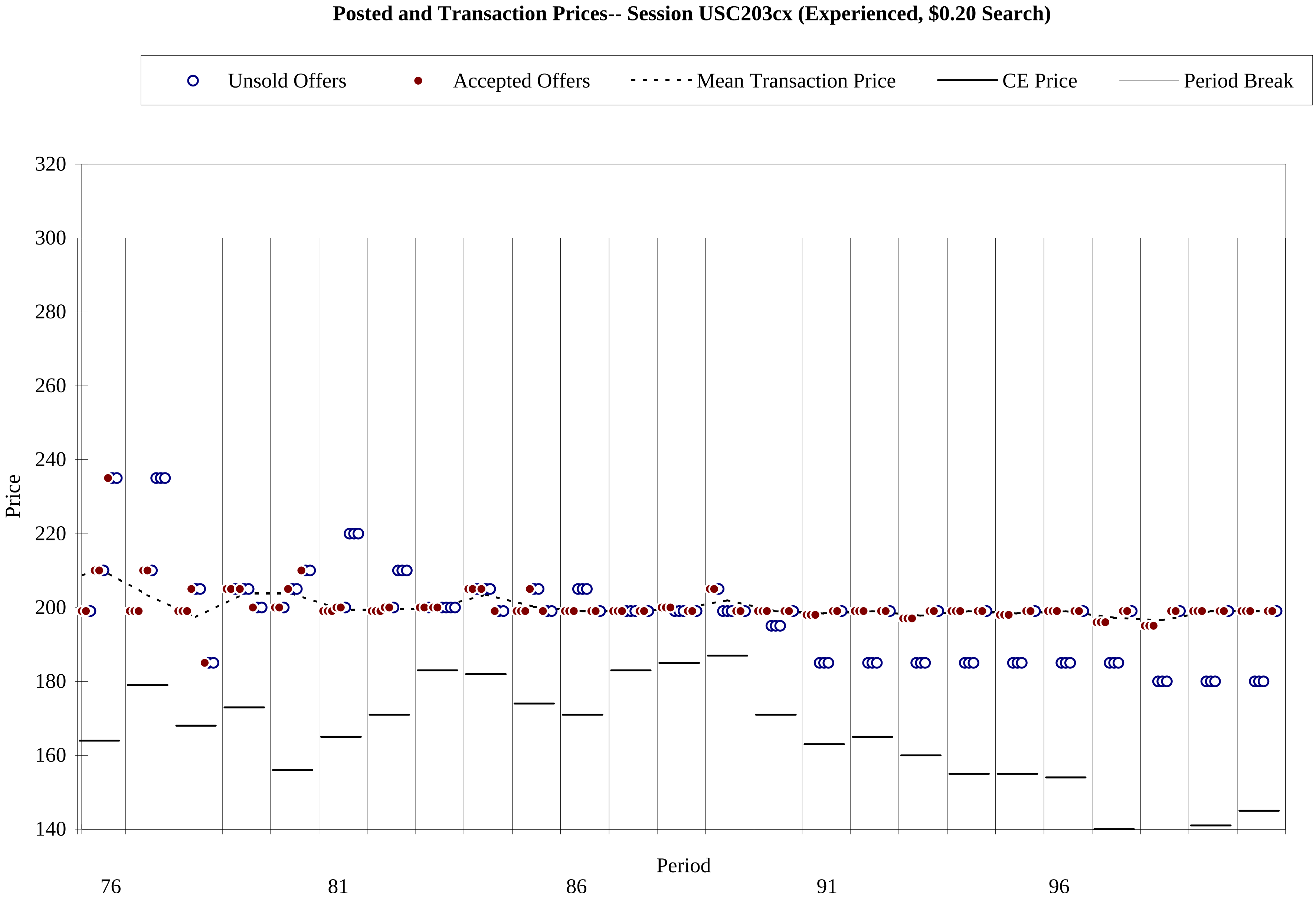
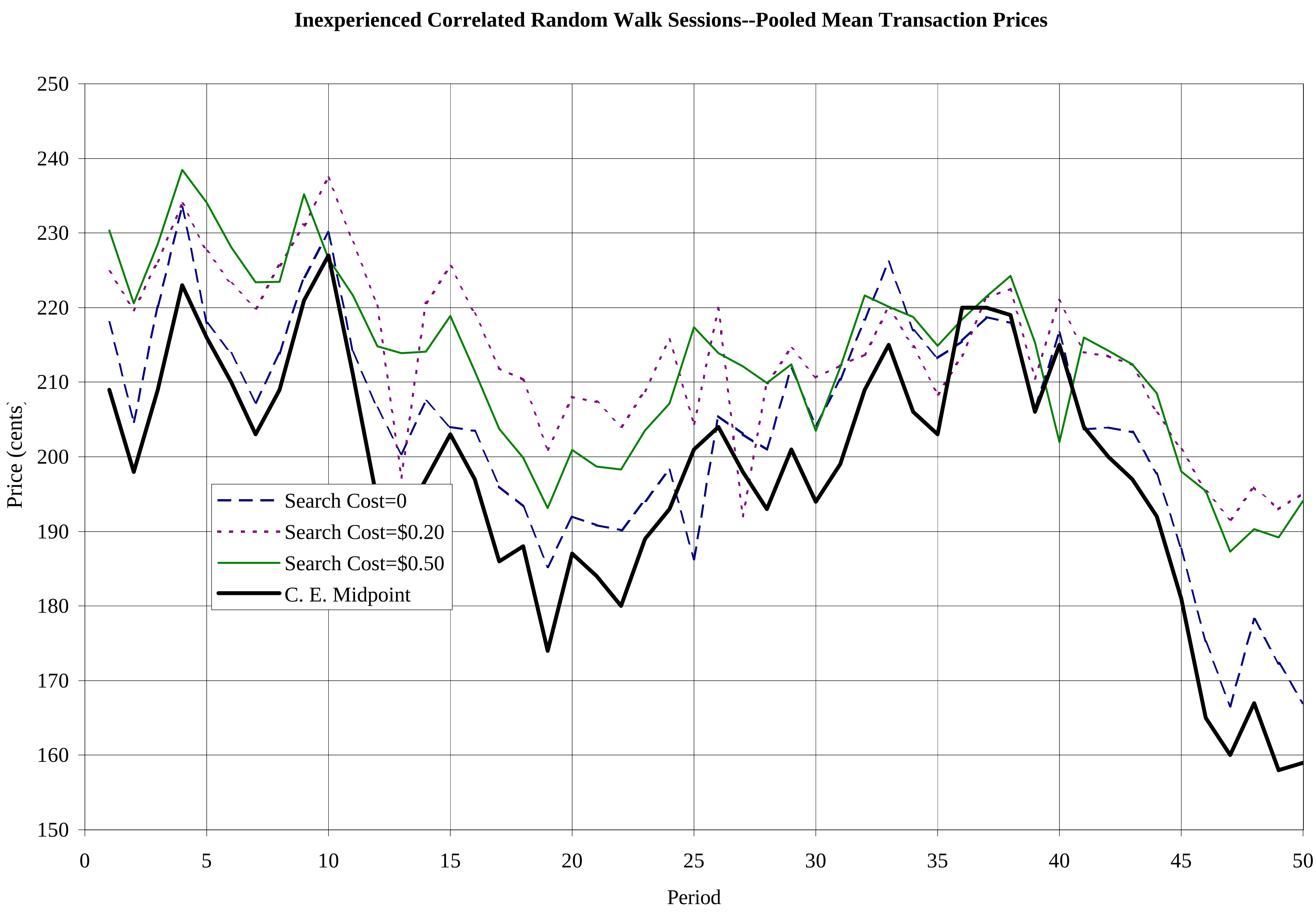
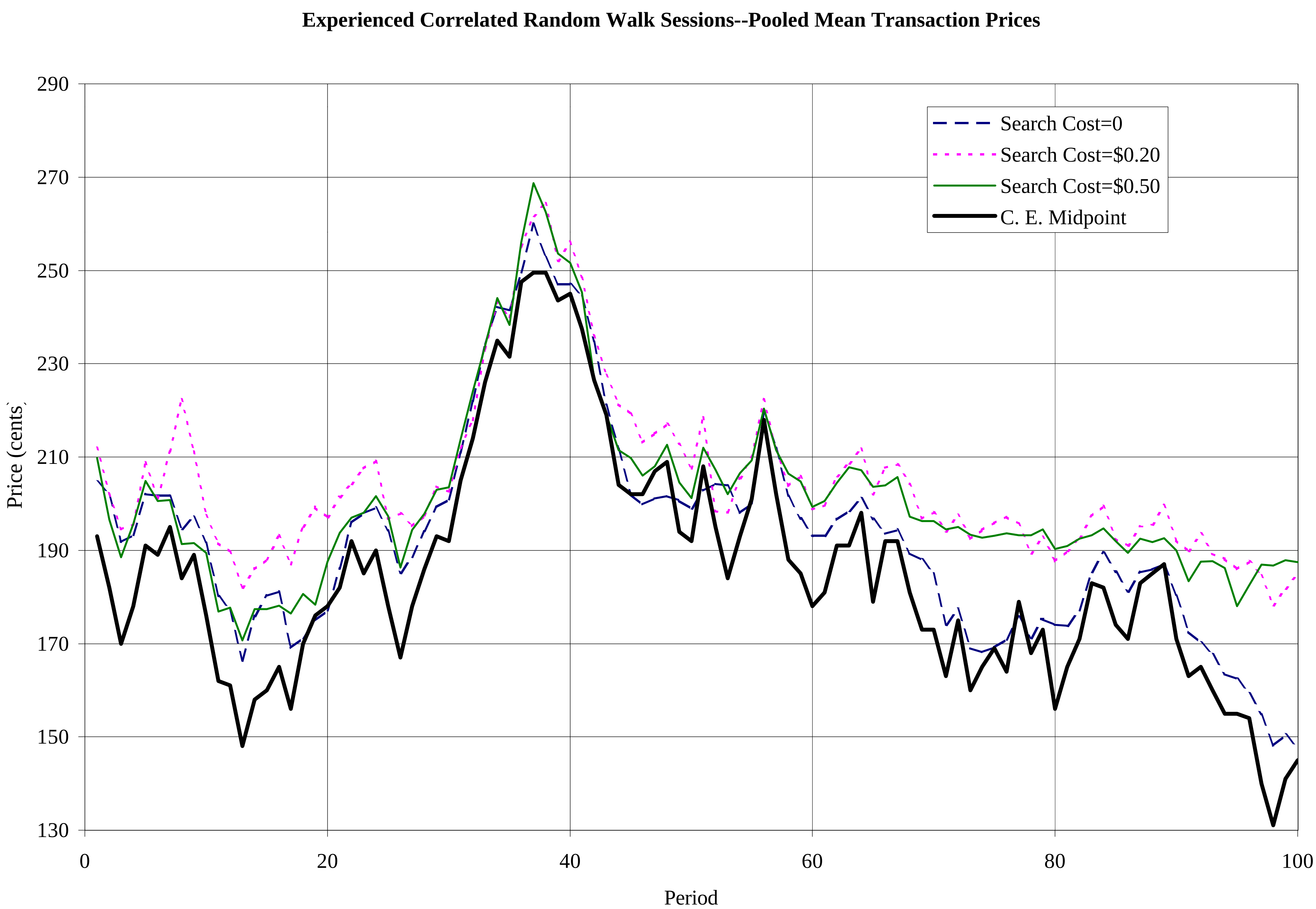

