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The Sackler Institute for Economic Studies

Tel Aviv University
The Eitan Berglas School of Economics

מכון סאקלר לכלכלה
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Founded by Raymond R. Sackler, M.D, and Mortimer D. Sackler, M.D.

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**SEARCH WITH LEARNING AND PRICE
ADJUSTMENT DYNAMICS***

by

✓
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ABSTRACT

This paper presents a theory of limited price responsiveness to cost shocks in a context of search with learning. Consumers confuse general cost shocks, common to all firms in the industry, with firm specific shocks. In the case of a general cost increase, this confusion leads to an excessive propensity to search, temporarily inhibiting price increases, lest they encourage search. In the case of an idiosyncratic shock, consumers initially search too little, allowing the prices of high cost firms to temporarily overshoot.

I.Introduction

Both formal research and casual observation suggest that, in the short run, prices reflect cost changes by less than conventional economic theory predicts. For example, Cachetti [1986] finds that prices of newsstand magazines may be allowed to fall by as much as twenty five per cent, in real terms, before being adjusted. Kashyap [1991] presents similar findings for prices in retail catalogues. Lach and Tziddon [1991] report that price quotations are not trivially short even during high inflation. And in his survey of firms, Blinder [1991] finds the median interval between price changes to be one year.

This paper presents a model of price adjustment dynamics which is able to account for such phenomena. It also produces a number of additional plausible and empirically testable predictions. The basic idea is the following. Suppose a firm considers increasing its price as the result of an unexpectedly high production cost. Its ability to do so without endangering market share may depend on its customers' perception of general cost conditions in the industry. Consumers who believe the price hike reflects an industrywide cost increase have little incentive to search for a better bargain elsewhere. In contrast, search might be a reasonable reaction if a price hike is interpreted as the result of an idiosyncratic cost increase specific to that seller. This suggests that when consumers are unable to adequately distinguish between general and firm-specific changes, cost changes may have only a limited impact on prices in the short run. For example, short run prices may fail to fully reflect even a general cost increase if sellers fear that higher prices may (albeit wrongly) be interpreted as idiosyncratic and encourage consumer search.

Formally, there are two firms which compete in prices. Consumers must physically visit a firm to learn its price, thereby incurring search costs. The firms'

production costs, which may be either "high" or "low", are subject to random cost shocks. A *uniform* shock has an identical effect on the production costs of all firms in the industry. An *idiosyncratic* shock changes the cost of only one firm. When a shock occurs, consumers are at first imperfectly informed about its type, but become better informed as time goes on. The main finding is that in the short run, before consumers are informed, prices may either undershoot or overshoot their longer run level.

Prices undershoot if both firms are initially low cost and experience a uniform cost increase. Perfectly informed consumers would expect both prices to increase in proportion to the common cost increase and would consequently accept a price increase without search. Imperfectly informed consumers entertain the possibility that an observed price increase is attributable to an idiosyncratic shock, and are consequently overly optimistic about the prospect of finding a lower price at the other firm. To discourage such search, price increases are initially restrained. Once consumers become better informed, and hence more pessimistic about the prospects from search, prices are freed to increase further, to more accurately reflect changed cost conditions. The extent of this price undershooting - the gap between the price before consumers are informed and that after they become informed - is found to be greater, the smaller the search cost.

Conversely, in the case of an idiosyncratic cost increase, the high cost firm's price initially *overshoots*. Because consumers place positive probability on a uniform increase, they are initially too pessimistic about the value of search. This empowers the high cost firm to raise its price by more than can be sustained in the long run. As consumers become better informed, their increased propensity to search compels the high cost firm to reduce its price.

Prices also overshoot if both firms are initially high cost and one firm enjoys an idiosyncratic cost decrease. As above, the consumers' initially overly

pessimistic view of search allows the high cost firm to maintain a relatively high price until their awareness of its (newly) low cost competitor compels a more robust discount. In contrast to the preceding case, this overshooting manifests as a gradual decline of the high cost firm's price from its pre-shock level.

When a firm's *own* cost decreases, however, its price is always fully reduced, without delay. Thus, in the cases of a general cost decrease, prices adjust without delay throughout the industry. This feature contrasts with menu cost models (Sheshinski and Weiss, 1977), which imply a symmetric response to cost increases and decreases.

The technical underpinning for my analysis of price adjustment dynamics is based on the analysis of search market equilibrium with consumer learning about prices. It shares this concern with the recent papers by Dana [1988] and Benabou and Gertner [1993]. Dana's objective, like mine, is to understand limited price responsiveness to cost shocks in a search setting. The assumed informational friction in his model is quite different from that of this paper, however. Dana's firms always have identical costs; uncertainty applies only to whether that common cost is high or low. Also, he focuses primarily on price stickiness while this paper is concerned with a broader range of adjustment dynamics. The information structure in Benabou and Gertner is closest to that of this paper. Indeed, my two state cost structure may be interpreted as a special case of their framework¹. The two papers differ in their orientation. Benabou and Gertner use a rich informational structure, including a continuum of cost states, to conduct a correspondingly rich exploration of the novel issues that arise when Bayesian learning is introduced in the conventional search paradigm. The simpler informational environment used in this paper is sufficiently tractable to address the analysis of price adjustment dynamics which such a modeling framework naturally suggests.

