Business as Usual: A Consumer Search Theory of Sticky Prices and Asymmetric Price Adjustment

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Abstract

Empirical evidence suggests that prices are sticky with respect to cost changes. Moreover, prices respond more rapidly to cost increases than to cost decreases. We develop a search theoretic model which is consistent with this evidence and allows for additional testable predictions. Our results are based on the assumption that buyers do not observe the sellers' costs, but know that cost changes are positively correlated across sellers. In equilibrium, a change in price is likely to induce consumer search, which explains sticky prices. Moreover, the signal conveyed by a price decrease is different from the signal conveyed by a price increase, which explains asymmetry in price adjustment.

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1 Introduction

A basic premise of "neo Keynesian" macroeconomic models is that prices do not immediately adjust to changes in costs — they are 'sticky' (Taylor 1980; Calvo, 1983; Woodford, 2003). This premise has been borne out by many empirical studies. In a survey of 200 firms, Blinder et al. (1998) found that the median firm adjusts prices about once a year. Hall, Walsh, and Yates (2000) obtained similar results in a survey of 654 British companies. In a study of newsstand prices of 38 American magazines over 1953–79, Cecchetti (1986) determined that the number of years since the last price change ranged from 1.8 to 14 years. Kashyap (1995), in a study of the monthly prices of mail-order catalog goods, found an average of 14.7 months between price changes. MacDonald and Aaronson (2001) determined that restaurant prices display a median duration of about 10 months. In a broad sample of consumer goods, Bils and Klenow (2004) found that the median consumer good changes prices every 4.3 months.

The standard explanation for price stickiness is that there is a fixed physical cost that firms must pay whenever they change a price — a menu cost. This approach is frequently criticized on the grounds that for most products it is difficult to identify any significant fixed physical costs of changing prices.

An alternative explanation for sticky prices is provided by the recent literature on inattentiveness (Mankiw and Reis, 2002; Reis, 2006). According to this view, agents have limited ability to absorb, process and interpret information. As a result, firms optimally fail to update their information about costs continuously, only doing so at specific dates. Accordingly, prices are only seldom adjusted.

The purpose of this paper is to develop a search theoretic model of sticky consumer prices. We consider an industry where input costs are sticky and show that consumer search costs lead to output prices that are stickier than input costs. To understand the mechanism for this "increasing stickiness" pattern, suppose that consumer prices are currently in equilibrium (specifically, in a Diamond-type equilibrium). The idea is that, if firm i's cost changes by a small amount, then firm i is better off by not changing its price. In fact, if price remains constant then consumers rationally believe there have been no cost shocks, and consequently refrain from searching: it's business as usual. By contrast, changing price "rocks the boat," that is, leads consumers to search; and the potential loss from consumers searching rivals' prices outweighs the potential gain from adjusting price to its new optimal level.

While our analysis is motivated by evidence of price stickiness, we are also interested in the stylized fact that prices adjust (upward) more quickly to cost increases than (downward) to cost decreases (see Peltzman, 2000, and references therein). Our model accounts for such asymmetric behavior in a natural way. The idea is that a small price increase (decrease) signals a positive (negative) cost shock. As a result, the potential gains from search are greater following a small price decrease than a small price increase. This implies that the above effect ("business as usual" beats "rocking the boat") is especially relevant following a small cost decrease.

■ **Related literature.** In addition to the inattentiveness literature mentioned above, a number of related papers develop models of sticky prices. Fishman (1995) uses a similar reasoning to ours to show that when consumers are uninformed about cost increases, prices increase more slowly than if they are informed. Fishman's model applies only to cost increases; moreover, it does not deliver price stickiness. Menzio (2006) also develops a search model in which prices are sticky or adjust slowly. In his model, it is costly for consumers to switch sellers. Therefore, consumers choose a seller on the basis of not only its current price but also expected future prices. To accommodate consumer preference for price stability, sellers commit to future prices (as a function of future costs). Prices may fail to adjust to cost changes because buyers use a seller's current price to predict its future prices. By contrast, in our model, sellers do not commit to future prices and consumers use the firm's current price to infer *competing* firms' *current* prices. Benabou and Gertner (1993) develop a related search theoretic model to analyze the effect of an aggregate shock on equilibrium price dispersion and welfare when firms' costs are determined as the product of a common inflationary factor and a privately observed idiosyncratic shock.