Posted and Transaction Prices-- Session USC203cx (Experienced, $0.20 Search)
Unsold Offers
Accepted Offers
Mean Transaction Price
CE Price
Period Break
Price
320
300
280
260
240
220
200
180
160
140
Period
76
81
86
91
96

Figure 6:



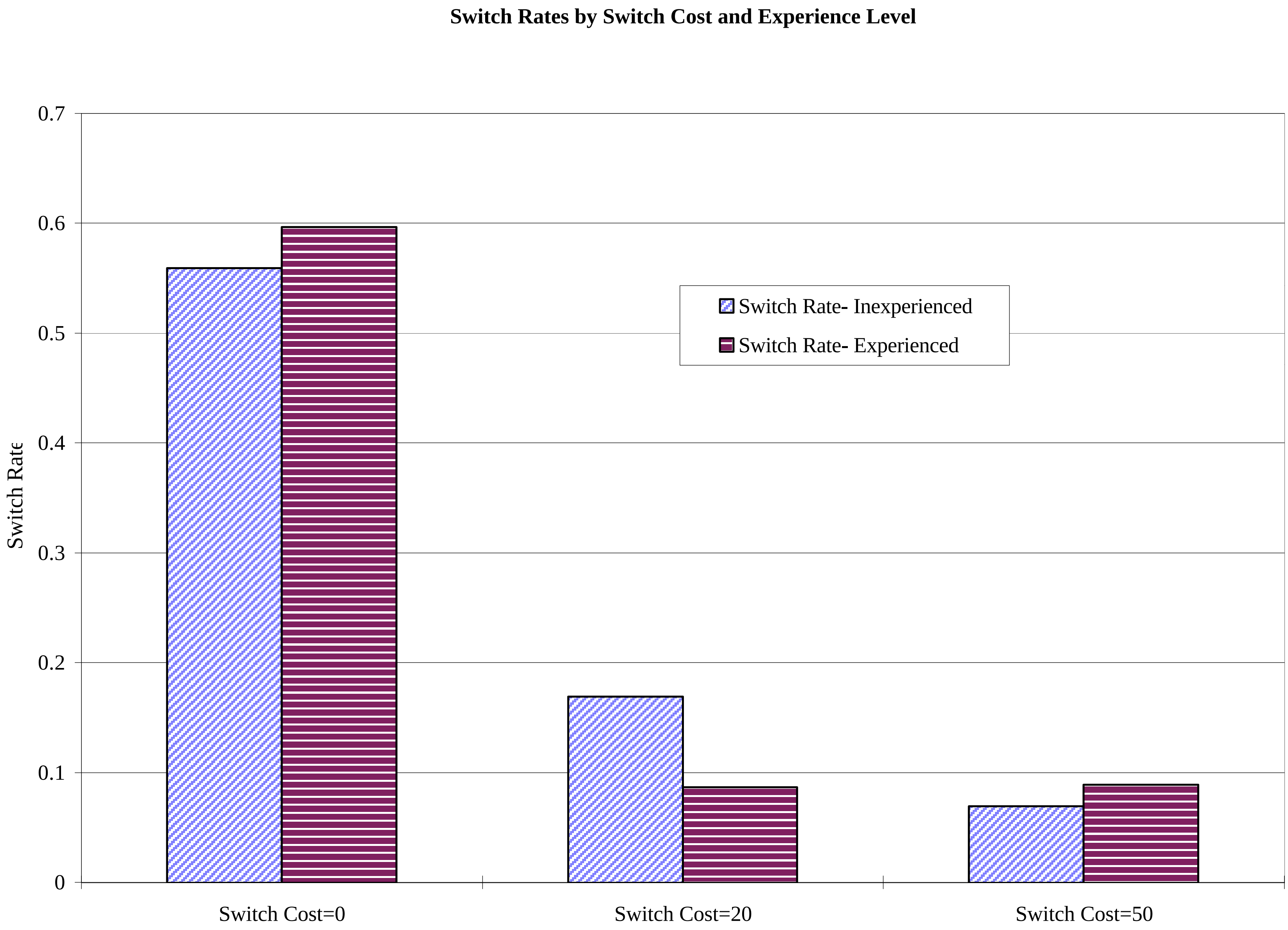
Inexperienced Correlated Random Walk Sessions--Pooled Mean Transaction Prices
250
240
230
220
210
200
190
180
170
160
150
Price (cents)
0
5
10
15
20
25
30
35
40
45
50
Period
Search Cost=0
Search Cost=$0.20
Search Cost=$0.50
C. E. Midpoint

Figure 7:



Experienced Correlated Random Walk Sessions--Pooled Mean Transaction Prices
290
270
250
230
210
190
170
150
130
Price (cents)
0
20
40
60
80
100
Period
Search Cost=0
Search Cost=$0.20
Search Cost=$0.50
C. E. Midpoint

Figure 8:


Switch Rates by Switch Cost and Experience Level
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Switch Rate
Switch Rate- Inexperienced
Switch Rate- Experienced
Switch Cost=0
Switch Cost=20
Switch Cost=50

APPENDIX A—INSTRUCTIONS TO TRADERS

UCSC Customer Market

October 1997

I. General

1. This is an experiment in the economics of market decision making. The National Science Foundation and other research organizations have provided funds for the conduct of this experiment. The instructions are straightforward, and if you follow them carefully and make good decisions you can earn a CONSIDERABLE AMOUNT OF MONEY which will be PAID TO YOU IN CASH at the end of the experiment.
2. In this experiment we create a market for a fictitious good. As a BUYER or SELLER in this market, you can use your computer to purchase or sell units of the good. Remember that the information on your computer screen is PRIVATE. To insure the best results for yourself and complete data for the experimenters, DO NOT TALK with other market participants while trade is in progress, and DO NOT DISCUSS your information with others at any point during the experiment.
3. After you log into your terminal, your computer screen will tell you whether you are a buyer or a seller and will display useful information about buying and selling opportunities.
4. Each time for buying and selling is called a TRADING PERIOD and will last about two minutes. At the start of each period, sellers POST PRICES, i.e., each seller enters a price for his or her units. When every seller has posted a price, the prices are shown to buyers as explained below. Each buyer decides whether or not to buy a single unit at the posted price. Then the trading period is over.
5. The digital clock in the upper right hand corner of your screen will tell you how much time is left. For example, 0 minutes and 47 seconds are left for the buyer shown in Figure 3.
6. At the end of the trading period, all units are "consumed" and your profits for that period are computed as explained below. The computer screen will display your profits for that period and your total profits over all periods so far. You may be asked at this time to forecast prices for the next period. Then the new trading period will begin. Everyone has new opportunities to buy or sell each period; old units do not carry over into the new period. There will be about 30 to 60 trading periods in this experiment.
7. At the end of the last trading period, you will be paid in cash your total profits converted at the stated rate, plus a $5.00 participation fee. For example, if your total profits for 50 trading periods were $24.36 and the conversion rate (written on the blackboard at the beginning of the experiment) were 0.5, then you would take home 0.5 x 24.36 + 5.00 = $17.18 in cash.

