Oligopoly Competition in Fixed Cost Environments

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Abstract

Many industries with avoidable fixed costs face competitive price instability problems in an attempt to maintain profitability. We designed an experimental environment where profitability is eroded by the addition of sunk and avoidable fixed costs. While we cannot reject the hypothesis that sunk fixed costs have no effect on prices, we observe a pattern of price signaling and responses which maintain above normal profits. This success implies that a firm does not have to exit such an industry in order to avoid loses, and may help to explain why some competitive industries appear to maintain an inefficient number of firms.

Keywords. Industrial Organization, Fixed Cost, Experimental Economics

JEL Classifications. L11, C92

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1 Introduction

Traditional economic theory tells a story about the ballistics of firm entry and exit in response to profits and losses normalized in relation to the market opportunity costs of the firm, (see *e.g.* Smith (1974)). The research reported in this paper began with the following question: in oligopolistic industries if firms are making losses are there alternative strategies, besides exit or explicit price collusion, that firms might pursue to avoid losses? In addressing this question we were aware that the standard story is complicated by two distinct concepts of fixed cost: traditional sunk costs and avoidable fixed cost. Hence, we wanted to include both sunk and avoidable fixed cost parameters in our study of the dynamics of price competition[1] in oligopoly behavior. In this study, however, we do not independently vary the two kinds of fixed cost. Instead, holding constant the non-cooperative equilibrium, we vary the slope of the linear demand, affording different potential rewards to firm attempts to coordinate a price increase.

Many industries with substantial avoidable fixed costs face competitive price instability problems in an attempt to maintain normal profitability. In transportation industries most of the direct cost is independent of the cargo transported, but can be avoided if the trip is canceled. For example, adding passengers to an airline flight may increase cost somewhat, but most of the cost is for fuel and crew, and can be avoided by not flying. Similarly, electric power generators incur an avoidable fixed cost just to maintain spinning readiness to generate power. Large fixed costs often involve non-fungible capital, making exit a costly strategy so that firms avoid it and favor other strategies. For example, the airline industry has been very innovative in designing fare structures that impose penalties on discounted tickets if the holder cancels or changes her flight plan leaving the airline with empty seats on the flight. Recently, some airlines are offering no-refund tickets and $100 change fees. Such penalties enable the airline to recover some of their fixed flight costs. Yet in spite of these adaptive pricing policies, the industry has been plagued by losses precipitated by the competition to fill seats.

Telser's (1988) analysis and illustration of allocation problems created by the existence of avoidable fixed costs, in which the core is empty, has

[1] We use the terms competition and competitive to refer to rivalry among the firms participating in the market, this is a behavioral definition (see S. Martin (2003), for a discussion of the term competition). We use the term competitive price to refer to the price that clears the market.

inspired experimental market studies designed to investigate these demanding environments. Van Boening and Wilcox (1996) developed an avoidable cost experimental design, in which the double auction institution—long known for its capacity to produce efficient competitive outcomes in stressful environments—does not converge to an efficient allocation. In their discrete cost environment, any market tendency to converge to a uniform "competitive" price allows inefficient higher cost suppliers to displace an efficient lower cost firm. This is because an efficient firm with high avoidable fixed costs requires a larger volume of sales than an inefficient firm to be profitable. At the competitive prices that would maintain this high volume, an inefficient smaller firm can enter profitably and impose losses on the more efficient firm.

Durham *et al.* (1996) have proposed a computer assisted two-part pricing mechanism in which firms can charge a vendor's fee in addition to posting unit prices and quantities as a potential means of overcoming the allocation problems that arise in these avoidable fixed cost environments. The vendor's fee, which must be paid by simulated fully revealing buyers before units can be purchased, provides a means whereby avoidable costs can be covered before units are committed for sale. (An alternative mechanism would allow firms to specify a minimum as well as a maximum purchase volume.) The posted-offer/vendor-fee experiments reported by Durham *et al.* (1996) yield improved but not ideal results. While the experiments achieve long sequences of efficient allocations, those outcomes yielded to episodes of instability. The results converge to more efficient levels than in the double auction experiments reported by Van Boening and Wilcox. However, the two sets of experiments are not comparable in terms of experience and number of periods. The Durham *et al.* experiments used much longer time sequences of repeat play than those of Van Boening and Wilcox, and generally, more repeated play results in more efficient outcomes in experimental double auction markets.

In a recent paper, Offerman and Potters (2002) examine the effect of entry fees on prices when two subjects are chosen from a group of four subjects to act as firms. They provide marginal evidence for an effect of a fixed entry fee (the fee is paid only once per five market periods). The potential for losses was not discernible from the paper. In Buchheit and Feltovich (2000) subjects play a repeated two-person Bertrand-Edgeworth game, with demand and costs similar to Kruse *et al.*. Subjects incurred a sunk (unavoidable) cost. They find that sunk costs have a non-monotonic effect on prices, which appear to decrease with time.

In this paper, the motivation parallels Van Boening and Wilcox, and

Durham *et al.*, except that we compare a traditional variable cost environment with one in which both sunk and avoidable fixed costs are added to the variable costs. A traditional environment is designed to provide a well defined (risk neutral) pure strategy equilibrium, which is profitable to each of five symmetric firms, while the profitability is eroded by the addition of sunk and avoidable fixed costs in the second environment. In fact, any tendency to minimize losses by converging to the competitive-Nash price of the traditional environment produces losses in the fixed cost environment. Because of the sunk fixed costs, these losses can only be partially reduced by producing nothing.