II. The Model

An industry includes two infinitely lived, risk neutral firms, each of which supplies a homogenous product at constant marginal cost. The firms compete in prices. A new consumer is born at each even numbered period, participates in the market for two periods and is replaced by a new consumer at the next even period. At each period of her life, a consumer has a downward sloping demand curve, $q(p)$, which denotes the quantity of the product she demands when the lowest available price is p^2 . The consumer surplus from buying at p is denoted $V(p)$.

At any period, an individual firm's production cost may randomly assume one of two values, $\underline{c}$ (low cost) or $\bar{c} > \underline{c}$ (high cost), as described below. Let $\pi(p, c) = (p - c) q(p)$ be the profit function of a monopoly whose cost is c and demand is $q(p)$. It is assumed that $\pi(p, c)$ is a concave function of p for $c = \bar{c}, \underline{c}$. The unique monopoly prices corresponding to $c = \bar{c}$ and $c = \underline{c}$ are denoted $\bar{p}$ and $\underline{p}$ respectively, $\bar{p} > \underline{p}^3$.

At any period, the state of the industry is described by the distribution of production costs between the firms. There are thus three possible states: $(\underline{c}, \underline{c})$, when both firms are low cost; $(\bar{c}, \bar{c})$, when both are high cost; and $(\underline{c}, \bar{c})$, when one firm is low cost and the other high cost⁴. The state at any period is fully determined by that of the preceding period according to a simple Markov process. The persistence probability that the state is unchanged from the previous period is β . μ is the probability of a transition from $(\underline{c}, \underline{c})$ to $(\bar{c}, \bar{c})$ or vice versa. Such a transition is referred to as a *uniform* change. ν is the probability that the cost of only one firm changes- that is, a transition from $(\underline{c}, \underline{c})$ or $(\bar{c}, \bar{c})$ to $(\underline{c}, \bar{c})$ or from $(\underline{c}, \bar{c})$ to $(\underline{c}, \underline{c})$ or $(\bar{c}, \bar{c})$. Such a transition is referred to as an

idiosyncratic change. For simplicity it shall be assumed that the state can only change at even numbered periods.

A firm is said to be *uniformly* high cost (low cost) if its competitor is simultaneously high cost (low cost) as well, and *idiosyncratically* high cost (low cost) if its competitor is simultaneously low cost (high cost).

There are two informational frictions. First, information about prices is not free; a consumer must pay a search cost of $s > 0$ to learn the current price and buy from any firm from which she has not previously bought⁵. As is well known, and elaborated upon below, this prevents a competitive equilibrium. Second, consumers only learn about changes in the cost distribution with a one period lag⁶. Thus at an even numbered period, consumers know only how costs were distributed at the *preceding* period, not at the current one. Since production costs can only change at even periods, all market participants are perfectly informed about costs at odd periods. The utility of a consumer who observes n prices before buying at price p is $V(p) - ns$, $n = 1, 2$ ⁷.

III. Equilibrium Pricing When Information is Perfect

In equilibrium, consumers search optimally, based on the best available information about prices, and firms set prices to maximize profits, taking their competitor's price and the consumers' search strategy as given. As is clarified below, knowledge of the cost distribution implies knowledge of the price *distribution* (though not of individual prices). Therefore, at odd periods, consumers face the problem of sequential search from a known price distribution. The solution of this problem is well known. In particular, the case in which firms' costs- and hence their preferences with respect to prices- are identical, was first analyzed by Diamond [1971]⁸. He showed that, as long as search costs are positive, the equilibrium price is the monopoly price corresponding to the common

production cost: $\underline{p}$ when the common cost is $\underline{c}$ and $\bar{p}$ when it is $\bar{c}$. Intuitively, when the firms have identical preferences with respect to prices, consumers expect them to charge the same price and, consequently, have no incentive to invest in costly search. Conversely, since consumers do not search, firms have no incentive to undercut each other's prices, empowering them to charge monopoly prices.