II. Sources of Profit

1. Each buyer can purchase a single unit of the good each period. If you are a buyer, you will see your VALUE of the unit displayed near the center of your screen. Always check the value at the beginning of each period, because it can change from period to period as explained in instruction 6 below. Different buyers generally have different values.
2. A buyer with value v who purchases a unit at price p earns PROFIT = v - p that period. For example, the buyer in Figure 2 would earn a profit of $2.86 - $1.94 = $0.92 if she purchases a unit at price $1.94. Note that she would earn a negative profit (lose money) if she paid a price above her value $2.86. Buyers who don't buy a unit automatically earn a profit of zero that period.
3. Each seller can sell several units of the good each period. If you are a seller, you will see your per-unit COST displayed near the center of your screen along with VOLATILITY and CAPACITY. Capacity is the maximum number of units you can sell in one period, for example 3 units for the seller in Figure 1. Volatility (for example, 0.20 in Figure 1) is the

maximum change in your cost from one period to the next, as explained in instruction 5 below.

4. A seller with cost c who posts price p earns PROFIT = p - c on every unit sold that period. For example, the seller in Figure 1 would earn a per unit profit of $1.94 - $1.51 = $0.43; his profit for that period would be $0.43 if he sells 1 unit, $0.86 if he sells 2 units, etc. Note that he would earn a negative profit (lose money) if he posts a price below cost of $1.51 and sells some units. Sellers who don't sell any units automatically earn a profit of zero that period.

5. Each period each seller's cost is randomly changed from the previous period's cost by an amount between -e and +e, where e is the volatility. For example, if e = $0.20, then the computer randomly draws a number from the list -.20, -.19, -.18, ..., -.01, 0, .01, ..., .19, .20 and adds this number to the previous period's cost. For example, the seller with cost $1.51 on period 8 would have cost $1.62 on period 9 if the draw were .11. Each number in the list is equally likely and the computer's draw each period is independent. This means that the draw does not depend on the actions of any buyer or seller, nor on the draws for the other sellers (or buyers) that period, nor on the numbers drawn on other periods. Volatility is the same for all sellers and doesn't change during the experiment. Volatility = 0.00 means that, although costs may differ across sellers, cost for each seller is unchanged from one period to the next.

6. Buyers' values can change from period to period in exactly the same way as sellers' costs. However, in many experiments, buyers' volatility is set to 0.00 as in Figure 2. In this case, values may differ across buyers but the value of each buyer is unchanged from one period to the next.

7. Important information will be written on the board at the beginning of the experiment. The information may include: the number of scheduled trading periods, the conversion rate for cash payments, the bonus for the best forecast (explained below), the volatility of buyers values and the volatility of sellers' costs, and perhaps additional details on first period values and costs.

III. How to Buy or Sell

1. Each buyer is the CUSTOMER of a specific seller. On the first trading day, each seller's customers are assigned randomly by the computer. After that, a seller's PRIORITY CUSTOMERS are the buyers who purchased from him on the previous trading period. His other customers are buyers who were his customers the previous period and who didn't buy any units (from any seller) that period. Customers get to see their own sellers' posted prices before non-customers, and priority customers are able to buy first, as explained in instruction 4 below.

2. If you are a seller, you post your price each period by typing in the price and then pushing the special [Post] key, p. For instance, typing the four keystrokes "148p" indicates that you are willing to sell as many units as you have (your capacity) at the price $1.48 per unit. Do not use a decimal point when typing in the numbers. After you post your price, the Post box will disappear from your screen.

3. After all sellers have posted prices, then the price of each seller is displayed on the screen of his customers. At this point, buyers don't see other sellers' prices, just their own seller's price.

4. Priority customers get the first opportunity to buy. If you are a priority customer, a highlighted message will appear in the upper right portion of your screen as in Figure 2. A clock (marked P for priority customer time) appears on all buyers' screens. You are guaranteed a unit at the posted price if you place your order while time remains. For example, the buyer in figure 2 has 1 minute and 28 seconds remaining to place her order as a priority customer. After all priority customers have responded (or P time has expired), then all remaining buyers (those who did not buy as a priority customer) have the

opportunity to buy at a seller's posted price on a first-come first-served basis. Another clock (marked R for regular buyer time) appears in the upper right corner of buyers' screens. Buyers who do not respond before time expires do not buy a unit that period.

5. At the bottom of each buyer's screen are three boxes indicating special keys for accepting a posted price (y), refusing to buy at any posted price this period (n), and for searching the prices of all sellers (s). A buyer who hits the n key is finished for that period, and will earn zero profit. A buyer who hits the y key will automatically purchase a unit at the posted price if the seller still has any units left. If the seller is out of units, then an error message will appear, and the buyer can either hit the n key or hit the s key.

6. If you hit the s (search) key then your screen will show the prices posted by all sellers as in Figure 3, and you can buy from any seller who still has unsold units. The screen lists all posted prices from lowest to highest. To accept a listed price, simply type the seller code and hit the y key. For example, the two keystrokes "0y" mean that you order a unit at the price posted by the seller with code 0. For example, the buyer in Figure 3 would buy a unit at price $1.30 if she typed "0y," or at price $2.40 if she typed "1y".

   IMPORTANT FACTS. There is a fee for search shown on the box on the bottom right corner of the buyer's screen, for example $0.20 in Figure 2. You have to pay that fee every day you hit the s key, even if you do not buy from anyone that period. If you do buy, then you are the new seller's customer the next period.

IV. At the End of The Period

1. When all buyers have responded (or when R time expires) every trader's screen will summarize the period's activities as in Figure 5 for sellers or as in Figure 4 for buyers. The profit calculations are shown in detail. Near the bottom of the screen the prices and sales for that period are summarized. For example, in Figures 4 and 5 we see that the lowest price seller sold 1 units at $1.00, the middle price seller sold 2 units at $2.30 and the high price seller sold 0 units at $3.00. The median (i.e, the middle price of the units sold, 1.00, 2.30 and 2.30) is therefore 2.30.

2. In some experiments all buyers will be asked each period to forecast the next period's median price. (Sellers set the prices so are not asked to forecast.) The buyer whose forecasts are closest over all periods will get the cash bonus shown on the blackboard at the beginning of the experiment.

V. Frequently Asked Questions

Q1: How do I erase a mistake? A. If you already hit the special key (p, y, n, s or f) then it's too late. If you haven't yet hit the special key, you can hold down the control key while pressing the h key to erase your mistake. Then you can retype. **Special note to sellers:** Be sure to look at the price you are about to post before pressing the s key. One seller meant to type 220 but actually just typed 22 before hitting the s key. His posted price then was 22 cents, not $2.20. He sold 3 units at 22 cents and lost lots of money that period.

Q2. As a buyer, can I buy more than one unit in the same period? A. No. In the present set of experiments, there is a limit of one unit per customer per period.

Q3. How does a seller know who his customers are? And how does a buyer know which seller is his? Do the codes seen after search tell you who the sellers are? A. No, the codes are based only on sellers' current posted prices, and don't reveal their identities. You don't know which person you are buying from or selling to in this experiment. As explained in the instructions (especially III.1) each buyer begins each period attached to the seller she last bought from. If she chooses to switch, she can usually tell from the posted prices whether her new seller is different from her present seller, but she can't tell whether he is someone she was attached to before a previous switch.

Q4. As a buyer who chooses to search, shouldn't I always just type "0y" after search? Doesn't that give me the best price? A: Yes, it does place your order at the best price, but that seller may have sold all his units already. Then you'd have to type "1y" to order from the next lowest price seller.

Q5. As a seller who doesn't sell anything, do I have to pay any costs that period? A: No. Think of sellers as making the units to order. You only incur the cost of a unit if the unit is sold. On periods you don't sell anything your profit is zero.