2 Environment

In each experimental session, five subjects are recruited, each to represent one of five firms with identical cost structures. The subjects were undergraduates at the University of Arizona. The experiments were run in 1992 and the average payoff was $20.25. Firms incur three kinds of costs in each period: (1) sunk cost (called “unavoidable” fixed cost in the instructions), (2) avoidable fixed cost (called “starting” cost in the instructions), and (3) variable cost in discrete marginal form. Two different cost treatments are studied. In the first treatment, categories (1) and (2) of fixed cost are each zero. In the second, each firm has a sunk fixed cost of 150 and an avoidable fixed cost of 220. The marginal unit cost conditions are the same in both treatments: each firm can produce 100 units at a cost of 4 per unit, 100 additional units at cost 4.5 per unit, and 100 at a cost of 5 per unit. Two different demand treatments are studied: demand L_e, $p = 17 - 0.01q$, and demand H_e, $p = 11.6 - 0.0055q$, where $(p, q) =$ (price, quantity). Demand L_e has a lower (steeper demand curve) price elasticity than demand H_e at the equilibrium price (which is the same for both demand curves). The two demand curves provide a comparison between one environment (Demand L_e) where it is easier to raise prices without a large loss in quantity sold and another environment (Demand He) where prices can be raised only with a large loss in quantity sold.

Simulated buyers are programmed to reveal demand. Units are chosen at random, without replacement, from the aggregate demand and allocated to 114 buyers consisting of 100 small buyers and 14 large buyers. The large buyer has five times as many units as a small buyer. In demand condition

	Inelastic Demand		Elastic Demand	
	Once Experienced	Twice Experienced	Once Experienced	Twice Experienced
Seller Cost	$13.50 Endowment	$0 Endowment	$13.50 Endowment	$0 Endowment
No Fixed	5(60)	4(80)	4(60)	4(50)
Fixed	4(60)	3(80)	3(60)	3(80)
Total	9	7	7	7

Table 1: *The number of sessions and trading periods (in parenthesis) per session by treatment condition. The total number of sessions is 30.*

L_e small buyers demand a maximum of 10 units (*i.e.* at a zero price) and large buyers demand a maximum of 50 units.[2] In demand condition H_e small buyers demand a maximum of 12 units and large buyers demand a maximum of 60 units.

The environment was sufficiently complex that we trained subjects in ten period experiments. We then brought them back in groups that were once-experienced to participate in experiments that were run for 60 periods. These twice-experienced subjects were then asked to return for a third time to participate in a set of 80 period experiments (except for the twice-experienced, no sunk cost, elastic demand sessions, which had 50 periods per session[3]). The cost parameters remained unchanged for all levels of experience, but subject groups were not constrained to remain of identical composition for all experience levels. Because the likelihood of losses was high, especially for the trainers (the first ten period sessions), subjects received initial endowments of $5.00 working capital in the trainer, $13.50 in the once-experienced sessions, but no endowment in the twice-experienced sessions.

The two levels of subject experience, two demand levels, and two cost treatments forms a $2 \times 2 \times 2$ design. Table 1 summarizes the parameters of

[2]The software makes provision for markets in which human buyers can be added, and the matching of buyers and firms can be assisted by a smart market center which maximizes surplus. Although Durham *et al.* (1996) makes use of the smart market features, the provision for human buyers has not yet been implemented in the software. When it is, one could run experiments with, say, 5 human buyers and 100 simulated small buyers.

[3]The number of periods was reduced to alleviate the boredom for 80 identical periods. The statistical analysis accounts for the different number of periods.

the environment and lists the number of experiments (and number of trading periods) for each of the 8 treatment cells. The periods in the once-experienced subject groups lasted 75 seconds, and the periods in the twice-experienced subject groups lasted 45 seconds. We reduced the length of the periods in the twice-experienced groups because in the earlier experiments there was substantial "dead" time between the last offer and the end of the period.

3 Institution

At the beginning of each trading period, each firm independently chooses a price and quantity (p_i, q_i). Simulated buyers are chosen in random order without replacement and each buyer purchases all units demanded at the lowest price quoted among the active firms in the current state of the market. If that firm's supply is inadequate to satisfy the buyer's demand, the buyer purchases from the remaining firm with the lowest price. If two or more firms quote tied prices, the buyer is randomly allocated to one of these firms. These procedures are identical to the computerized, posted offer market (see Ketcham, Smith, Williams (1984)). We now discuss the procedures that differ from this standard market.

If a subject does not choose a new (p_i, q_i) in the allotted time then the choice from the previous period is automatically used. The screen display for the interactive program is shown in Figure 1. The three types of costs and their parametric values for a given subject appear in the upper left-hand window of the subject's screen. The subject's choice of price and quantity are entered into the top center *offer* window on the screen, *eg.*, $(p_A, q_A) = (6.03, 300)$. At the end of each period, the *income statement* window in the upper right hand corner reports sales revenue less starting cost less variable cost to determine net revenue. From the latter is subtracted sunk (unavoidable fixed) cost to yield the bottom line profit. Also, at the end of each period, the price offered by each firm is reported in the center-screen *results* display. Privately, each firm is informed how many units it sold, the number of buyers and its own profit.[4]

[4]As is well known from experimental comparisons, Nash and competitive equilibria have their best chance of being achieved under private, not complete, information on the environment. The software program, however, enables the experimenter to initialize experiments at whatever level of complete information that is desired (see Figure 1, in the *results* window).