The preceding logic does not apply when the firms have different costs and, hence, diverse price preferences. Reinganum [1979] has shown that under those conditions, the industry equilibrium is characterized by price dispersion. Just as in the (Diamond) case of homogenous costs, the low cost firm's price is determined as $\underline{p}$, independently of search costs. However, the high cost firm's price depends on the search cost. A consumer who is charged $p > \underline{p}$ by the high cost firm, expects the competing, low cost firm's price to be $\underline{p}$. Her gain from search is thus $V(\underline{p}) - V(p)$. Let $\hat{p}$ be the consumer's *reservation price* - the price at which the gain from search equals its cost:

$$(1.1) \quad V(\underline{p}) - V(\hat{p}) = s.$$

The optimal sequential search strategy is thus to accept prices below $\hat{p}$ and search if the price is higher than $\hat{p}$. The high cost firm's optimal response to this strategy is to charge $\min(\bar{p}, \hat{p})$. Let $\hat{s} > 0$ satisfy:

$$(1.2) \quad V(\underline{p}) - V(\bar{p}) = \hat{s}.$$

By (1.1), $\hat{p}$ is increasing in s . Thus the high cost firm's price is $\bar{p}$ if $s > \hat{s}$ and is increasing in s if $s < \hat{s}$; See figure 1. This result is very intuitive. When production costs are heterogeneous, the high cost firm's market power is contained by the threat of consumer search. This threat is less effective, the higher the cost

of search. When this cost is high enough, search ceases to be a viable option. Then, the high cost firm's market power is unhindered by the presence of a low cost competitor.

IV. Equilibrium Pricing When Information is Imperfect

At even periods, consumers are uncertain whether or not the firms have identical production costs, and hence prices. Because they are then sampling from an *unknown* distribution, the potential gain from search is more difficult to evaluate. Specifically, suppose both firms are actually high cost. By erroneously putting positive probability on the possibility that firms' costs and prices diverge, consumers *overvalue* the expected gain from search. Conversely, when costs are actually heterogeneous, the assignment of positive probability to cost and price homogeneity causes search to be *undervalued*.

Thus, at even periods the problem is one of equilibrium search with Bayesian learning about prices, an issue which, with the notable exceptions of Benabou and Gertner and Dana, has been largely neglected in the equilibrium search literature. I shall derive a *Bayesian perfect equilibrium* for this case.

Determining the low cost firm's price is easy; Since $\underline{c}$ is the lowest possible production cost in *any* state, the low cost firm's price should be the same as the odd numbered periods. The logic of the preceding section thus implies that $\underline{p}$ is also the low cost price at even periods¹⁰.

Imperfect information *does* affect the high cost price. Recall from the previous section that when the state is known, the idiosyncratically high cost firm's price diverges from that of the uniformly high cost firm if s is below the critical value, $\hat{s}$. Proposition 1 establishes the important fact that this is not the case when the state is imperfectly known.

Proposition 1:

At even periods, the prices of an idiosyncratically and a uniformly high cost firm are identical, whatever the search cost.¹¹

Proof of Proposition 1: See the appendix.

Thus, at even periods, the high cost price cannot help consumers distinguish between a uniformly and idiosyncratically high cost seller. The gains from search can then only be evaluated on the basis of the preceding period's (known) cost distribution. These considerations must, in turn, be reflected by the high cost price.

Let t denote an even numbered period and $t-1$ the preceding, odd numbered period. There are three cases to consider, corresponding to the possible states at $t-1$.

Case 1: The High Cost Price when Both Firms are Initially Low Cost

Suppose both firms were low cost at $t-1$ and let $p' > \underline{p}$ be the high cost price at period t . The observation of p' implies a transition to either $(\bar{c}, \bar{c})$ - in which case firms charge identical prices and search is pointless - or $(\underline{c}, \bar{c})$ - in which case the return from search is $V(\underline{p}) - V(p)$. The probabilities of these transitions are, by Bayes' rule, $\sigma = \mu(\mu+v)^{-1}$ and $1-\sigma$ respectively. Thus the expected gain from search is $(1-\sigma)\{V(\underline{p}) - V(p)\}$.

Let $\tilde{p}$ be the value of p for which this equals the cost of search:

$$(2.1) \quad (1-\sigma)\{V(\underline{p}) - V(\tilde{p})\} = s.$$

A consumer who assigns probability $1 - \sigma$ to $(\underline{c}, \bar{c})$ optimally accepts prices $\leq \tilde{p}$ without search and searches if the price is greater than $\tilde{p}$.

Proposition 2:

If both firms were low cost at (odd) period $t-1$, then $\min\{\bar{p}, \tilde{p}\}$ is the highest equilibrium price for a high cost firm at period t .

Proof of Proposition 2: Suppose $\tilde{p}$ is indeed the equilibrium price. The characterization of a Bayesian perfect equilibrium must include a description of the consumers' out of equilibrium beliefs (i.e., how their beliefs about the state are affected by *any* price, not only the equilibrium price). Suppose that consumers' beliefs are unaffected by the prices she observes; that is, regardless of what price is observed, probability $1 - \sigma$ is assigned to $(\underline{c}, \bar{c})$.¹² Then, by (2.1), she optimally accepts prices $\leq \tilde{p}$ and rejects prices $> \tilde{p}$ to search. If a deviant firm charges more than $\tilde{p}$, its customers search and buy from its cheaper competitor. Therefore prices greater than $\tilde{p}$ yield zero profit. Concavity of the profit function then implies that $\min\{\bar{p}, \tilde{p}\}$ is the high cost firm's optimal price. This establishes $\tilde{p}$ as an equilibrium price.