Figure 1. Seller's Screen

```
********************************************************************************
  Cust: Version 1.0           Period # 2    Player # 0                      S
     Seller Screen



        Your current cost:  1.51
        Volatility: 0.20
        Your capacity: 3



    Please post a price....



 ====>
                               +-------+
                               |   P   |
                               |       |
                               | POST  |
                               +-------+
********************************************************************************
```

Figure 2. Buyer's Screen

```
********************************************************************************
  Cust: Version 1.0           Period # 2    Player # 1                1m 28s P
    Customer Screen                                      *Priority Customer*




        Your current value: 2.86
        Volatility: 0.00




    Seller's price:   1.94

 1 out of 2 players have finished.
 ====>
           +-------+           +-------+           +-------+
           |   Y   |           |   N   |           |   S   |
           |       |           |REJECT |           |SEARCH |
           |ACCEPT |           |  ALL  |           | 0.20  |
           +-------+           +-------+           +-------+
********************************************************************************
```

Figure 3. Buyer's Screen after Search

```
********************************************************************************
  Cust: Version 1.0           Period # 3    Player # 1                0m 47s R
    Customer Screen

                                                Seller's  Seller's
                                                 Coded #   Price
        Your current value: 1.66               ----------------------
        Volatility: 0.20                            0       1.30
                                                    1       2.40
                                                    2       2.98

    To switch, enter a seller's coded # and 'y'.

 ====>
            +-------+           +-------+
            |   Y   |           |   N   |
            |       |           |REJECT |
            |ACCEPT |           |  ALL  |
            +-------+           +-------+
********************************************************************************
```

Figure 4. Buyer's Interim Screen

```
********************************************************************************

                      PLAYER #1'S RESULTS FOR PERIOD #3

              Value:          1.66             Period     Profit
            - Price:          1.00           ---------------------
           ------------------------              1         2.80
            = Surplus:        0.66               2         0.92
            * # Bought:          1               3         0.46
           ------------------------           =====================
            = Gross Profit:   0.66             Total       4.18
            - Search Cost:    0.20
           ========================
            = Net Profit:     0.46

   Prices: 1.00 (1) 2.30 (2)
   Median:  2.30
```

(Note: The 2 lines above are not shown in the sessions with no interim screen price information)

```
********************************************************************************
```

Figure 5. Seller's Interim Screen

```
********************************************************************************

                       PLAYER #0'S RESULTS FOR PERIOD #3

                                             Period     Profit
                                           ---------------------
           Price:          1.00                1        1.52
         - Cost:           0.72                2        0.43
        -----------------------                3        0.56
         = Unit Profit:   0.28             =====================
         * # Sold:           2               Total      2.51
        =======================
         = Net Profit:    0.56



   Prices: 1.00 (1) 2.30 (2)
   Median:  2.30
```

(Note: The 2 lines above are not shown in the sessions with no interim screen price information)

```
********************************************************************************
```

1 Appendix B. Theoretical Sketches

Unfortunately existing literature does not include models of a posted offer market with switch costs and persistent idiosyncratic shocks to the surplus inherent in a buyer-seller attachment. As noted in the main body of the paper, there are a number of helpful articles, but none that directly provides testable hypotheses for our experiment. The purpose of this appendix is to sketch a theoretical basis for the hypotheses we test, and to encourage theorists to pursue further what seems to be an important, interesting and fruitful avenue of research.

The market has a finite set of sellers $j = 1, ..., J$ who produce indivisible units of the good to order, so there are no unsold units and no inventory. Sellers produce at zero fixed cost and at constant marginal cost in each period. Seller j begins period t by observing own marginal cost c_{jt}. Next he posts price p_{jt}, fills buyers' orders for n_{jt} indivisible units, and earns profit $\pi_{jt} = (p_{jt} - c_{jt})n_{jt}$.

There is also a finite set of buyers $i = 1, ..., I$, each characterized by her privately known value (or willingness to pay) v_i for a single unit. The values are independent across buyers and constant over time. Buyer i begins period t by observing the price posted by her attached seller $j(i)$. Next she decides whether to switch. Switching incurs a sunk cost $C \geq 0$ but allows her to observe a sample of $N \geq 1$ prices drawn randomly from the current distribution of posted prices. Then she decides whether to purchase a unit at posted price p_{it} ($= p_{j(i)t}$ if she didn't switch, and $=\min\{p_{jt} : j \in \text{sample}\}$ if she did switch). The buyer's gross profit in period t is 0 if she doesn't transact and is $v_i - p_{it}$ if she does. The net profit is the the same as the gross profit if she didn't switch; the sunk cost C is subtracted if she did switch.

Marginal cost c varies across sellers j and evolves over time $t = 0, 1, 2, ..., T \leq \infty$ via the process

$$\ln c_{jt+1} = \eta + \alpha \ln c_{jt} + e_{jt}. \tag{1}$$

Special cases of interest include (a) constant cost: $\alpha = 1$ and $\eta = e_{jt} = 0$, (b) autoregressive cost: $0 < \alpha < 1$, and (c) geometric random walk cost: $\alpha = 1$ and e iid Normal.

Attachments also link each period to previous periods. Seller j begins period t with n_{jt-1} customers; after observing his new posted price p_{jt} some attached customers may leave and others may attach themselves. For simplicity we assume that the seller observes the number n_{jt} of units sold each period but not the identity of his customers or how long they remain attached. Buyers and sellers all use the same factor $\delta \in (0, 1]$ to discount future periods.

Sellers maximize expected present value of current and future profits. A seller's Bellman equation is

$$W(c,n) = max_p E[(p-c)n'(p) + \delta W(c', n'(p))], \tag{2}$$

where $p = p_{jt}$ is posted price; the transition from current cost $c = c_{jt}$ to next period's cost $c' = c_{jt+1}$ is defined in equation (1), and the transition from $n = n_{jt-1}$ to $n' = n_{jt}$ is defined in equation (11) below. The expectation is taken over n' and c', conditioned on n and c. Proposition 3 below shows that under fairly general stationary conditions the Bellman equation has a well defined solution $p = P(c,n)$. Given the joint distribution of sellers' costs and numbers of attached customers, the function P induces a distribution $F(p)$ of posted prices, as discussed below. Then $G(q) = 1 - (1 - F(q))^N$ is the distribution of the best (lowest) posted price q in a sample of N posted prices drawn randomly from F. The notation E_G below will indicate expectations taken with respect to G rather than F.

Buyers also maximize expected present value of current and future profits. A buyer's Bellman equation is $V(v,p,F) = \max\{V_r, V_s\}$, where the values for remaining attached (r) and for switching (s) are given by

$$V_r = \max\{0, (v-p)\} + \delta E V(v, p', F(p'|p)) \text{ and} \tag{3}$$

$$V_s = E_G \max\{0, (v-q)\} + \delta E_G V(v, q', F(q'|q)) - C. \tag{4}$$

Proposition 1 below shows that under very mild technical conditions the solution to the Bellman equation exists and is characterized by a reservation price function $b = B(v,F)$. The buyers' optimal choice is then

$$z = \begin{cases} r & \text{if } p \leq b \\ s & \text{otherwise} \end{cases} \tag{5}$$

and the buyer purchases whenever WTP v exceeds current posted price, p if $z = r$ or q if $z = s$.[1]

Figure A1 provides an overview of how the model elements fit together. For example, the distributions $F(p)$ of posted prices and $A(v)$ of buyer values induce the distribution $H(b)$ of reservation prices via the reservation price function $B(v,F)$. In equilibrium the state distributions F and H are self-reproducing. The next section

[1]This rule assumes that buyers never purchase at a loss (although in a more complex world a rational buyer might do so to preserve an attachment) and never fail to purchase when observing a posted price below value (although in a more complex world a rational buyer might do so to affect the seller's future behavior). These simplifying assumptions are quite consistent with the laboratory data, as noted in the body of the paper.

develops these functions and distributions in more detail, and presents comparative statics with respect to the major exogenous elements.

2 Some Results

The first step is to analyze the function describing the buyer's expected profit when switching. The gross per period profit from a single search is $\max\{0, v - q\}$, since the buyer will prefer not to transact (and thus earn zero profit) when the lowest available price q is above his value v. Since q has distribution $G(q) = 1 - (1 - F(q))^N$, the gross value of switching is the expected profit

$$\phi(v|G) = \int_0^\infty \max\{0, v - q\} dG(q) = \int_0^v (v - q) dG(q) \tag{6}$$

The function ϕ is graphed in Figure A2. It resembles the standard graph of the value of a call option as a function of the current spot price. The direct analogy, however, is to a put option as a function of exercise price v.[2] The function ϕ is the convolution of the distribution G with the wedge function $\max\{0, v\}$; sometimes we will refer to it as a convolved wedge (cf Feller, Vol II p143ff). Most of its properties are well-known in search theory and/or option theory, but it is convenient for future reference to collect them here.