Regarding asymmetric price adjustment, the most related pieces are Lewis (2005), Tappata (2006) and Yang and Ye (2006). In Lewis' model sellers are homogenous sellers, buyers form adaptive expectations about the current price distribution and buyers search sequentially and optimally with respect to past prices but not necessarily with respect to actual prices. In Tappata (2005) and Yang and Ye (2006) there are two cost states, firms have identical costs and use mixed strategies to set prices; and consumers, who are imperfectly informed about the current cost, search non-sequentially. When the cost is known to consumers, search is more intensive and there is greater price dispersion in the low cost state than in the high state. Thus if the cost turns low but consumers believe it to be high, buyers have less of an incentive to search and therefore sellers have less of an incentive to lower prices. In neither of those models are prices sticky.

The paper is structured as follows. In Section 2, we lay down the basic model structure. Next we completely solve for a particular numerical example yielding sticky prices (Section 3). Section 4 presents a general result on price stickiness. Section 5 focuses on asymmetric price adjustment; it includes a number of empirical testable implications of our model. We conclude with Section 6.

2 Model

We consider a model with two firms and a continuum of consumers (of mass two). Time is infinite and discrete: $t = 0, 1, \ldots$ In each period, consumers demand a quantity $q(p)$ from the seller with the lowest observed price, where $q(p)$ represents a downward sloping demand curve. We have in mind a product which is consumed repeatedly and for which the quantity demanded is sensitive to price. Examples include cable, cell phone, and restaurant services, when the buyer is the final consumer;[1] and production inputs (such as flour), when the buyer is a firm (such as a bakery).

1. The demand for cable and cell phone services is downward sloping to the extent that following a price increase consumers switch to a lower q tier or plan, respectively. The demand for restaurant meals is downward sloping to the extent that, as prices increase, consumers dine out less frequently or skip desert, wine, more expensive dishes, etc.
The model could also accommodate the case of unit demand by introducing heterogenous consumers with different reservation prices. This would lead to a more complicated model.

Let $\mu(p)$ be the consumer's surplus from buying at price p. Let $\pi(p; c)$ be a firm's profit given price p, cost c, and a mass one of consumers. We assume that $\pi(p; c)$ is quasi-concave and denote by $p^m(c)$ the monopoly price for a firm with cost c. Seller i's unit cost at time t, c_{it}, evolves according to a Markov process where the state is given by both sellers' costs. The probability of a change in the state is given by γ; that is, with probability $1 - \gamma$ both sellers' costs are the same as in the previous period.

We assume that the Markov transition function is common knowledge. At each period t, firm i is informed about its own cost. By contrast, consumers only learn about changes in the state every k periods. Specifically, consumers are perfectly informed about firms' costs at periods $0, k, 2\,k$, and so on, but any changes in the state which occur between periods $n\,k$ and $(n+1)\,k$ are only learned at period $(n+1)\,k$, for $n = 0, 1, \ldots$[2] Similarly, firm j only learns about changes in firm i's cost every k periods. The idea is that it is too costly for agents to continually update and interpret information about the economy, so agents are "inattentive" to new information most of the time and only update information at pre-specified intervals. The assumption that this updating is coordinated between consumers is clearly artificial and is made for tractability — in a richer model k would be endogenously derived from model parameters and the dates at which information is updated might be distributed across individuals.

At periods $0, k, 2\,k, \ldots$ consumers are randomly assigned to each seller, a mass one to each seller; that is, every k periods a consumer is randomly reassigned to a different seller. This assumption is inessential but simplifies the analysis by ensuring that a consumer bases his decision of whether to search only on his utility from consumption up to the time that new information arrives and not on his future utility over his entire horizon. Sellers then simultaneously set prices. Each seller's price is initially observed only by the consumers attached to it. Consumers then decide whether to observe the other seller's price, at a cost s.