It remains to show that no higher equilibrium price exists. First observe that the equilibrium price cannot be greater than $\bar{p}$. If it were, one firm could safely reduce it to $\bar{p}$ without losing any customers (customers who search will discover the competitor's price to be higher and return to the deviant), thereby increasing profits. Suppose the high cost price is higher than $\tilde{p}$. Then consumers who observe that price assign probability $1 - \sigma$ to $(\underline{c}, \bar{c})$ and, by (2.1), search before buying¹³. Then the high cost firm loses all its customers to a low cost competitor while sharing its customers with a high cost competitor. By unilaterally charging slightly less than the equilibrium price, a high cost firm doubles its sales if its

competitor is high cost and loses nothing if it is low cost. Thus a high cost price greater than $\tilde{p}$ does not exist. QED.

While proposition 2 established $\min\{\bar{p}, \tilde{p}\}$ as the *highest* price for the high cost firm, the possibility of still lower equilibrium prices remains open and is discussed below.

Comparison of (1.1) and (2.1) reveals that $\tilde{p} > \hat{p}$. The latter is the reservation price of an informed consumer who is certain that search for $\underline{p}$ will be successful. $\tilde{p}$ is the reservation price of an imperfectly informed consumer, who is uncertain whether the low price is available at the other firm and is therefore willing to accept a higher price before investing in search.

Let $\tilde{s}$ be the critical value of the search cost above which the high cost firm achieves full monopoly power (analogous to $\hat{s}$ at odd periods):

$$(2.1) \quad \tilde{s} = (1-\sigma)\{V(\underline{p}) - V(\tilde{p})\}$$

Thus the high cost price is less than $\bar{p}$ and increasing in s for $s < \hat{s}$, and $\bar{p}$ otherwise.

Comparison of (1.2) and (2.2) reveals that $\tilde{s} < \hat{s}$; monopoly power is more easily achieved, the more pessimistic consumers are about search.

Proposition 2 established $\min(\tilde{p}, \bar{p})$ as the *highest* equilibrium price for the high cost firm. Still lower equilibrium prices also exist, as is shown in appendix 1. There it is argued that the out of equilibrium beliefs required for their existence are less plausible than those which support $\min(\tilde{p}, \bar{p})$. For this reason the latter has been selected as the equilibrium high cost price in the rest of the paper¹⁴.

The analysis of the high cost price in the remaining cases is similar to that of case 1. The main difference is that in those cases the high cost price is determined by the persistence probability, as well as the search cost.

Case 2: The High Cost Price when Both Firms are Initially High Cost

Let p'' be the period t high cost price when both firms were high cost at period $t-1$. In contrast to the preceding case, an encounter with the high cost price at period t does not constitute evidence of a change in the cost distribution. Therefore, consumers who observe p'' believe that both firms are still high cost with probability β - in which case search has no value - and that one firm has turned low cost with probability ν , in which case the value of search is $V(\underline{p}) - V(p'')$. Let $\tilde{\tilde{p}}$ be the consumers' reservation price for this case, derived analogously to $\tilde{p}$ and given by:

$$(3.1) \quad V(\tilde{\tilde{p}}) = V(\underline{p}) - s/\nu.$$

$\tilde{\tilde{p}}$ and $\tilde{p}$ have similar properties: both are increasing in s and both are greater than $\underline{p}$. Similar arguments to those advanced in the analysis of case 1 establish the high cost price as $\min\{\tilde{\tilde{p}}, \bar{p}\}^{15}$.

Observe that $\tilde{\tilde{p}}$ is increasing in the persistence probability β (a higher β implies lower ν); Since search was of no value in the initial state, its expected value at t is lower, the higher the persistence probability.

Denote by $\tilde{\tilde{s}}$ the critical value of the search cost for this case:

$$(3.2) \quad \tilde{\tilde{s}} = \nu\{V(\underline{p}) - V(\tilde{\tilde{p}})\}.$$

Case 3. The High Cost Price when Costs are Initially Heterogeneous

The persistence probability has a reverse effect on the high cost price if production costs are initially heterogeneous. Then search is most valuable in the status quo and loses its value only if both firms become high cost. Therefore, the greater the persistence probability, the *more* valuable search is. The value of search when the high cost price is p is $\beta[V(\underline{p}) - V(p)]$. This gives the consumer's reservation price as $\tilde{\tilde{p}}$, defined by:

$$(4.1) \quad V(\tilde{\tilde{p}}) = V(\underline{p}) - s/\beta$$

which is increasing in the search cost and decreasing in β . Note in particular that $\tilde{\tilde{p}}$ goes to $\hat{p}$ as β approaches 1.

The critical value of the search cost is denoted as $\tilde{\tilde{s}}$, given by:

$$(4.2) \quad \tilde{\tilde{s}} = \beta\{V(\underline{p}) - V(\tilde{\tilde{p}})\}.$$

Table 1 summarizes the preceding analysis, listing the high cost price and critical value of the search cost at an even period associated with different cost changes.