Proposition 1 *Given a cumulative distribution function G with expectation μ and with support bounded below by $p_o \geq 0$ and bounded above by $p_1 \leq \infty$, let (6) define $\phi(v|G)$ on $v \geq 0$. Then*

1. $\phi'(v|G) = G(v) \in [0, 1]$;
2. $\phi(v|G) = 0$ *for* $v \leq p_o$ *and* $\phi(v) = v - \mu$ *for* $v > p_1$;
3. ϕ *is strictly increasing for* $v \geq p_o$;
4. ϕ *is convex, and is strictly convex on the support of* G;
5. ϕ *has a well-defined inverse function* $\phi^{-1} : (0, \infty) \to (p_o, \infty)$;
6. *the functional* $G \mapsto \phi(v|G)$ *is continuous (in any standard topology on the space of distribution functions) and preserves the partial order of second-order stochastic dominance (2SD), i.e.,* $F \succeq_{2SD} G \Longleftrightarrow \phi(v|F) \leq \phi(v|G)\ \forall v \geq 0$;

[2]The resemblance to the call option diagram is thus not due to put-call parity, but rather to an obscure identity between a call as a function of expected spot price and a put as a function of exercise price.

7. *$v \geq \phi(v|G) \geq max\{0,\ v-\mu\}$ for all v and G, and if G is 2SD-maximal (i.e., degenerate or zero variance) then $\phi(v|G) = \max\{0, v-\mu\}$ for all v.*

Proof: Integrating equation (6) by parts yields $\phi(v|G) = (v-q)G(q)|_{q=0}^{v} - \int_0^v (-1)G(q)dq = 0 + \int_0^v G(q)dq$. Hence item 1 follows by the Fundamental Theorem of Calculus. Items 3-5 are immediate consequences of item 1 and the properties of distribution functions, e.g., that G is left-continuous, non-negative, and increasing everywhere, and is strictly increasing on its support.

As for item 2, recall that G has support contained in $[p_o, p_1]$, so $G(v) = 0$ and hence $\phi(v|G) = 0$ for $v \leq p_o$. For the second part of item 2, note that $\phi(v|G) = \int_0^\infty \max\{0, v-q\}dG(q) \geq \int_0^\infty (v-q)dG(q) = v-\mu$, and that equality holds for $v \geq p_1$. The main part of item 7 now follows directly since $p_o = p_1 = \mu$ for a degenerate distribution. The first part of item 7 follows from items 1 and 2: a function that is 0 at 0 and has slope less than 1 lies beneath the positive diagonal.

Finally, for item 6, it is well-known that continuity holds by definition of the weak* topology and stronger topologies (cf Feller or Royden 198x, pxx). Standard theorems (or definitions) show that 2SD is equivalent to the inequality $\int_0^v F(q)dq \leq \int_0^v G(q)dq\ \forall v$, e.g., Mas-Colell et al 1995, p 199. But the by-parts formula above shows that this inequality is equivalent to $\phi(v|F) \leq \phi(v|G)$. □

We now are ready to derive the reservation price function $B(v|F)$ under the simplifying assumption that posted prices are constant. See Figure A3 for a typical graph of the function.

Proposition 2 *Let the posted price distribution F, the sample size $N \geq 1$, the WTP v, the discount factor $\delta \in (0,1)$, and the switch cost $C \geq 0$ be given and constant. Suppose also that each seller's posted price is constant. Then there is a unique reservation price $b = B(v|F, N, \delta, C) \in [0, \infty]$ such that the buyer's value function V is maximized by policy (5). Moreover,*

1. *$b = B(v) = \infty$ for $v \leq v_o = \phi^{-1}((1-\delta)C|G)$;*

2. *$\lim_{v \downarrow v_o} B(v) = v_o$;*

3. *$b = B(v)$ is differentiable, concave and increasing with slope ≤ 1 for $v \in [v_o, p_1)$, where p_1 is the supremum of the suppport of F;*

4. *$b = B(v)$ is strictly increasing for $v \in [v_o, p_1)$ if $\delta < 1$ and is always constant for $v \geq v_u$.*

Proof: Observe first that if the buyer chooses not to switch this period at posted price b, he will make the same choice forever after since posted prices are assumed constant. Hence the value function in this case is the perpetuity $V_r(b,v) = \max\{0, (1-\delta)^{-1}(v-b)\}$. On the other hand, if the buyer decides to switch at posted prices b and higher, the value function is defined recursively by $V_s(b,v) = -C + (1-\delta)^{-1}\int_0^b (v - q)dG(q) + \int_b^v (v-q)dG(q) + \delta(1-G(b))V_s(b,v)$. The last two terms account for the fact that the buyer will switch again if the best price in the sample is above b. Collecting the terms in V we get

$$(1-\delta+\delta G(b))V_s(b,v) = -C + (1-\delta)^{-1}\int_0^b (v-q)dG(q) + \int_b^v (v-q)dG(q). \quad (7)$$

The key to the first part of the proposition is to demonstrate that $V_r \geq 0 \geq V_s$ for all $v \leq v_o$. $V_r \geq 0$ is immediate from its definition, but it is a bit trickier to show that $0 \geq V_s(b,v)$ no matter how b is chosen, if v is sufficiently small. Note that $\inf_v \sup_b [V_s(b,v) \geq 0] = \inf_v [V_s(v,v) \geq 0]$, because RHS, the right hand side of (7), is maximized at $b = v$ for any $\delta < 1$ (and the left hand side is zero at the relevant point). Thus v_o is defined by the equation $0 = \text{RHS}|_{[b=v]} = -C + (1-\delta)^{-1}\phi(v,G)$. Using Proposition 1 item 5, we conclude that $0 \geq V_s(b,v)$ for all $v \leq v_o = \phi^{-1}((1-\delta)C|G)$, and that $v_o \geq p_o$.

Now consider the function $R(b,v) = (1-\delta)(1-\delta+\delta G(b))(V_s - V_r) = (1 - \delta + \delta G(b))(v-b) + (1-\delta)C - \int_0^b (v-q)dG(q) - (1-\delta)\int_b^v (v-q)dG(q)$, defined for $v > b, v_o$. By direct computation in the case G has a density g, we find $\partial R/\partial b = -(1-\delta+\delta G(b)) + \delta g(b)(v-b) - g(b)(v-b) + (1-\delta)g(b)(v-b) = -(1-\delta+\delta G(b)) < 0$. Hence for fixed v the function R is strictly decreasing in b, and the same conclusion follows from a limiting argument when G has a mass point (discontinuity) at b. Note that $R(v,v) = (1-\delta)C - \phi(v|G) < 0$ for $v > v_o$, since the expression is 0 for $v = v_o$ and ϕ is increasing by item 3 of the previous proposition. On the other hand, $R(0,v) = (1-\delta)(v + C - \phi(v|G)) \geq (1-\delta)C > 0$, where the first inequality uses item 7 of Proposition 1. Hence by the intermediate value theorem there is a unique $b^* = B(v,...)$ between 0 and v such that $R(b^*,v) = 0$. In other words, the reservation price function $B(v,...)$ is defined implicitly by the relation $R(b,v) = 0$.

One can now check directly that $\lim_{v \downarrow v_o} B(v) = v_o$, completing the proof of items 1 and 2. Note that $\partial R/\partial b = (1-\delta+\delta G(b)) - G(b) - (1-\delta)(G(b) - G(v)) = (1-\delta)(1-G(v))$. The key remaining step is to implicitly differentiate the relation $R(b,v) = 0$, to obtain

$$\partial B/\partial v = -\frac{\partial R/\partial v}{\partial R/\partial b} = (1-G(v))/(1+\beta G(B(v)), \quad (8)$$

where $\beta = \delta/(1-\delta)$. This differential equation, with boundary value $B(v_o) = v_o$, defines the reservation value. The RHS of (8) is easily seen to be continuous, non-negative, decreasing and bounded above by 1, and the numerator is 0 for $v > p_1$, so the rest of the proposition follows. $\square$

Several comments are in order.

- The proposition states that very low WTP buyers optimally will never switch. The intuition simply is that rational switching requires that the expected gross profit $\phi(v|G)$ must exceed the amortized switch cost $(1-\delta)C$, which is not possible when v is near the lowest possible price p_o.

- The main part of the proposition states that for buyers with midrange WTP ($v \in (v_o, p_1)$), a buyer with higher WTP will tolerate somewhat higher prices from his seller than will a buyer with lower WTP. The intuition is that a buyer who switches may get a very bad draw and not buy at all in the current period. An increase in the buyer's WTP increases the opportunity cost of a bad draw and so increases the switch threshold b.

- With recall of the currently attached seller, the intuition and results are qualitatively the same although slightly more complicated. The analogue of equation (8) has the extra term $(F(v) - F(b)) \geq 0$ in the denominator, so the reservation price function lies below the no-recall version for $v > v_o$.

- The differential equation (8) is more complicated than it seems. The function B has an inverse g over the relevant interval, whose derivative is the reciprocal of the derivative of B. In the deterministic equilibrium discussed below, $N = 1$ and we can write $G(p) = F(p) = g(p) - v_o$. It therefore appears that the differential equation can be rewritten as $dg/dv = (1 + \beta F(B(v))/(1 - F(v)) = (1+\beta(v-v_o))/(1+v_o-g(v))$. Straightforward manipulations yield the analytic solution $g(v) = 1 + v_o - \sqrt{1 - 2(v-v_o) - \beta(v-v_o)^2}$ given the initial condition $g(v_o) = v_o$. Unfortunately, the derivative dg/dv on the left hand side of the rewritten equation is evaluated at $b = B(v) = g^{-1}(v)$ rather than at v as the analytic solution presumes. Therefore the equation is a differential-delay equation rather than an ordinary differential equation. The proposition ensures that a unique solution exists but we do not know how to write it in closed form.