Throughout the paper, we will be considering the case when $k = 2$, though many of our qualitative points apply more generally. Finally, we will

2. It is sufficient that consumers are informed of the cost distribution, not which firm has what cost — in equilibrium knowledge of the cost distribution and one firm's price implies the other firm's price.

be looking at Bayesian Equilibria (BE) of the above game.

3 An example

In order to understand the main intuition, it helps to begin by considering a specific numerical example. Recall that we assume $k = 2$, so that consumers are informed about the state at even numbered periods but not at odd numbered periods. Consider first an even numbered period, say period 0, and suppose both firms have cost $c_{i0} = \frac{1}{2}$. With probability $1 - \gamma$, c_{i1} is the same as c_{i0}. With probability γ, both costs change. Given that costs change, they are independently and uniformly distributed in $[0, 1]$. We will assume that the value of γ is very small. For the purpose of deriving the equilibrium, it helps to think of the set of states when costs change as measure zero (thus, $\gamma = 0$), though, by continuity, the results will also hold for small γ. Finally, suppose that demand is given by $q = a - p$. (In the particular equilibrium depicted in Figure 1, we consider $a = 2$ and $s = 1/200$.)

Let us first consider pricing at $t = 0$. Suppose that strategies and beliefs in $t = 1$ do not depend on $t = 0$ prices. (Later we will return to this assumption.) Then the situation is analogous to the Diamond (1971) pricing game. In equilibrium, both firms set their monopoly price. Monopoly price is given by $p^m(c) = (a + c)/2$, which in our example yields $p_{i0} = 1.25$. To see that this is indeed a Nash equilibrium, notice that, if both firms set the same price, then consumers have no incentive to search. Since consumers do not search, no firm has an incentive to set a different price. In fact, as Diamond (1971) has shown, this is the unique equilibrium.

Let us now focus on pricing in $t = 1$. We will show that the following constitutes a Bayesian Equilibrium (see Figure 1 for a graphical representation). The sellers' pricing policy is as follows:

$$p_{i1} = \begin{cases} p^m(c_{i1}) & \text{if} \quad c_{i1} \leq c' \\ p^m(c') & \text{if} \quad c' < c_{i1} \leq c'' \\ p_{i0} & \text{if} \quad c_{i1} > c'' \end{cases}$$

Regarding buyers, their strategy is as follows:

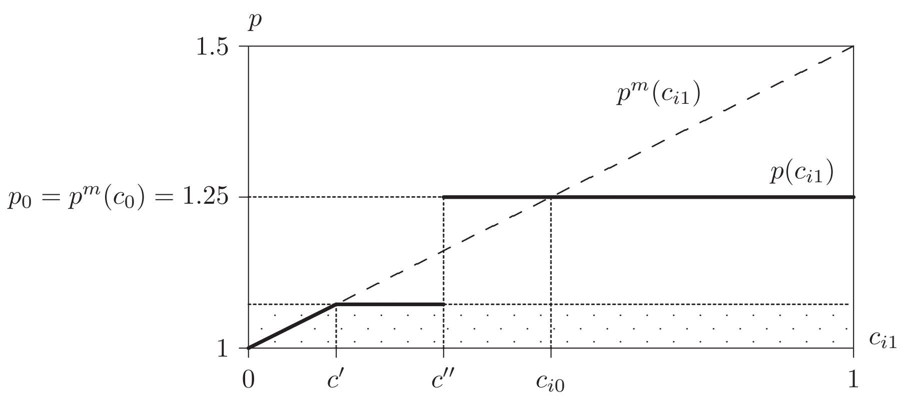

Figure 1: Equilibrium price as a function of cost in numerical example. Costs are uniformly distributed; demand is linear: $q = 2 - p$; initial cost is $c_0 = .5$ for both firms. The equilibrium cost thresholds are given by $c' = .107$, $c'' = .322$

If $p = p_{i0}$ or $p \leq p^m(c')$, then do not search.

Otherwise, search.

Notice that, if costs do not change, then prices do not change either. Moreover, there is a wide range of values of c_{i1} (specifically, $c_{i1} \in [c'', 1]$) such that prices remained unchanged. In this sense, the above equilibrium *magnifies* the stickiness of input costs: in period 1 (and more generally, in a period $t < k$), prices remain constant with greater probability than costs remain constant.