V. Price Adjustment Dynamics

This section uses the analysis of the preceding section to describe the price adjustment dynamics that are consistent with the model. Each of the following scenarios describes the evolution of prices from an odd period $t-1$ to period $t+1$, in response to different cost shocks at period t .

Scenario 1: $(\underline{c}, \underline{c}) \Rightarrow (\bar{c}, \bar{c})$.

Prior to the shock, the price of each firm is $\underline{p}$. At $t+1$, after information about the cost shock is fully revealed, each firm's price is $\bar{p}$. The extent to which the period t price reflects the uniform cost increase, however, depends on the search cost. The price adjusts to $\bar{p}$ without delay, at period t , only if $s \geq \tilde{s}$. Otherwise, the period t price is only $\tilde{p} < \bar{p}$ and the "full" increase to $\bar{p}$ is postponed to the following period. Moreover, since by (2.1), $\tilde{p}$ is increasing in s , the extent to which the period t price undershoots its ultimate level is greater, the lower the search cost.

Scenario 2: $(\underline{c}, \bar{c}) \Rightarrow (\bar{c}, \bar{c})$

The case of interest is $s < \hat{s}^{16}$; then, prior to the shock, the high cost firm's price is only $\hat{p} < \bar{p}$ at $t-1$, when costs are heterogeneous, and increases to $\bar{p}$ at $t+1$, once it becomes known that both firms are high cost. The full increase to $\bar{p}$ takes place at period t only if $s > \tilde{\tilde{s}}$. Otherwise the price increases only gradually; at first to $\tilde{\tilde{p}}$ and then, at $t+1$, to $\bar{p}$. Since $\bar{p}$ is independent of the search cost, while $\hat{p}$ and $\tilde{\tilde{p}}$ are decreasing in s , and approach $\hat{p}$ as s goes to zero, the gap between the prices at periods t and $t+1$ is greater the smaller the search cost, as in scenario I.

Recall that $\tilde{\tilde{p}} \rightarrow \hat{p}$ as the persistence probability $\beta \rightarrow 1$. Thus in this scenario, the price change between periods t and $t+1$ is smaller, the greater the persistence probability, going to zero as $\beta \rightarrow 1$.

Discussion: Scenarios 1 and 2 are broadly consistent with the empirical evidence, cited in the introduction, that prices are slow to respond to increased production costs. In contrast to "menu cost" explanations for price inertia (e.g., Sheshinski

and Weiss, 1977), which appeal to real costs of changing prices, such as costs of printing new price catalogues, attaching new price labels and so on, this paper advances an information - search theoretic explanation (in the spirit of an informal argument suggested by Okun [1981]).

The preceding analysis implies that incomplete information can only *restrain* short run price adjustments, not eliminate them altogether. For example, in scenario 1 (a uniform cost increase), the high cost price increases by some amount even when the search cost is small. By contrast, menu cost models predict that prices do not change *at all* in the short run. Complete price inertia can also be obtained in my framework by adding a *small* cost of changing prices, which, on its own, is too small to have an effect. Specifically, consider a menu cost which is of too small an order of magnitude, relative to $\pi(\bar{p}, \bar{c}) - \pi(\underline{p}, \underline{c})$, to affect pricing when consumers are perfectly informed. One can then choose a search cost sufficiently small that $\pi(\hat{p}, \bar{c}) - \pi(\underline{p}, \underline{c})$, is of the same order of magnitude as the menu cost. For search costs of this order or less, then, a uniform cost increase has *no* effect on prices in the short run. *All* of the price change is then postponed to the following period, when the scope of price change is unrestricted by the threat of consumer search and is therefore unaffected by a small menu cost. By contrast, for the conventional menu cost explanation to apply, the cost of changing prices must be of the same order of magnitude as the change in production costs to be significant.¹⁷

The preceding scenarios may be interpreted as describing upwardly "sticky" prices, in response to general and idiosyncratic cost increases. The following scenario, which describes how a high cost firm's price adjusts to a decline in its *competitor's* cost, may be interpreted as *downward* price stickiness.

Scenario 3: $(\bar{c}, \bar{c}) \Rightarrow (\underline{c}, \bar{c})$.

Each firm's initial price is $\bar{p}$. If $s < \hat{s}$, the high cost firm must reduce its price to $\hat{p} < \bar{p}$ at $t+1$ but can charge more at period t : $\bar{p}$, if $\tilde{s} < s < \hat{s}$, or $\tilde{p} > \hat{p}$ otherwise. Thus the high cost price overshoots at period t . As a result of the consumers' imperfect awareness of the (newly) low cost firm's existence, the full decline of the high cost price, from its pre shock level, is postponed by a period¹⁸.