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┌─────── COSTS ────────┐ ┌──────── OFFER ────────┐ ┌──── INCOME STATEMENT ───┐
│ Unavoid. Cost: 220   │ │                       │ │                         │
│ Starting Cost: 150   │ │                       │ │ sales revenue    1800   │
│                      │ │                       │ │ starting cost -   150   │
│ Variable Cost:       │ │ Number of Units: 300  │ │ variable cost -  1350   │
│  Units   Cost per Unit│ │                       │ │-------------------------│
│   1-100       4.00   │ │      Unit Price: 6.03 │ │   net revenue     300   │
│ 101-200       4.50   │ │                       │ │ unavoid. Cost -   220   │
│ 201-300       5.00   │ │ The offer is confirmed.│ │        Profit      80   │
└──────────────────────┘ └───────────────────────┘ └─────────────────────────┘
  SELLER A        Period:  3          Capital:   160          Clock: 32
   ┌ Period  2 Results──── A ─────── B ─────── C ─────── D ─────── E ──┐
   │                                                                   │
   │    PRICE OFFERED│    6.00      6.10      6.01      6.08      6.05  │
   │    UNITS OFFERED│     300                                         │
   │       UNITS SOLD│     300                                         │
   │ NUMBER OF BUYERS│      29                                         │
   │    PERIOD PROFIT│      80                                         │
   └  Previous: PgDn  Next: PgUp ──────────────────────────────────────┘
┌──────────────────────────────────────────────────────────────────────────┐
│                                                                          │
└──────────────────────────────────────────────────────────────────────────┘
  change box:→ ▌ increase:↑ ▌ decrease:↓ ▌ switch profit/price:→ ▌ Default
                ┌─ Units ───┐  ┌── Price ──┐             ┌── Profit ─┐
                └── 300 ────┘  └── 6.00 ───┘             └──  80  ───┘
```

Figure 1: Interactive Screen Display.

These results can be scrolled using the *page down* or *page up* keys to access perfect recall of the market's past history. Immediately above the *results* window appears a statement of the subject's *capital* or cumulative current balance: initial capital plus all profits minus all losses through the current period. During a period the remaining time appears adjacent to *clock*, which is immediately above and to the right of the *results* window.

At the bottom of the screen is a *calculator* tool designed to assist a subject in making an offer. By pressing a default key, the previous period's quantity, price and profit appear in the space shown. By scrolling any two of the three variables—quantity, price, and profit—the third is computed for the subject on the assumption that all units are sold at the indicated price. For example, if units and profit are chosen, the calculator determines what selling price would generate the designated profit target. For the assumption to be valid that all units offered will be sold requires the subject to estimate residual demand at the specified price, but the tool allows the outcome space to be easily explored. During the experiment, subjects soon discover that all units offered may not be sold.

4 Equilibrium and Predictions

When there are no fixed costs both demand conditions define a risk neutral Bertrand–Nash pure strategy equilibrium at $(p_i^N, q_i^N) = (5.0, 300)$ for each firm $i = 1, \ldots, 5$. In our experimental environment the Nash equilibrium is also a competitive equilibrium, since at a price of 5 the supply and demand equal 1200. Under both demand conditions the market quantity is 1200 when all five firms offer 300 units at a price of 5. If demand is split equally between the 5 firms, each firm sells 240 units. For either demand condition, when all 5 firms offer 300 units at a price of 5, each firm receives an expected profit of $5(240) - 4(100) - 4.5(100) - 5(40) = 150$. Figure 2 graphs the two different demand conditions and each firm's (interchangeable) location on the supply schedule; the shaded area (firms' surplus) represents the total profit of all firms at the competitive-Nash equilibrium, and is equal to 750. Of course, an equilibrium in monetary payoffs need not be an equilibrium in utilities, and this is one possible source of any observed variability across our environments.