Given $k = 2$, consumers will learn the firms' costs at $t = 2$. This will lead firms to adjust prices to a new Diamond-type equilibrium. In other words, even if costs do not change from $t = 1$ to $t = 2$, prices will change (assuming costs, but not prices, changed in $t = 1$). In this sense, the pattern implied by the equilibrium above is one of delayed impact of cost changes on prices. Moreover, for higher values of k, we could have several small cost changes in periods $1, 2, \ldots, k - 1$, none of which would be reflected in a price change. In this sense, the above results imply that output prices change with lower frequency than input prices.

To summarize, the implication of the equilibrium strategies is a pattern of price stickiness whereby (a) prices vary less frequently than costs, and (b) prices respond slowly to cost changes.

We now show that the above strategies are indeed a Bayesian equilibrium. We begin by showing that the buyers' strategy is optimal and their beliefs consistent. If the buyer observes a price $p_{i1} = p_{i0}$, then with probability 1 costs have not changed; and, given the sellers' strategy, the rival firm's price has not changed. This implies that the gains from search are zero. Suppose now that the buyer observes $p \neq p_{i0}$. This implies that costs have changed. In particular, the rival firm's cost is uniformly distributed in $[0, 1]$. For a small value of p (specifically, for $p < p^m(c')$), expected surplus in case the buyer searches for the lowest price is given by

$$\int_0^c \mu\big(p^m(x)\big)\, d\,x + (1 - c)\ \mu\big(p^m(c)\big).$$

where c is the cost level such that $p = p^m(c)$. In words, if seller j's cost is $x < c$, then the buyer receives surplus $\mu\big(p^m(x)\big)$. If, on the other hand, $x > c$, then the buyer sticks with seller i's $p^m(c)$ and earns a surplus $\mu\big(p^m(c)\big)$.

Given our assumption of linear demand, we have

$$\begin{aligned} p^m(c) &= \frac{1}{2}\,(a + c) \\ \mu(p) &= \frac{1}{2}\,(a - p)^2. \end{aligned}$$

Substituting in the above expressions and simplifying, we get a *net* expected benefit from searching equal to

$$R(c) = c^2\left(\frac{a}{8} - \frac{c}{12}\right).$$

The derivative of $R(c)$ with respect to c is given by $\frac{(a-c)\,c}{4}$, which is positive. Moreover, $R(0) = 0$. It follows that there exists a positive value of c, say c', such that, given the above seller strategies, the net benefit from search is positive if and only if $p_{i1} > p^m(c')$ (and $p_{i1} \neq p_{i0}$). Specifically, c' is given by $R(c') = s$.

Consider now the seller's strategy. Notice that, along the equilibrium path, no search takes place. This implies that, in considering what price to set, each firm is only concerned about its customers' search behavior. In other words, at best a firm manages not to lose it customers; it will never attract its rival's customers. For $c < c'$, the seller's strategy is clearly optimal: consumers do not search even as the seller sets its monopoly price.

If $p^m(c') < p_{i1} < p_{i0}$, then consumers search. Given the rival seller's pricing strategy, the deviating seller keeps its buyers if and only if the rival's cost is greater than c'', which happens with probability $1-c''$. Of all the price levels between $p^m(c')$ and p_{i0}, the deviating seller prefers $p^m(c)$: it maximizes profits given a set of buyers; and the set of buyers does not depend on price (within that interval). If follows that the deviation profit is given by

$$(1-c'')\big(a - p^m(c)\big)\big(p^m(c) - c\big).$$

Since the profit function is quasi-concave, the best alternative price levels are $p^m(c')$ and p_{i0}. The seller prefers $p = p^m(c')$ if and only if

$$\big(a - p^m(c')\big)\big(p^m(c') - c\big) > \big(a - p_{i0}\big)\big(p_{i0} - c\big).$$

In the linear case we are considering, it can be shown that

$$\big(a - p^M(c')\big)\big(p^M(c') - c\big) - \big(a - p_{i0}\big)\big(p_{i0} - c\big) = \frac{1}{2}\left(c_{i0} - c'\right)\left(\frac{c_{i0} + c'}{2} - c\right).$$