- Part 4 of the proposition ensures that the reservation price function has a well defined inverse $B^{-1} : [v_o, B(v_u)] \to [v_o, p_1]$. The distribution of reservation prices now can be written as $H(b) = 0$ for $b < v_o$, $= A(B^{-1}(b)) - A(v_o)$ for $v \in [v_o, B(\infty)]$, and $= 1 - A(v_o)$ if $v \in [B(\infty), \infty)$.

- The conditional distribution for buyers remaining attached to a given seller posting price p is the trucation at p, viz, $H(b|p) = H(b)/H(p)$ if $b \leq p$ and $=$ 1 otherwise. This result uses the simplification that all sellers know nothing about the customer base except its size.

- If the initial assignment of buyers to sellers is independent of the sellers' posted price, then the fraction of buyers who switch is $\gamma = 1 - \int_0^\infty H(p)dF(p)$. With no changes in sellers' posted prices or buyers' values, over time the buyers' values become more correlated with sellers' posted prices, $H(p)$ converges to $H(p|p) = 1$, and γ converges to 0.

- What if the distribution F is constant but individual sellers' prices adjust as their costs change according to equation (1b)? In this case we can no longer write $V_r = \max\{0, (1-\delta)^{-1}(v-b)\}$, but the $V_r = V_s$ condition still defines a reservation price with the same basic properties as before. The analogue of equation (8) turns out to be

$$dB/dv = (1 - G(v))/(1 - \delta E[(\partial V/\partial p)(\partial p'/\partial p))]. \tag{9}$$

  The qualitative properties of B remain the same but details of the transition from p to p' determine the exact results. The expectation in the denominator is negative for any reasonable specification of the transition (because $\partial V/\partial p < 0$), so the denominator is > 1 and the slope of B therefore is still bounded between 0 and 1. The exact expression for v_o is different, but otherwise the properties listed in the proposition still are valid.

We now turn to attachment dynamics. If the sample size is $N = 2$ then a seller with i attached customers who posts price p will end up with j customers with probability

$$m_{ij}(p) = \begin{cases} \sum_{k=0}^{i} \binom{i}{k} (1-H(p))^k H(p)^{i-k} \binom{2\gamma S}{k+i-j} (1-F(p))^{k+i-j} F(p)^{2\gamma S+j-i-k} & \text{if } i \leq j \\ \sum_{k=0}^{j} \binom{i}{k+i-j} (1-H(p))^{k+i-j} H(p)^{j-k} \binom{2\gamma S}{k} (1-F(p))^k F(p)^{2\gamma S-k} & \text{if } j < i \end{cases} \tag{10}$$

for $0 \leq i, j \leq \bar{n}$.

In (10) the parameter $S = I/J$ is the number of buyers per seller and γ is the fraction of buyers who switch. Hence with sample size $N = 2$, the expression $2\gamma S$ is the number of unattached buyers who sample a given seller's price. The expression is exact in a balanced random sampling process without replacement; in an iid sample it is just the expected number of buyers who sample. For sample size $N > 2$ the expression is simply $N\gamma S$; of course, one also replaces $F(p)$ by $1-(1-F(p))^{N-1}$ in the compound binomial formulas.

The rather messy formulas have straightforward interpretations. The probability that a seller with i attached buyers will end up with $j > i$ attached buyers is the probability that the number of new attachments exceeds the number of exits by $j-i$. This probability is the sum of the probability of exactly $k+j-i$ new attachments and k exits, where k ranges from 0 to the maximum possible number of exits, i. The probability of exactly k exits is the usual binomial expression built from the probability $H(p)$ that an attached buyer will not exit.[3] The probability of exactly $k+j-i$ new attachments is a binomial expression built from the probability $F(p)$ that a buyer from the switch pool will find that the given seller's price is higher than the alternative. There is a parallel interpretation of the formula for $j < i$.

The transition function for the seller's state variable (c, n) now can be expressed in terms of generic pdf's as follows.

$$f(c', n'|c, n) = f(c'|c) m_{nn'}(P(c, n)), \tag{11}$$

where the cost transition $f(c'|c)$ is described in equation (1) and the matrix component $m_{nn'}$ from (10) is evaluated at $p = P(c, n)$. We now derive the pricing function P.

Proposition 3 *Let the cost c, the discount factor $\delta \leq 1$, the reservation price distribution H, and the posted price distribution F be given and constant. Then*

1. *Then there is a unique posted price $p = P(c, n; \delta, F, H) \in (0, \infty]$ that maximizes the seller's value function W in (2);*
2. *$P(c, n; \delta, F, H)$ is differentiable and increasing in c and increasing in increasing in n; and*
3. *The state transition is described by (10) and (11) above.*

Proof: Details are suppressed, but the basic argument follows. The state transition formulas (10) and (11) define $Q = E(n'|p, n)$. Ignoring a seemingly inessential

[3] This expression has generalized binomial coefficents calculated using the gamma function. It assumes that attached buyers have the same distribution of reservation prices as does the buyer population as a whole. The next to last bulleted remark above indicates the sort of modifications needed when buyers have time to sort themselves out. In the deterministic equilibrium below we replace $H(p)$ by $H(p|p) = 1$ and have $\gamma = 0$ so M becomes the identity matrix.

Jensen's inequality problem and abusing notation slightly, we can rewrite (2) as the deterministic functional equation $W = (p-c)Q + \delta W(c, Q)$. Using subscripts to denote partial derivatives, write the FOC as $0 = Q(p, n) + (p-c)Q_p + \delta W_Q Q_p$. Implicitly differentiating in c we get

$$P_c = (1 - \delta W_{cQ})/(1 + (Q_{pp}/Q_p)(p - c + \delta W_Q)). \quad (12)$$

The first part of item 2 follws from assuming (and later checking) that $W_Q > 0$ and $W_{cQ} \leq 0$, while $Q_p < 0$ and dominates Q_{pp} in absolute value, so both numerator and denominator of (12) are positive. The second part of item 2 follows from a similar implicit differentiation in n. Item 1 is proved using similar reasoning as in the previous proposition. Item 3 is a straightforward check. □

3 Equilibrium

Of course, the distributions H and F are not exogenous, but rather adjust endogenously as buyers and sellers respond to each other. We focus here on competitive equilibrium, in which no agent needs to account for how his actions affect the other side of the market.[4] Thus we have no real problem with the exogeneity assumed in the previous section, but still need to impose mutual consistency on H and F.

First consider the constant cost case in (1a). We seek a deterministic equilibrium where sellers don't change price and buyers don't switch. Let $J(c)$ represent the CDF of seller cost and define the general indicator function $\mathbf{1}_Z(x)$ as 1 when x satisfies condition Z and as 0 otherwise. Let $a(n)$ be the fraction of the J sellers who have exactly n buyers attached, $n = 0, ..., \bar{n} \leq \infty$ and let $\mathbf{a}$ be the vector of these market shares.

Definition: Given cost and value distributions $J(c)$ and $A(v)$, a deterministic steady state equilibrium (DSSE) is a pricing rule $P(c, n)$, a reservation price function $B(v)$ and a distribution of buyer-seller attachments with market shares $\mathbf{a}$ such that

1. $F(p) = \sum_0^{\bar{n}} a(n) \int \mathbf{1}_{[P(c,n) \leq p]}(c, n) dJ(c)$ is the induced distribution of posted prices;
2. $H(b) = \int_0^\infty \mathbf{1}_{[B(v) \leq b]}(v) dA(v)$ is the induced distribution of reservation prices;

[4]Conceptually a Bertrand-Nash equilibrium is not that much more complicated. For instance, each seller takes as exogenous the distribution of other sellers' prices but exploits his ability to influence the distribution F to which buyers respond. It is our impression that such strategic behavior is unimportant in our markets so we don't pursue the idea here.

3. $p = P(c, n)$ maximizes W in equation (2) with $c' = c$ and $n' = n$;[5]

4. $b = B(v)$ in rule (5) maximizes V in equation (3) given $p' = p$ and $F(p) = F(p'|p)$; and

5. $\sum_0^{\bar{n}} na_n = S \int \mathbf{1}_{[p_{j(v)} \leq v]}(v) dA(v) \leq S$ and $\gamma = 0$.

That is, given the exogenous constant cost and value distributions, in DSSE the distributions of posted and reservation prices reproduce themselves, all buyers and sellers maximize, supply equals demand and nobody switches.