Scenario 3 demonstrates that prices may be slow to respond to lower *competitors'* costs. However, a firm always adjusts its price without delay if its *own* cost is reduced. Because consumers always accept $\underline{p}$ without search, nothing deters a low cost firm from fully reducing its price to $\underline{p}$ without delay. Thus in case of a uniform cost decrease, from $(\bar{c}, \bar{c})$ to $(\underline{c}, \underline{c})$, prices adjust to $\underline{p}$ at once. In contrast, menu cost models, which are based on exogenous costs of changing prices, imply symmetric price inertia in both directions.

A different sort of price adjustment dynamic follows an idiosyncratic price increase. Rather than generating a pattern of gradually increasing or decreasing prices, this shock produces an initial price rise followed by a subsequent price reduction.

Scenario 4: $(\underline{c}, \underline{c}) \Rightarrow (\underline{c}, \bar{c})$.

The initial price is $\underline{p}$. If $s < \hat{s}$, the high cost price is $\hat{p}$ at period $t+1$ once information is revealed, at $t+1$, but is set at either $\bar{p}$, if $\tilde{s} < s < \hat{s}$, or $\tilde{p}$, if $s < \tilde{s}$, at period t . As in scenario III, the high cost firm hides behind the possibility of a uniform shock to increase its price by more than cost conditions warrant. In contrast to scenario III, in which this manifests as a gradual decline of the high cost price, here the effect is one of an initial price increase, followed by a

retraction to a level intermediate to the pre- shock price and the short run (period t) price.

Additional Remarks

1. A somewhat troubling implication of the model is that prices may fluctuate even when costs are unchanged at period t. Suppose both firms are initially high cost and remain high cost at period t. The price is $\bar{p}$ at both t-1 and t+1. If the search cost is sufficiently small, however, the price decreases to $\tilde{\bar{p}}$ at period t even though the state is unchanged, because consumers always attribute some probability to an idiosyncratic cost decrease.

Similarly, if costs are initially heterogeneous, the high cost price must rise from $\hat{p}$ at t-1 to $\tilde{\hat{p}}$ at t, if $s < \hat{s}$, or from $\hat{p}$ to $\bar{p}$, if $\tilde{\hat{s}} < s < \hat{s}$, even if costs are unchanged, because consumers always put some probability on a uniform increase.

However, recall that $\tilde{\bar{p}} > \bar{p}$ if the persistence probability, β , is sufficiently large and that $\tilde{\hat{p}} \rightarrow \hat{p}$ as $\beta \rightarrow 1$. Thus the assumption that shocks are relatively infrequent is sufficient to ensure that significant price changes occur only in response to actual cost changes.

An alternative approach is to assume that whenever a cost shock occurs, consumers receive an imperfect signal, which reveals no information about its type (idiosyncratic or uniform). In the absence of this signal, consumers are confident that the preceding period's state persists. Such a modification of the model ensures that prices change only if costs do, without otherwise substantively affecting the preceding analysis.

2. The preceding analysis has assumed that the low cost monopoly price is always a viable price for the high cost firm. It is now easy to assess the consequences of abandoning this assumption. Consider first the case of perfect information. If the firms have different costs, then, for a sufficiently small search cost, $\hat{p} < \bar{c}$. In this case the cost differential is sufficiently large to exclude the idiosyncratically high cost firm from the market. More interesting is the effect of incomplete information. Consider a uniform cost increasing shock when both firms are initially low cost. If s is sufficiently small that $\hat{p} < \bar{c}$, the period t price is $\bar{c}$ and all consumers search. In that case, incomplete information brings about a competitive outcome although both firms revert to monopolistic pricing after information about costs is revealed. Analogous remarks apply to other cost scenarios with obvious modification.

3. Equation (2.1) implies that $\tilde{p} \rightarrow \underline{p}$ as $s \rightarrow 0$. Thus in the *limit*, the period t price is completely inert.. If $s = 0$, however, a competitive equilibrium obtains at each period: the price equals the marginal cost of the highest cost firm in the industry. Thus, if both firms are initially low cost and turn high cost at period t , the price increases from $\underline{c}$ to $\bar{c}$ without any delay. This discontinuity between complete price flexibility when $s = 0$, and extreme price rigidity when s is arbitrarily small (but positive) is but a reflection of the broader "Diamond paradox", that even a small search cost transforms a competitive market to a monopolistic one.

Conclusion

This paper has presented a theory of limited price responsiveness to imperfectly perceived cost changes, in a context of search with learning. The changes in question may be understood as real cost changes, such as oil shocks, but may also be more broadly interpreted as unexpected inflation. It is shown that short run price adjustment may be characterized by undershooting or overshooting.

Empirically, undershooting (scenario 1) is consistent with the evidence for upward price stickiness reported by Cachetti, Kashyap, Lach and Tziddon and others. Overshooting in response to idiosyncratic cost increases is followed by subsequent price reductions, as consumers become better informed and more prone to search (scenario 4). This feature, of price reductions, is consistent with the surprisingly high frequency of price reductions during high inflations, reported by Tomassi [1993] for Argentina and Lach and Tziddon for Israel (see also Weiss, 1983, p.8). An empirically testable implication of my explanation for such price reductions is that they are preceded by above average price increases.