Let $c'' \equiv \frac{c_{i0}+c'}{2}$. Clearly, the above difference is positive if and only if $c < c''$. It follows that the seller's best alternative to $p^m(c)$ is $p^m(c')$ if $c < c''$ and p_{i0} otherwise. The no-deviation constraint is most binding precisely when $c = c''$, in which case it becomes

$$(1-c'')\big(a - p^m(c'')\big)\big(p^m(c'') - c''\big) \le \big(a - p_{i0}\big)\big(p_{i0} - c\big).$$

We are not aware of a general analytical proof that this conditions holds. In the linear case, a sufficient condition is that a be large enough. An alternative set of sufficient conditions is $c_{i0} < 1$ and $a \ge c_{i0}$. All of these conditions are satisfied by the parameter values we consider.

Finally, pricing above p_{i0} is clearly a dominated strategy as the seller would lose all of its customers. (Notice that the maximum value of cost is lower than p_{i0}, so the seller can always make a positive profit.)

4 General result

We now consider a more general result that does not depend on the very specific distributional assumptions underlying the example in the previous section. For simplicity, we continue to assume $k = 2$, though the nature of our result is more general. Our general result depends however on some key restrictions to a class of Bayesian equilibria (BE) as well as assumptions regarding the stochastic process governing costs. As often happens with price signalling games, there exist multiple BE. Consider the example in the previous section and an alternative equilibrium whereby, if costs do not change, then firms decrease prices by ϵ. By similar arguments to those in Section 3, one can construct a BE with such feature. Notice in particular that a firm whose cost does not change would be worse off by not changing price. In fact, in equilibrium consumers interpret no price change as implying there was a cost change. Consequently, they search, only to find out that the rival firm did lower its price by ϵ. Even if ϵ is very small (and lower than search cost), it is still greater than zero. Consequently, consumers switch to the rival seller. In summary, we can construct a continuum of BE. We thus consider two equilibrium properties that effectively rule out unreasonable equilibria like the one above.

Definition 1 (Markov) *A Bayesian Equilibrium satisfies the Markov property if seller strategies and buyer beliefs in $t = 1$ only depend on history through $t = 0$ costs.*

This property implies that equilibrium prices in $t = 0$ can be analyzed as part of a one-shot game because prices in $t = 0$ have no impact on future beliefs or strategies.

Definition 2 (status quo) *A Bayesian Equilibrium satisfies the status quo property if prices do not change when costs do not change.*

This property avoids the kind of unreasonable equilibria described above, where consumers interpret sticky prices and implying that costs have changed.

Regarding the stochastic process of firm costs, the assumption below implies that, given that costs change, the new value of cost is imperfectly correlated across firms. There are different ways of formally expressing these properties and we could write down a different set of assumptions from the ones below. While the exact way in which the assumptions are formulated is not critical, the the feature of imperfect positive correlation is crucial.

Specifically, let $c_{it} \in [\underline{c}, \overline{c}]$. Let $F(c_{i1}, c_{j1} \,|\, c_{i0}, c_{j0})$ be the joint density of costs at $t = 1$ *conditional on a cost change.* Let $F_i(c_{i1} \,|\, c_{j1}, c_{i0}, c_{j0})$ be the corresponding marginal distribution. Let $f(c_{i1}, c_{j1} \,|\, c_{i0}, c_{j0})$ and $f_i(c_{i1} \,|\, c_{j1}, c_{i0}, c_{j0})$ be the corresponding densities. In the following statement, for simplicity we omit the arguments of f and f_i.

Assumption 1 (conditional cost independence) *(a) f and f_i are continuous everywhere; (b) there exists a $\rho < 1$ such that $1 - \rho \leq \frac{f_i f_j}{f} \leq 1 + \rho$ for all c_{i1}, c_{j1}; (c) there exist $\underline{f}, \overline{f}$ such that $0 < \underline{f} \leq f_i \leq \overline{f} < \infty$ for all i, c_{i1}, c_{j1}.*

We are now ready to state our main result.