To demonstrate that $(5.0, 300)$ is an equilibrium, suppose a single firm offers $(p, q) = (5.01, q)$, $q > 0$. Then that firm's expected profit is zero since the other firms' total offer of 1200 units at price 5.0 will exhaust the demand at the lower price. Also, suppose a single firm offers $(p, q) = (4.99, q)$, $q > 0$. The profit maximizing quantity at $p = 4.99$ is 200 units. Since \$4.99 is the lowest price of the five firms, all 200 units will be sold for a profit of $4.99(200) - 4(100) - 4.5(100) = 148$, which is less than the equilibrium profit of 150. In addition, when a firm offers units at a price of 5, it can only reduce profits by offering less than the maximum available quantity of 300. When the firm offers between 201 and 300 units the profit is the same as the profit from an offer of 300 units. At prices above 5 reduction of quantity will strictly reduce profits.

The fixed cost treatment maintains the above competitive-Nash equilibrium. In addition to the marginal costs shown, a firm that produces any positive quantity of output incurs an avoidable fixed cost of 150, which is exactly equal to the firm's surplus, and a sunk (unavoidable) cost of 220. The combination of sunk and avoidable costs yields a corresponding net loss of 220 (the fixed cost) at $(p, q) = (5.0, 300)$. Zero output (and revenue) is not strictly preferred to this net loss of 220, since then the loss remains at 220 (the unavoidable fixed cost). Nor can the loss be avoided by charging a price above or below 5.0, by the argument offered above. Therefore, (5.0, 300) re-

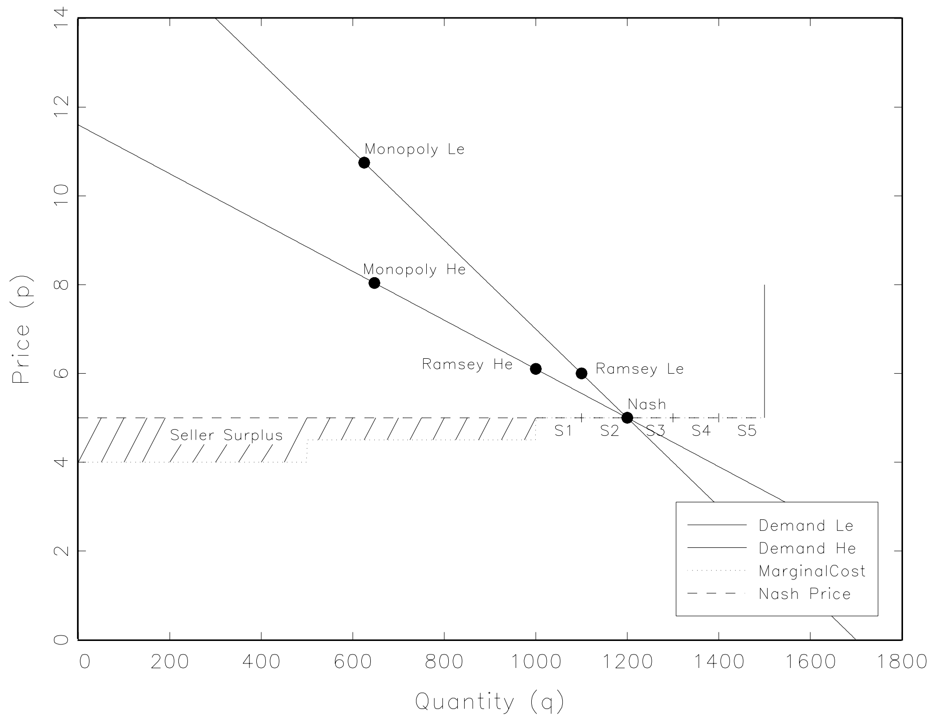

Figure 2: Demand Figures.

mains a pure competitive-Nash equilibrium in the second environment. This theoretical results provides our first research question:

- Will mean contract prices be close to the risk neutral competitive-Nash price of 5.0? (Statistical Hypothesis H_0.)

But what will competing firms do in this harsh fixed cost environment? One solution would require withholding supply on the part of firms so that no subset of the other firms could satisfy demand. Any such implicit contract to limit output by more than 20% would create residual demand conditions where a profitable mixed strategy Nash equilibrium with a distribution support from somewhere above the Ramsey break–even price to the monopoly price would rule. But even if this withholding agreement were enforced, earlier work which examined mixed strategy behavior in a zero fixed cost oligopoly environment, found behavior which does not correspond to random pricing (Kruse, Rassenti, Reynolds and Smith, 1993).[5] Instead of withholding supply, a more obvious and easily implementable coordinating strategy for the firms is to engage in price signaling, which we define empirically in the next section. Although there is an incentive to signal in an attempt to achieve greater profits in both of the cost environments, in the fixed cost environment no positive profit is possible without it.

By setting a higher price in this period a firm hopes that other firms will raise their prices next period. Why don't firms see this as a ruse by the signaling firm? A useful benchmark, at which signaling begins to become a less costly strategy, is the Ramsey break–even price. Below the Ramsey price losses are incurred, and since the firm is already incurring losses, the alternative is to raise its price. This unilateral action will produce zero sales, and one avoids all but the sunk cost. By offering yet a higher price a firm may be strategically committing to a higher price in the next period, perhaps

[5] In that work there were four firms with identical constant marginal costs and residual demand when three of the four priced competitively. The mixed strategy Nash equilibrium was computed for different capacity levels by numerically solving the integral–differential equations which describe the equilibrium conditions. These theoretical distributions predict the qualitative direction of shift of the data with shifts in the capacity parameters. But the observed price distributions, (1) differed significantly from the predicted distributions, and (2) exhibited too much auto correlation in time to be consistent with the Nash mixed strategy hypothesis. However there was a significant amount of continuing price variability over time that would not have been inconsistent with the signaling and cycling hypotheses being examined here.

lower than its current price, but greater than its price in the previous period. Other firms are in the same position, and have a powerful incentive to follow any such leader.