Menu cost models provide an alternative explanation for short run divergence between costs and prices. There are two empirically important differences between menu cost theories and the information theoretic approach of this paper. First, according to the former, expected and unexpected cost changes should have identical effects on prices while my model implies an asymmetric response to expected (about which market participants are well informed) and unexpected changes. Second, menu cost models imply symmetric adjustment dynamics to upward and downward cost changes, while in this model, prices adjust more readily to cost decreases than increases.

Empirical studies of the correlation between relative price variability and inflation may provide some indirect evidence on these two issues, if that association is believed to be the consequence of price rigidities (however, see

Fischer [1981] for several other possible explanations). With regard to the first, this evidence is mixed; Fischer [1981] and Lach and Tziddon find that both expected and unexpected inflation raise price variability, while Blejer and Leiderman [1982] report that only unexpected inflation matters. With regard to the second issue, Fischer [1982] argues that U.S. and German data strongly support the view that only inflation, not deflation, affects relative price variability. This is suggestive of an asymmetric response to increases and decreases.

Appendix

Appendix 1:

The purpose of this appendix is to show that any price p , $\hat{p} < p < \min \{ \tilde{p}, \bar{p} \}$ may also be supported as a high cost equilibrium price if consumers who observe a price greater than p updates her beliefs by assigning probability 1 to the idiosyncratic shock (Bayes' rule does not apply to events off the equilibrium of path). Since $\hat{p}$ is the reservation price of a consumer who believes that the shock is idiosyncratic, a price greater than p leads to search and zero profit for the deviant. This in turn effectively restricts firms from charging more than p .

However, the out of equilibrium beliefs that sustain such equilibria seem to be arbitrarily and unconvincingly prejudiced against the uniform shock. In particular, since both idiosyncratically and uniformly high cost firms have a similar incentive to charge more than p , why should a higher price tilt beliefs towards the idiosyncratic shock? It seems more natural that in response to *any* price less than $\bar{p}$, whether an equilibrium price or not, a consumer remains agnostic and continues to attribute probability σ to the uniform shock. By contrast, $\tilde{p}$ does not require such arbitrary beliefs for its support. As argued above, $\tilde{p}$ is an equilibrium price even if consumers' beliefs about the probability of a uniform shock are independent of the price they observe, and is the only equilibrium price with this property. It therefore seems a natural focal equilibrium and I focus on it in the rest of the paper.

Proof of Proposition 2:

Either $\hat{p} \geq \bar{p}$ or $\hat{p} < \bar{p}$. Suppose $\hat{p} \geq \bar{p}$. Then the monopoly price cannot trigger search even if consumers are certain that the low price is available at the other firm. Therefore the high cost firm will charge $\bar{p}$ in this case regardless of whether the shock is idiosyncratic or uniform. Thus the proposition is true in this case.

Suppose $\hat{p} < \bar{p}$ and the two types of high cost firms charge different prices.

Let p_h be the price of the idiosyncratically high cost firm and p_u the price of the uniformly high cost firm. Then, p_h reveals that the shock is idiosyncratic and that, therefore, by proposition 1.2, the other price in the market is $\underline{p}$. Thus if $p_h > \hat{p}$, buyers would optimally reject p_h , search and buy from the low cost seller. Therefore $p_h \leq \hat{p}$. If $p_h < \hat{p}$, buyers would accept a slightly higher price rather than search. Therefore, since $\hat{p} < \bar{p}$, a deviation to $\hat{p}$ by an idiosyncratically high cost firm is profitable, by concavity of the profit function. This proves that $p_h = \hat{p}$. By analogous reasoning, $p_u \geq \hat{p}$. Since we are assuming that $p_u \neq p_h$, it follows that $p_u > \hat{p}$. Now observe that if $p_u \neq p_h$, p_u reveals that the shock is uniform. A consumer that observes p_u must therefore believe that the other seller's price is p_u as well. Therefore p_u cannot trigger search. Thus, if $\hat{p} < p_u \leq \bar{p}$, the idiosyncratically high cost firm would profitably deviate to p_u without triggering search, to increase profit per customer (by concavity). So the only possibility is that $p_u > \bar{p}$. But then a uniformly high cost firm could profitably reduce its price to $\bar{p}$ without losing customers. This final contradiction completes the proof that $p_u = p_h$.

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¹ Benabou and Gertner (BG) analyze the effect of an aggregate shock on equilibrium price dispersion and welfare in a setting where individual firms' production costs are determined as the product of a common inflationary factor and a privately observed cost shock. They assume that costs are continuously distributed over $(\underline{c}, \bar{c})$. They identify three regions of the search cost. If the search cost is sufficiently high, firms always charge their monopoly price. For intermediate search costs, low cost firms charge their monopoly price and high cost firms charge the consumers' reservation price. For still lower search costs, firms with sufficiently high production costs price at cost and trigger search. The equilibrium derived in this paper when consumers are imperfectly informed (see section 4) which forms the basis for the analysis of price adjustment dynamics, may thus be viewed as a limiting case of the GB model, when the distribution of production costs is concentrated on two mass points at the boundaries of its support. Specifically, the case $s \geq \tilde{s}$ in my analysis corresponds to the first, highest search cost region of BG. The case $s < \tilde{s}$ corresponds to their intermediate search cost region. Finally, the case $\tilde{p} < \bar{c}$, in which consumers search and firms price at cost, corresponds to their low search cost region.