Proposition 1 (price rigidity) *Suppose that, with probability $1 - \gamma$, $c_{i1} = c_{i0}$. There exist $\gamma', s', \Delta_0(s), \Delta_1(s)$ such that, in a Bayesian equilibrium satisfying Definitions 1–2 and Assumption 1, if $\gamma < \gamma'$, $s < s'$, $c_{i0} > \underline{c}$, $|\, c_{i0} - c_{j0} \,| < \Delta_0(s)$, and $|\, c_{i1} - c_{i0} \,| < \Delta_1(s)$, then $p_{i1} = p_{i0}$.*

In words, if c_{i0} and c_{j0} are sufficiently close together, the search cost is sufficiently small and if a firm's cost changes by a small amount, then its price remains constant. As shown in the previous section, this result implies stickiness in two senses: first the effect of a cost change is typically delayed (in the case when $k = 2$, a cost change in $t = 1$ is reflected in a price change at $t = 2$); and second, the frequency of price changes is lower than the frequency of cost changes (in the case when $k = 2$, cost change both at $t = 1$ and $t = 2$, whereas price only changes at $t = 2$).

The assumption that costs in $t = 0$ are close to each other allows us to apply the Diamond (1971) equilibrium in period 0. In the Appendix, we discuss an extension of Proposition 1 to the case when cost differences are significant.

5 Asymmetric price stickiness

Several studies (Peltzman, 2000, and references therein) indicate that prices decrease more slowly when costs go down and that they increase when costs go up. In this section we show that our model can accommodate this pattern

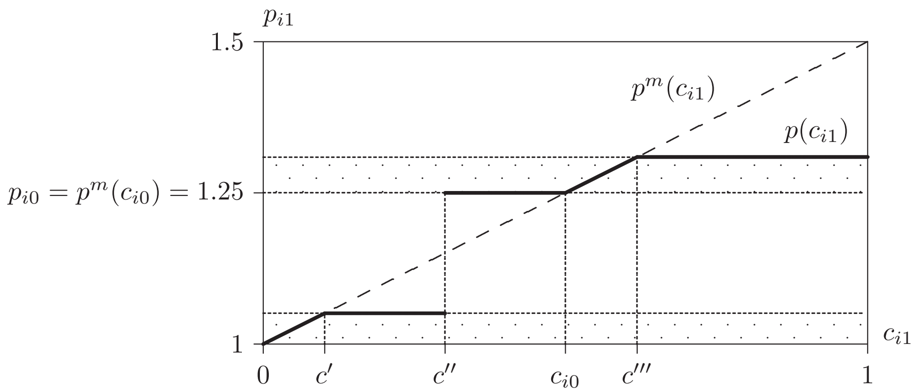

Figure 2: Equilibrium price as a function of cost in numerical example. Costs are uniformly distributed; demand is linear: $q = 2 - p$; initial cost is $c_{i0} = .5$ for both firms. The equilibrium cost thresholds are given by $c' = .102$, $c'' = .301$, $c''' = .619$.

in a natural way. In the example presented in Section 3, we assumed that, conditional on a cost change, firm i's cost is independent of firm j's. One would expect some positive correlation between firm costs when they change. We now consider a revised version of the example where costs are correlated.

As before, costs change with a (small) probability γ. We now assume that, if costs change, then either both costs increase or both costs decrease. Specifically, costs are independently and uniformly distributed in $[0, c_{i0}]$ (if costs increase) or $[c_{i0}, 1]$ (if costs increase). We moreover assume, as before, that $c_{i0} = c_{j0}$.

The derivation of the Bayesian equilibrium is similar to Section 3. The crucial difference with respect to the previous example is that firms increase prices when their cost increases. The reason is that a price increase by firm i signals a cost increase by firm i. And, to the extent that costs are correlated, it also signals an increase in firm j's price. It follows that consumers may prefer not to search despite a cost increase, provided it's small enough.