We further encourage the incentive for dynamic profit taking by reducing each firm's initial working capital across experience levels: (1) the trainer firms who participated in only 10 trading periods are endowed with \$5 each per experiment; (2) once-experienced firms each received \$13.50; and (3) twice-experienced firms receive no endowments. Consequently, for the latter sessions no net earnings are possible unless prices are maintained above the Ramsey price when fixed costs are present. Since the subjects return for three sessions, they are well aware of what has to be achieved if they are to make a profit. We note here that we will use the term "Twice-experienced" to denote the environment where subjects were twice-experienced, received no endowments, and had either more or fewer periods than than the "Once-experienced" subject sessions. Any statistical test of experience level is not strictly a test of experience, because of the confounding effects of endowment and period numbers. But it is strictly a test between the two environments. We could have eliminated the "Once-experienced" sessions from our results, but we thought the observations were "interesting".

The above considerations lead to the following research questions:

- Will Twice-experienced subjects adapt by maintaining higher mean contract prices than once-experienced subjects? (This will lead to statistical hypothesis H_1.)
- Will contract prices be higher in the fixed plus variable cost environment than in the variable cost only environment? (Statistical Hypothesis H_2.)

The range over which all firms can benefit by charging prices above the break even Ramsey price differ under the two different demand environments. Under the demand L_e conditions, any given increase in price causes a smaller reduction in sales than under demand H_e. Consequently:

- Will mean contract prices will be higher under demand L_e than under demand H_e? (Statistical Hypothesis H_3.)

We note, however, that the pure strategy Nash equilibrium and the competitive price equilibrium, both with and without fixed costs, are unaffected by the change in demand structure. Thus, static Nash theory would predict no change in behavior in the demand L_e and demand H_e environments.

Next, we consider the role of price signaling in these dynamic price-setting processes.[6] We define a signal as occurring when offers are submitted which are unlikely to be competitive in a world where price competition continues. Suppose that more quantity is submitted in a given period than can be sold at the posted prices. Then in the subsequent period, a price signal is defined as any price submitted by any firm that is greater than or equal to the lowest posted price that failed to attract buyers in the previous period. When all quantity submitted is sold at the posted prices in a given period (this can only happen if some firms withhold capacity), then in the subsequent period, any price submitted by any firm that is greater than the highest price at which all other firms could have sold if that firm had not competed, is considered a signal. The experiments reported are replete with such signals that we attribute to conscious efforts to induce price increases.

The next two questions simply mimic the first three with respect to the amount of signaling we should expect to observe if indeed there is a correlation between signaling and contract prices:

- Will twice-experienced subjects signal more frequently than once experienced subjects? (Statistical Hypothesis H_4.)

- Will more signals will be sent in the fixed cost environment than in the no fixed cost environment? (Statistical Hypothesis H_5.)

When demand elasticity increases there is less room for price manipulation, so the profitability of a signal becomes much more tenuous as higher prices are less viable. This motivates our last question:

- Will more signals will be observed under demand H_e than under demand L_e? (Statistical Hypothesis H_6.)

5 Results

To examine the first set of questions, we must first provide a measure of contract price in an experimental period. We define the contract price in

[6]See Friedman and Hoggatt (1980, pp. 124–129, 147–154, 192–193) for a study of experimental oligopoly in which price signaling phenomena are analyzed, apparently for the first time in the experimental literature.