When does DSSE exist? For simplicity, suppose for the moment that $A(v)$ and $J(c)$ both are uniformly distributed on [0, 1]. We first consider the possibility of a uniform price equilibrium at some price p^*, i.e., $F(p) = 1$ if $p \geq p^*$ and $= 0$ otherwise. Then the gross gain to switching is $\phi(v, F) = \max\ \{v - p^*, 0\}$, and $B(v, F) = p^* + (1 - \delta)C = v_o$ for $v \geq v_o$ and as usual $B(v, F) = \infty$ for $v < v_o$. Hence H is a step function with mass $1 - v_o$ at v_o and mass v_o at ∞. Thus if $C > 0$ and $\delta < 1$ then every active customer has a reservation price v_o strictly above p^*. This is consistent with the $\gamma = 0$ condition of DSSE but is inconsistent with seller maximization – some or all sellers have the incentive to raise price by $(1 - \delta)C$ as in the Diamond (1973) equilibrium. But here there is no monopoly price to halt the upward ratchet of price. Hence no uniform price DSSE exists. The argument is a bit messier but still goes through with continuous but not necessarily uniform value and cost distributions.

We now elaborate the dispersed price DSSE suggested earlier. Suppose for simplicity that $S = 1$ and that switchers sample only one new price when they search, so N=1 and $G(p) = F(p)$. Consider an assortive 1:1 match of buyers and sellers with $b = p$, i.e. $B(v) = P(c, 1)$, in every buyer-seller pair. We continue to assume that v is uniformly distributed on [0, 1] and to write $B^{-1}(b) = g(b)$. Then $H(b) =$ fraction of buyers with reservation price $\leq b$ =fraction of buyers with WTP $\leq g(b)$ $= A(g(b)) - A(v_o) = g(b) - v_o$. Of course we also have $H(b) = F(p) =$ fraction of sellers with posted price $\leq p = b$. Hence $G(p) = F(p) = g(p) - v_o$ as claimed earlier, and as explained there, the differential-delay equation describing the distributions can be rewritten as $dg(B(v))/db = (1 + \beta(v - v_o))/(1 + v_o - g(v))$ with initial condition $g(v_o) = v_o$, where $v_o = \phi^{-1}((1 - \delta)C|F)$. One uses the contraction map fixed point theorem to prove there is a unique solution g to the equation, hence unique distributions F and G.

[5]The constancy of c is assumed because otherwise there is an essential stochastic component. The constancy of n is a special case of (10) with $\gamma = 0$.

The resulting families of DSSE can be described as follows. Buyers with low WTP (viz, $v \leq v_o$) are either inactive or are matched with even lower cost sellers who extract all the surplus by charging $p = v$. The other buyers are matched with sellers who charge their reservation price, leaving them the surplus $v - B(v) > 0$. As long as the seller cost distribution is stochastically dominated by H (which is dominated in turn by the uniform distribution A) then all sellers can find a customer in DSSE. In this case, there is a unique DSSE with everyone active and with assortive matching, viz, the k^{th} percentile buyer is the customer of the k^{th} percentile seller for all k. There are continua of slightly different DSSE with the same distributions but with buyer-seller matches scrambled subject to the constraint that the seller posting price p has cost $c \leq p$. And there are other DSSE (with slightly different v_o and $F = G = H$) in which some high cost sellers and low WTP buyers are inactive. It seems clear that similar but messier families of DSSE could be found after relaxing the simplifying assumptions of uniform distributions, $N = 1$, $S = 1$, and $a(0) + a(1) = 1$.

The intuition for these families of DSSE is clear. Sellers can't attract additional customers (because the switch pool is empty) so they charge the highest possible price their customer will bear, v for low WTP buyers or b for the rest. The lowest price sellers don't increase price because their customers would become inactive, and the higher price sellers don't increase price because their customers would find it worthwhile to switch.

Now consider stochastic costs. The random walk specification (1c) doesn't permit a steady state distribution that in any sense is competitive, because over time the expected gap between costs of different sellers grows without bound. More promising is the autoregressive specification (1b), $\ln c_{jt+1} = \eta + \alpha \ln c_{jt} + e_{jt}$, with $0 < \alpha < 1$. If e is iid Normal with mean 0 and variance σ^2 then it is easy to check that in the unique steady state distribution $J^*(c; \alpha, \eta, \sigma)$, the log cost is Normal with mean $\eta/(1-\alpha)$ and variance $\sigma^2/(1-\alpha^2)$. Notice that some active sellers each period will find that their costs have increased so much that it is no longer profitable to serve all their attached customers, and other sellers will find that their costs have decreased so much that it is worthwhile to try to attract new customers. Hence we look for equilibria with $\gamma > 0$ and with nontrivial pricing functions $P(c, n)$ that depend on n as well as c.

In steady state, the cost distribution reproduces itself, distributions of posted and reservation prices reproduce themselves, and all buyers and sellers maximize given the cost and value distributions. The definition is complicated by the fact that the distributions of n and c (and the value of γ) are jointly determined. Write the joint cdf $\mathcal{J}(c, n) = \Pr[\text{cost} \leq c \ \& \ \#\text{customers} \leq n]$ and write the conditional joint cdf $\mathcal{J}(c', n'|c, n)$ for current seller state (c', n') conditioned on last period's actual state

(c, n). Self-reproduction of the sellers' joint distribution then can be written generally as

$$\mathcal{J}(c, n) = \sum_{k=0}^{\bar{n}} \int_{x=0}^{\infty} \mathcal{J}(c, n|x, k) d\mathcal{J}(x, k). \tag{13}$$

The definition of stochastic steady state will specialize this general formula using (11) and the autoregressive cost specification (1b). It must account for the distribution of attachments $\mathbf{a}$, and will refer to the conditional posted price distribution $F(p'|p) = \Pr[\text{current posted price} \le p' \text{ given that previous posted price} = p]$. Self reproduction of $\mathcal{J}(c, n)$ and use of a consistent pricing rule $P(c, n)$ ensures that $F(p) = \int F(p|x)dF(x)$, i.e., F also reproduces itself.

Definition: Given constant value distribution $A(v)$, steady state cost distribution $J^*(c)$, and transition rule $\mathcal{J}(c', n'|c, n)$ consistent with (11) and (10), a stochastic steady state equilibrium (SSSE) is a pricing rule $P(c, n)$, a reservation price function $B(v)$ and a distribution of buyer-seller attachments with market shares $\mathbf{a}$ such that there is a joint conditional distribution $\mathcal{J}^*(c, n)$ with the given marginals $J^*(c) = \mathcal{J}^*(c, \bar{n})$ and $a_n = \mathcal{J}^*(\infty, n) - \mathcal{J}^*(\infty, n-1)$, and

1. $F(p) = \sum_0^{\bar{n}} a(n) \int \mathbf{1}_{[P(c,n) \le p]} dJ^*(c)$ is the induced distribution of posted prices;
2. $H(b) = \int_0^{\infty} \mathbf{1}_{[B(v) \le b]} dA(v)$ is the induced distribution of reservation prices;
3. $p = P(c, n)$ maximizes W in equation (2) given F, H and $\mathcal{J}(c', n'|c, n)$;
4. $b = B(v)$ in rule (5) maximizes V in equation (3) given the distribution of alternative prices $F(p)$ and the attached seller's transition rule $p' = p$ induced by $\mathcal{J}(c', n'|c, n)$ and pricing rule P;
5. $\mathcal{J}^*$ reproduces itself in (13) as applied to $\mathcal{J}(c', n'|c, n)$; and
6. $\sum_0^{\bar{n}} n a_n = S \int \mathbf{1}_{[p_{j(i)} \le v_i]}(v_i) dA(v_i) \le S$ and $\gamma = 1 - \int_0^{\infty} \int_0^{\infty} H(p'|p) F(dp'|p) F(dp) > 0$.

Much work remains. What conditions ensure that SSSE exists? or that the pricing rule is sticky at the individual seller level (i.e., P_c ¡1) or market level? What can be said about the equilibrium distributions of reservation prices and posted prices? How does the analysis change if sellers (say) act as Bertrand-Nash competitors? We hope that future work by ourselves and others will answer such questions.