² The consumer's demands at her two periods are assumed to be independent; the product is unstorable (e.g. a service or a perishable product) and there is no intertemporal substitution of consumption.

³ Since marginal costs are constant, and all buyers are identical, the monopoly price is independent of the number of buyers.

⁴ Since the state is defined by the cost *distribution*, the identity of the low and high cost firms is immaterial.

⁵ At her second period, it is costless for a consumer to learn the current price of the firm she patronized in the preceding period. Otherwise, the first period customers of an idiosyncratically high cost firm that charges more than $\underline{p}$ will optimally visit its competitor at the second period. Alternatively, it may be assumed that second period consumers do not remember from which store they bought at their first period.

⁶Firms are always perfectly informed about their own current costs. It is immaterial for the analysis whether they are perfectly informed about their competitor's costs. Thus the issue is incomplete, rather than asymmetric, information.

⁷It is assumed that the search cost is not so large that consumers prefer not participate in the market. Alternatively, it could be assumed that the first price observation is costless.

⁸Diamond actually assumed that consumers have unit demand, in which case price preferences are independent of production costs. The result, that positive search costs sustain monopoly power, carries over trivially to the present setting.

⁹Since its profit function is concave, the high cost firm prefers $\hat{p}$ over any lower price while any higher price earns zero profit.

¹⁰ A formal proof is as follows. Let p_l denote the price of a low cost firm, and p_h that of an idiosyncratically high cost firm. Suppose $p_l < \underline{p}$. If $p_h > p_l$, the low cost firm can increase its price up to $\min\{\underline{p}, p_h\}$ without triggering search, while increasing profit per customer, by concavity of the profit function. If $p_h < p_l$, an analogous argument obtains for the high cost firm. Thus $p_l \geq \underline{p}$. Suppose $p_l > \underline{p}$. If $\underline{p} < p_h$, deviation to $\underline{p}$ is profitable for the low cost firm. If $p_h < \underline{p}$ and $p_l > p_h$ ($p_l \leq p_h$), a slight price increase is profitable for the high cost (low cost) firm. Thus $\underline{p}$ is the unique equilibrium price for the low cost firm.

¹¹This is obvious if firms are no better informed than consumers. The formal proof is required if firms learn about the state without delay; see footnote 6.

¹²This is obviously the case if firms are uninformed; an uninformed firm's price can obviously not affect buyers' beliefs.

¹³Since the high cost price is pooled between the idiosyncratically and uniform high cost firm, the equilibrium price cannot change the consumers' prior.

¹⁴ At any rate, allowing for still lower prices will only strengthen the results. Thus my results are not dependent on a "refinement" of sequential equilibrium.

¹⁵ As in the preceding subsection, lower equilibrium prices exist but require unintuitive beliefs.

¹⁶If $s \geq \hat{s}$, the high cost price is $\bar{p}$ even at $t-1$.

¹⁷ This argument is reminiscent of Akerloff and Yellen (1985).

¹⁸ The effect of the search cost on this dynamic is less clear cut than in the preceding scenarios. The smaller is s , the lower is the price at $t+1$, $\hat{p}$.

However, lower s also defines a lower value for the interim price, $\tilde{\tilde{p}}$.

TABLE 1

type of transition	period t price	critical search cost
$(\underline{c}, \underline{c}) \Rightarrow (\bar{c}, \bar{c})$	$\tilde{p}$ (eq. 2.1)	$\tilde{s}$ (eq.2.2)
$(\bar{c}, \bar{c}) \Rightarrow (\bar{c}, \underline{c})$	$\tilde{p}$ (eq. 2.1)	$\tilde{s}$ (eq.2.2)
$(\bar{c}, \underline{c}) \Rightarrow (\bar{c}, \bar{c})$	$\tilde{\tilde{p}}$ (eq. 3.1)	$\tilde{\tilde{s}}$ (eq.3.2)
$(\underline{c}, \underline{c}) \Rightarrow (\bar{c}, \bar{c})$	$\tilde{\tilde{p}}$ (eq.4.1)	$\tilde{\tilde{s}}$ (eq.4.2)

$$\tilde{p} \quad \tilde{\tilde{p}} \quad \tilde{\tilde{\tilde{p}}} > \hat{p} \quad ; \quad \tilde{s} \quad \tilde{\tilde{s}} \quad \tilde{\tilde{\tilde{s}}} < \hat{s}$$

FIGURE 1

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