Seller Cost	Inelastic Demand: Once Experienced $13.50 Endowment	Inelastic Demand: Twice Experienced $0 Endowment	Elastic Demand: Once Experienced $13.50 Endowment	Elastic Demand: Twice Experienced $0 Endowment
Fixed Cost	7.02	7.13	6.50	7.33
No Fixed Cost	6.27	8.12	5.81	6.37

Table 2: *The median contract price by treatment condition.*

an experimental period to be the weighted average of prices for that period. That is:

$$p^c = \frac{\sum_{k=1}^{5} p_k * q_k}{\sum_{k=1}^{5} q_k}, \tag{1}$$

where p_k is the price submitted by subject (firm) k, and q_k is the quantity sold by subject (firm) k, for each of the 5 firms. We summarize the median contract prices in Table 2. Except for the trainer sessions, and early in the once-experienced sessions, firms tended to follow the dominant strategy of offering their entire capacity at the price that they quoted.

We notice from Table 2 that twice experienced subjects have higher average contract prices than the once experienced subjects. We also note that, except for twice-experienced inelastic demand sessions, there are higher contract prices in the fixed cost treatment. There are higher average prices when demand is inelastic. These observations conform to our hypothesis H_2 and H_3. In Figure 3 we present the mean contract price by period for each of the sessions by treatment cell.

To examine the statistical significance of the first questions, we model the price data as a linear mixed-effects model (see Laird and Ware (1982) for a description of this method, which is commonly used in experimental sciences).

Let p^c_{ij} be the contract price of the i^{th} session and the j^{th} period. The general linear mixed model for the data is:

$$p^c_{ij} = \alpha + \beta_d d + \beta_f f + \beta_e e + \beta_i + \epsilon_{ij}, \quad i = 1, \ldots, 30 \qquad j = 1, \ldots t_i, \tag{2}$$

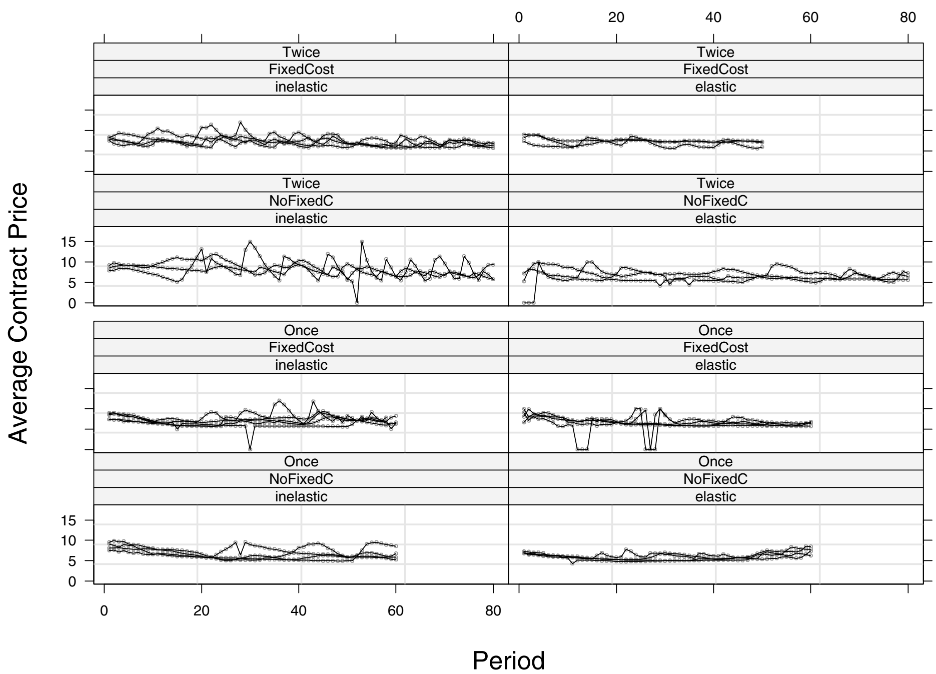

Figure 3: Contract Price by Treatment and Period.

	Value	Std.Error	DF	t-value	p-value
Intercept	6.97	0.105	1938	66.40	$< .0001$
d	-0.36	0.105	22	-3.49	0.0020
f	0.10	0.105	22	0.98	0.3348
e	0.33	0.105	22	3.19	0.0042
d:f	0.23	0.105	22	2.26	0.0337
d:e	-0.07	0.105	22	-0.72	0.4767
f:e	-0.15	0.105	22	-1.49	0.1479
d:f:e	0.18	0.105	22	1.76	0.0912

Table 3: *The fixed effects coefficients for the mixed effect model of contract price. The treatments are* ***experience (e)****,* ***demand (d)****,* ***fixedcost (f)****, and their interactions denoted by* ***d:f****, etc. and the errors follow an AR(3,2) process.*

where $\beta_d, \beta_f, \beta_e$ are the coefficients of the factor effects, β_i is the random effect for session i, and t_i is the number of periods in session i. The random effect is assumed to be independent $N(0, \sigma_b)$, and the within session errors ϵ_{ij} are assumed to be independent $N(0, \sigma_e)$.

In our particular specification the design factors are **experience (e)** (twice-experienced = 1), **demand (d)** (highly-elastic = 1), **fixedcost (f)** (fixed-cost = 1), and their interactions. The design matrix for factors is a Helmert contrasts, which allows us to interpret the intercept as the mean level of the contract price. The results are listed in Table 3.

We first examine the hypothesis that the mean contract price is equal to the competitive-Nash price:

$$\mathrm{H}_0 : \text{intercept} = 5.0, \tag{3}$$

from the estimation of (2) the 95% confidence interval for the intercept is (6.76,7.18). The risk neutral competitive-Nash model of H_0 is strongly rejected.

Significant effects on experience and demand level support hypothesis 1 ($\beta_e > 0$) that experienced subjects are able to increase the mean price level, and hypothesis 3 ($\beta_d > 0$) that elastic demand pushes the price level down. There is no significant evidence to support hypothesis 2 ($\beta_f > 0$) that mean contract price increases due to the introduction of fixed costs. We cannot reject the hypothesis that across all observations the fixed cost treatment has

	Value	Std.Error	t-value	p-value
Intercept	0.63	0.053	11.82	0.000
d	0.11	0.053	2.19	0.038
f	0.14	0.053	2.66	0.014
e	0.05	0.053	1.10	0.281
d:f	0.11	0.053	2.15	0.042
d:e	-0.03	0.053	-0.64	0.524
f:e	-0.08	0.053	-1.63	0.116
d:f:e	0.00	0.053	0.06	0.950

Table 4: *The coefficient table for the signaling linear model.*

no effect on prices. This finding is consistent, however, with the standard economic principle that fixed costs should not affect decision making at the margin.