Figure A1: Model Elements

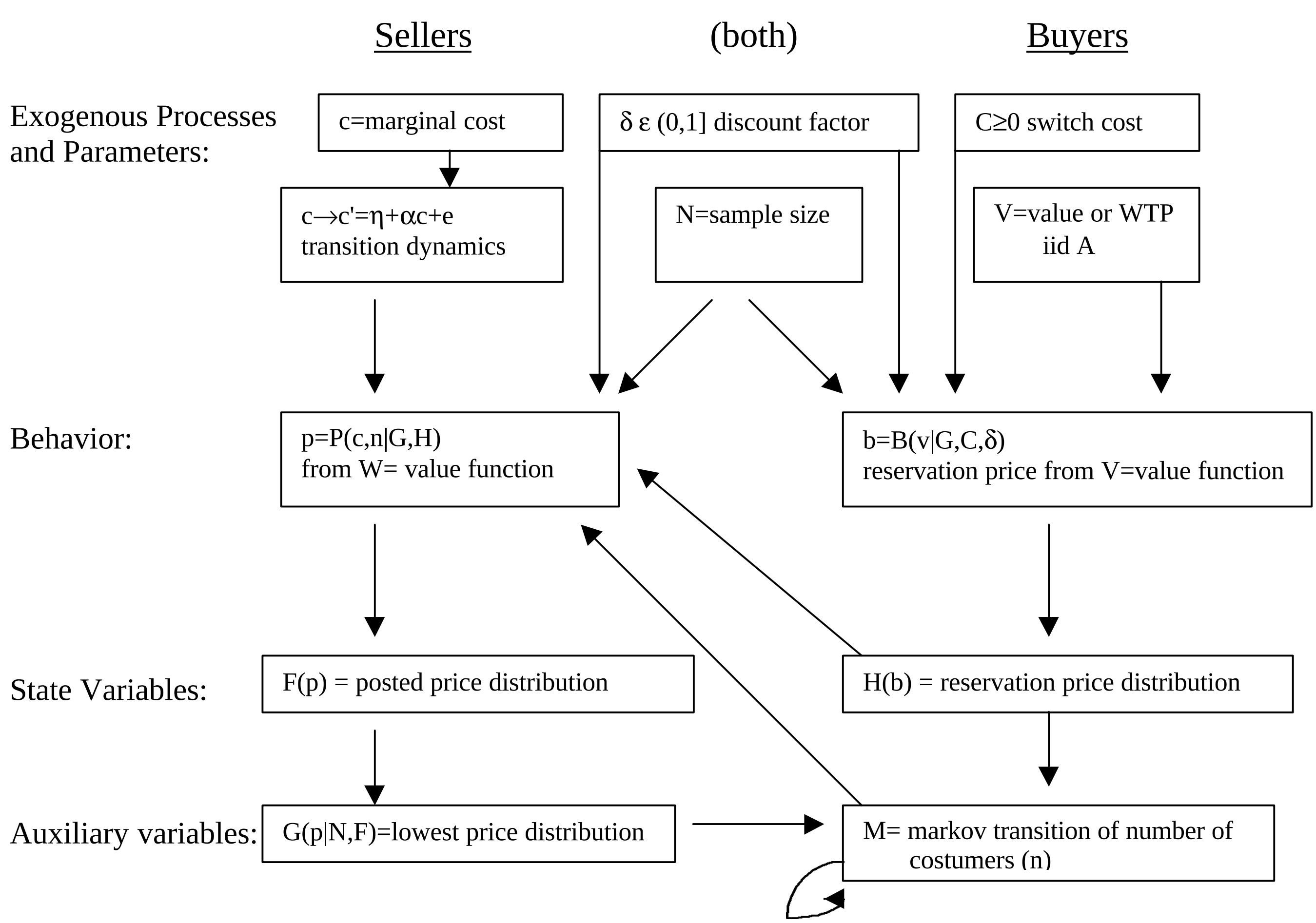
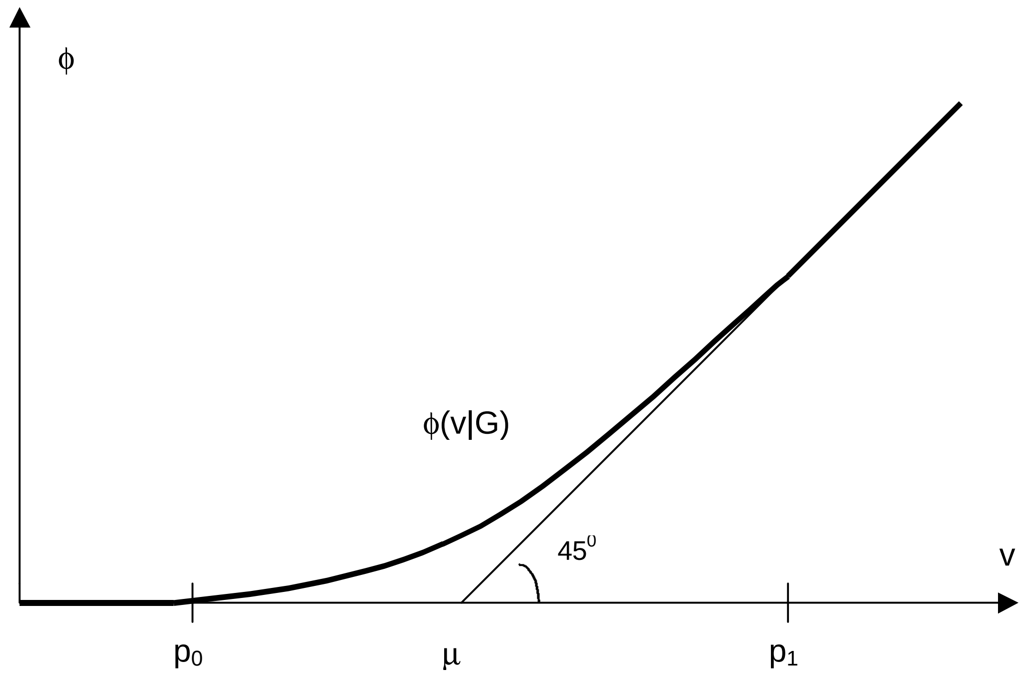


Figure A2: The Convolved Wedge



The expected gross profit function ϕ is the convolution of the wedge function max{0,v} with the distribution function G of lowest sample price.

APPENDIX C—SUPPLEMENTARY DETAILS FOR BUYER SWITCH (TABLE 6) AND SELLER PRICE (TABLE 7) MODELS

Discouraged Buyers

To identify the discouraged buyers, we fit a gamma distribution to the observed minimum prices for that session to obtain an empirical distribution *G* and then numerically integrate $\int_0^v (v-q)dG(q)$ to estimate the expected gross profit from switching. We classified buyers as discouraged when this estimate was smaller than the amortized switch cost (1-*d*)*C*. As explained earlier, the discount factor *d* is approximated by *T*/(2+*T*), where *T* is the number of periods remaining in a 25 period run.

This procedure yields 312 discouraged out of 6590 total buyer-periods with positive switch costs (4.7 percent), mainly *v*=\$2.00 buyers in the final 2-9 periods and *v*=\$2.25 buyers in the final 1-2 periods in the high switch cost (*C*=\$0.50) sessions, plus a few *v*=\$2.00 buyers in *C*=\$0.20 sessions. Small idiosyncrasies theoretically would drastically alter buyer behavior near the discouragement threshold, so we also present alternative estimates excluding 418 buyer-periods that are within 5 periods of the discouraged periods' range. We also checked 2-period and 10-period cushions but found no real difference from the 5-period cushion.

"Discouraged" buyers do occasionally switch. Their switch rate is about 5.7% overall and 5.6% when experienced, or very roughly half of the rate for nondiscouraged. A behavioral explanation is boredom: discouraged buyers typically can't profit by transacting with the current seller and may feel the desire to do *something* even when it is not likely to be profitable.

The Price Distribution *F*

A final implementation issue for the Table 6 regressions is how to control for shifts across sessions in the price distribution *F*. The distribution is endogenous, so we use an instrumental variables approach. Each session we find parameters of the gamma distribution that best fit the posted prices, and then regress these parameters on the exogenous session treatment variables. The fitted (predicted) gamma parameters each session imply a mean and variance for *F*, which are included as instruments in the Table 6 models.

Most of the other explanatory variables in Table 6 (as well as the seller price model in Table 7) are truly exogenous, since they are experimenter-controlled treatments. Two are endogenous but predetermined: the previous period median price or the number of periods since the last switch. For the sake of completeness we also considered an instrumental variables approach for the predetermined variables but we were unable to find a set of reliable instruments. Fortunately we had better luck where it matters, in instrumenting the contemporary endogenous price distribution.

Buyer and Seller Model Robustness Checks

We checked the robustness of the buyer switch model results (Table 6) to including all buyers ("discouraged" or not), to replacing the discount factor proxy $T/(2+T)$ by T, and to interacting switch cost dummies with experience dummies and with information dummies. Nothing of substance changed, except that the coefficient with the wrong sign according to BH6 became insignificant when we included interactions for switch cost and information dummy variables. The interactions between switch cost and experience also reconcile an apparent discrepancy between Table 6 and Figure 8; in particular, this interaction indicates that higher switch costs lead to lower switch rates only in the inexperienced sessions, consistent with Figure 8.

We also checked the robustness of the seller price model (Table 7) with respect to alternative specifications. The most informative results again came from interacting switch costs with information dummies. The estimates indicate that sellers post roughly the same prices for all switch cost treatments in the full interim information treatment (coefficient estimates are less than 23 cents and at best marginally significant) but post prices 73 cents above baseline with high search cost and 53 cents above baseline with low search cost (both very significant) when there is no interim information. An interpretation is that the reverse effect in SH7 (buyers with little price information are less price elastic and sellers exploit this) dominates and tends to overshadow the predicted SH5 effect of switch cost.