Though the five firms would make significant earnings at the competitive price of 5 without fixed costs, the 114 automated, demand revealing buyers encourage persistent successful efforts to maintain contract prices above the competitive margin. Consequently, in this environment, adding fixed cost has no significant positive influence in changing the posted price level. We would expect, as conjectured in Coursey *et al.* (1984), and demonstrated by Kruse (1991), that mean prices would be significantly lower if a *small* number of strategic human buyers were used in place of many, automated, demand revealing buyers.

The median contract price of 7.13 in the fixed cost, inelastic demand, twice-experienced cell leads us to suspect interaction effects. The interaction effect between fixed cost and demand is marginally significant. The more stressful of the fixed cost circumstances did produce marginally significant successful efforts to maintain higher mean prices. This result suggests an appealing behavioral principal: that fixed costs will affect pricing behavior when it becomes a matter of survival for firms.

We next report in Table 4 simultaneous tests hypotheses H_4 – H_6 with a regression analysis using the above measure of total signaling activity in each session, and dummy variables for experience, demand, fixed costs, and interaction effects. The dependent variable is the mean number of signals per period for each experimental session.

Not surprisingly, there are significant efforts to increase profitability by increasing the number of price signals under the more stressful circumstances (elastic demand and fixed costs). But experience seems to have little to do with the number of signals generated, though we have already observed that it does significantly affect prices. How do experienced firms achieve higher prices? One intuitive explanation is that the subjects use price signals to precommit to a higher pricing strategy. Or, as noted by a referee: "Perhaps it is the case that the experienced players read the same signals more insightfully, and thus more signals are not useful at the margin." This led us to some *ex post* data mining.

For each individual experimental session, we estimated the influence of the presence of a signal on the mean contract price of the next period. Thus:

$$p^c_{ij} = \alpha_i + \beta_i p^c_{i(j-1)} + \sigma_i I(\text{signal}_{i(j-1)}) + \epsilon_{ij}, \quad j = 1, \ldots, t_i, \quad i = 1, \ldots, 30, \quad (4)$$

where p^c_{ij} is the contract price in period j of experimental session i, $I(\text{signal}_{ij)})$ is 1 if there is a signal in period j, session i and 0 if there is no signal, t_i is the number of periods in session i, and ϵ_{ij} is the error term. Fourteen of the sessions had significant values for σ_i at the 5% level or better. However, the signal measure was much more likely to have an effect in the twice experienced, inelastic demand sessions, which had 7 out of 7 significant values for σ_i at the 5% level, indicating that this signal measure was likely to have had an effect on subsequent contract prices.

On an individual level we look at the commitment of subjects to maintain a high price after sending a price signal. Thus:

$$p_{ij} = \beta_i p_{i(j-2)} + \sigma_i I(\text{signal}_{i(j-1)}) + \epsilon_{ij}, \quad j = 1, \ldots, t_i, \quad i = 1, \ldots, 150, \quad (5)$$

where p_{ij} is the offer price in period j by subject i, $I(\text{signal}_{ij)})$ is 1 if there is a signal in period j, by subject i and 0 if there is no signal, and ϵ_{ij} is the error term. Seventy-eight percent of the subjects had positive values for σ_i, indicating that when a signal was sent the subject was more likely to submit a price higher than the price in the previous period.

In Figure 4 we provide the time series of average contract price for each experimental session. Inspection of these series clearly reveals that Edgeworth style cyclical patterns are a common characteristic in many of the sessions. However there does not appear to be any consistent pattern or statistical regularity.

Finally, Figure 5, which plots the individual maximum offer prices that are greater than the monopoly price, as well as the mean contract price in

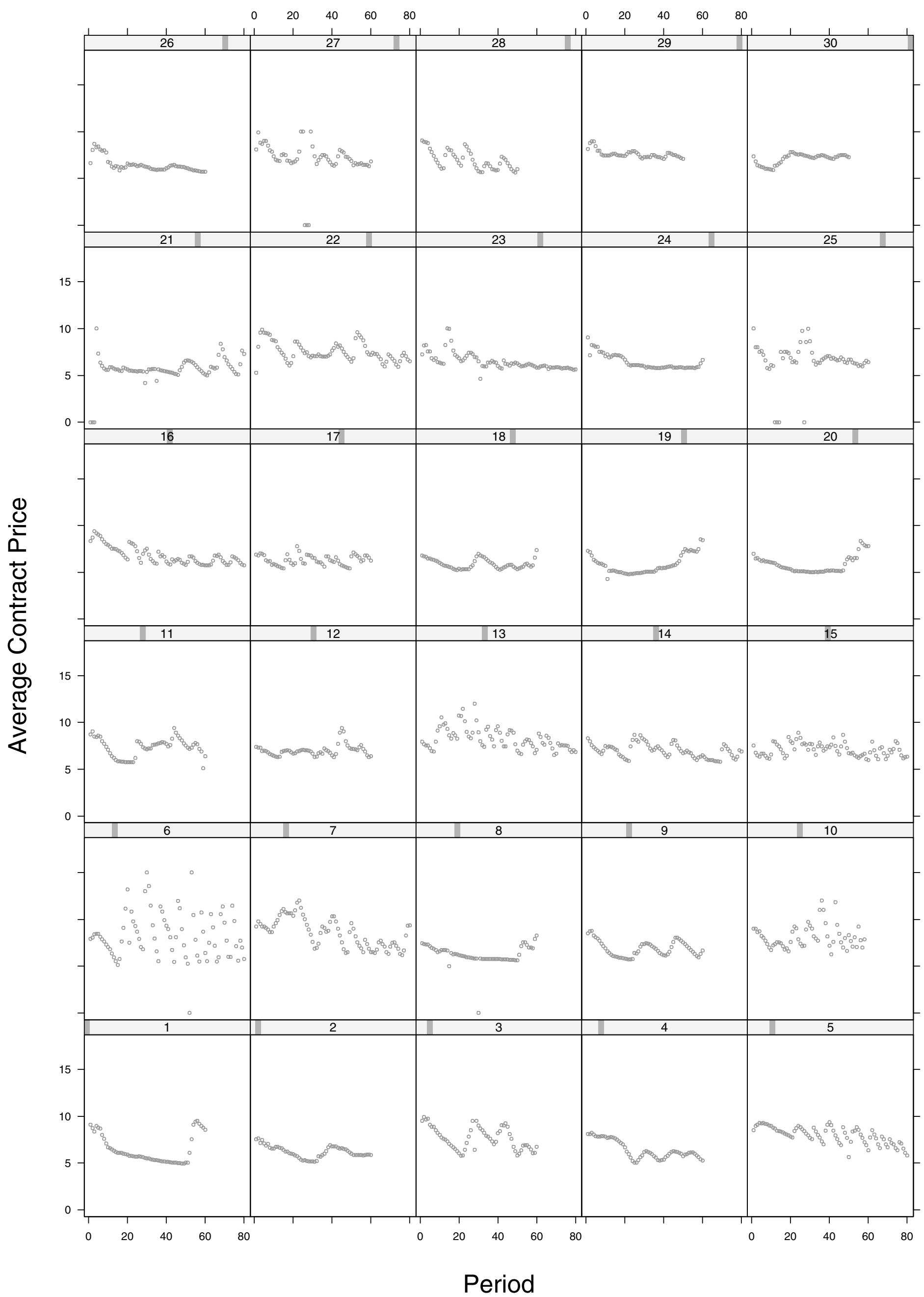

Figure 4: Individual Session Time Series of Contract Price.

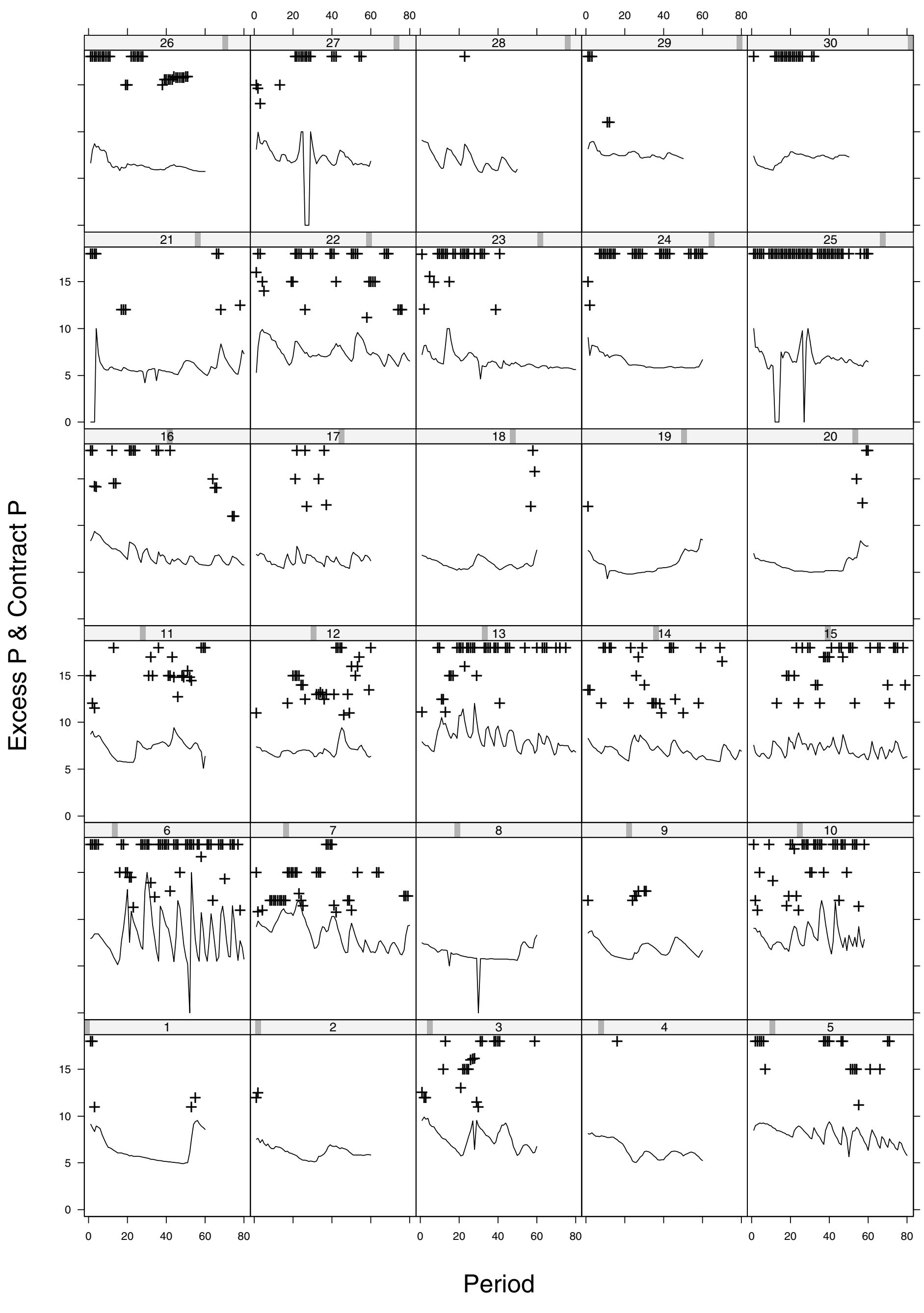

Figure 5: Individual Session Time Series of maximum offers above Monopoly Price and the Contract Price.

each period, indicates that signaling at absurdly high prices was extremely common.

6 Conclusions

In environments where decision-makers face both sunk and avoidable fixed costs, we observe a pattern of price signaling and responses which maintain above normal profits; firms succeed, even through their joint conduct is clearly very competitive. This success means that firm's do not have to exit such an industry in order to avoid loses (or for the industry to maintain profitability), and may help to explain why some competitive industries appear to maintain an inefficient number of firms over much longer periods of time than expected. However, in our experimental environment, we cannot reject the hypothesis that the fixed cost treatment has no effect on prices. This finding is consistent, however, with the standard economic principle that fixed costs should not affect decision making at the margin.

A closer examination of the data suggests that the form of competition firms engage in is responsible for their profitability. Below the Ramsey price, losses are incurred, and the alternative, since the firm is already incurring losses, is to raise its price. This unilateral action produces zero sales, and avoids all but the sunk cost. However, by setting a higher price in this period a firm hopes that other firms will raise their prices next period. Why don't firms see this as a ruse by the signaling firm? By offering a higher price in a period, a firm may be committing to a price in the next period, perhaps lower than its signal, but greater than its price in the previous period. Formally, the commitment in the next period must take the form of a mixed strategy to ensure that the other firms are unable to predict and simply undercut the signaler's price. Other firms in the same position, would then have a strong incentive to raise their prices as they trade off the cost of being the firm left out of the market in the next period against the benefit of more profits. Firms will maintain positive profits if they can work out a repeated response that allows each to partake of profits on various occasions. For example, as long as firms' price responses are sufficiently randomized and prices stay above the Ramsey price, different firms will be rationed each period, but their losses in these periods will be outweighed by increased profits in periods in which they sell.

References

[1] Buchheit, Steve and Nick Feltovich, (200). "The Relationship Between Sunk Costs and Firms' Firms Pricing Decisions: An Experimental Study". Mimeo, University of Houston, October.

[2] Durham, Yvonne, Stephen J. Rassenti, Vernon L. Smith, Mark Van Boening and National T. Wilcox, (1996). "Can Core Allocations Be Achieved in Avoidable Fixed Cost Environments Using Two-Part Pricing Competition?", *Annals of Operations Research, Special Issue on Computational Economics*, edited by S. Thore and G. Thompson, Vol. 68, August, 61–88.

[3] Friedman, James W. and Austin C. Hoggatt, (1980). *An Experiment in Non-cooperative Oligopoly*, Greenwich, Conn: JAI Press Inc.

[4] Ketcham, Jon, Vernon L. Smith, and Arlington Williams, (1984). "A Comparison of Posted-Offer and Double-Auction Pricing Institutions," *Review of Economic Studies* **51**: 595–614.

[5] Kruse, Jamie B., (1991). "Contestability in the Presence of an Alternate Market: An Experimental Evaluation," *Rand Journal of Economics* **22**: Spring, 136–147.

[6] Kruse, Jamie B., Stephen J. Rassenti, Stanley S. Reynolds and Vernon L. Smith, (1994). "Bertrand–Edgeworth Competition in Experimental Markets," *Econometrica* **62**: March, 343–371.

[7] Laird, N. M. and J. H. Ware (1982). "Random-effects models for longitudinal data", *Biometrics* **38**: 963–974.

[8] Martin, Stephen (2003). "Globalization and the Natural Limits of Competition", Mimeo, Department of Economics, Purdue University, January.

[9] Offerman, Theo and Jan Potters (2002). "Does Auctioning of Entry Licenses Induce Collusion? An Experimental Study". Mimeo, CREED, University of Amsterdam, September.

[10] Smith, Vernon L. (1974). "Optimal Costly Firm Entry in General Equilibrium," *Journal of Economic Theory*, December.

[11] Telser, L. G., (1988). *A Theory of Efficient Cooperation and Competition*, Cambridge: Cambridge University Press.

[12] Van Boening, Mark V. and Nathaniel T. Wilcox, (1996). "Avoidable Cost: Ride a Double Roller Coaster," American Economic Review **6,3**:, June, 461–477.