Specifically, the seller's equilibrium strategy is given by

$$p_{i1} = \begin{cases} p^m(c_{i1}) & \text{if} \quad c_{i1} \le c' \\ p^m(c') & \text{if} \quad c' < c_{i1} \le c'' \\ p_{i0} & \text{if} \quad c'' < c_{i1} \le c_{i0} \\ p^m(c_{i1}) & \text{if} \quad c_{i0} < c_{i1} \le c''' \\ p^m(c''') & \text{if} \quad c_{i1} > c''' \end{cases}$$

Regarding buyers, their strategy is as follows:

$$\begin{array}{lll} \text{if} & p_{i1} \le p^m(c') & \text{then do not search} \\ \text{if} & p^m(c') < p_{i1} < p_{i0} & \text{then search} \\ \text{if} & p_{i0} \le p_{i1} \le p^m(c''') & \text{then do not search} \\ \text{if} & p_{i1} > p^m(c''') & \text{then search} \end{array}$$

These equilibrium strategies are illustrated in Figure 2. Similarly to Section 3, they imply a pattern of price stickiness whereby (a) prices vary less frequently than costs, and (b) prices respond slowly to cost changes. Moreover, we now notice a clear asymmetry in the way prices respond to small cost changes: prices remain unchanged following small cost decreases but increase following small cost increases. Finally, we never observe large price increases, whereas we do observe large price decreases.

We now show that the above strategies constitute a Bayesian equilibrium. For low values of c, the seller's strategy is similar to Section 3. As before, we have threshold levels c' and c''. One difference is that, by observing a price lower than p_{i0}, consumers believe costs to be distributed in $[0, c_{i0}]$. This implies greater expected benefits from searching. As a result, we obtain lower values of c', c'' than in Section 3.

Now suppose that p_{i1} is greater than, but close to, p_{i0}. Given the sellers' pricing strategy, buyers infer that costs are uniformly distributed in $[c_{i0}, 1]$. By searching, a buyer receives an expected surplus

$$\frac{1}{(1 - c_{i0})} \left(\int_{c_{i0}}^{c} \mu\big(p^m(x)\big) \, d\, x + (1 - c_{i0}) \, \mu\big(p^m(c)\big) \right).$$

where c is the cost level such that $p = p^m(c)$. In words, if seller j's cost is $x < c$, then the buyer receives surplus $\mu\big(p^m(x)\big)$. If, on the other hand, $x > c$, then the buyer sticks with firm i's $p^m(c)$.

By not searching, the buyer receives a surplus $\mu\big(p^m(c)\big)$. Given our assumption of linear demand, we get a *net* expected benefit from searching equal to

$$R(c) = \frac{(a - c_{i0})^3 - (a - c)^3}{24\, c_{i0}} + \frac{(a - c)^2\,(c_{i0} - c)}{8\,(1 - c_{i0})}.$$

The derivative of this expression with respect to c is given by $\frac{(a-c)\,(c-c_{i0})}{4\,(1-c_{i0})}$, which is positive. Moreover, $R(c_{i0}) = 0$. It follows that there exists a value of c greater than c_{i0} such that the net benefit from search is equal to the search cost. Let c''' be such value, that is, $R(c''') = s$. It follows that, for $p_{i0} < p_{i1} \leq p^m(c''')$, consumers are better off by not searching.

By the same token, if $p_{i1} > p^m(c''')$, then consumers prefer to search. The fact $p_{i1} > p_{i0}$ signals that costs are uniformly distributed in $[c_{i0}, 1]$, as in the previous case; and since $R(c) > s$, it pays to search.

This concludes the proof that the buyers' strategy is a best response to the seller's strategy; and that the buyers' beliefs are consistent with the sellers' strategy. Regarding the seller's strategy, the argument is essentially identical to Section 3.

■ **Empirical implications.** The preceding example shows that when the *direction* of cost change is sufficiently correlated across firms, then, for small cost changes, prices respond more rapidly to cost increases than to cost decreases. We now derive a series of empirical implications of this theoretical result.

□ **Speed of price response to cost changes.** Throughout the paper, we have been considering the case when $k = 2$, that is, buyers know both seller's costs at even periods ($t = 0, 2$) but not during odd periods ($t = 1, 3$). As Figure 3 illustrates, our equilibrium seems consistent with the idea that, for small cost changes, prices respond more rapidly to cost increases than to cost increases. Specifically, the figure considers a situation where costs increase by a bit from $t = 0$ to $t = 1$ and then decrease by a bit from $t = 2$ to $t = 3$. As can be seen, a cost increase is immediately reflected in

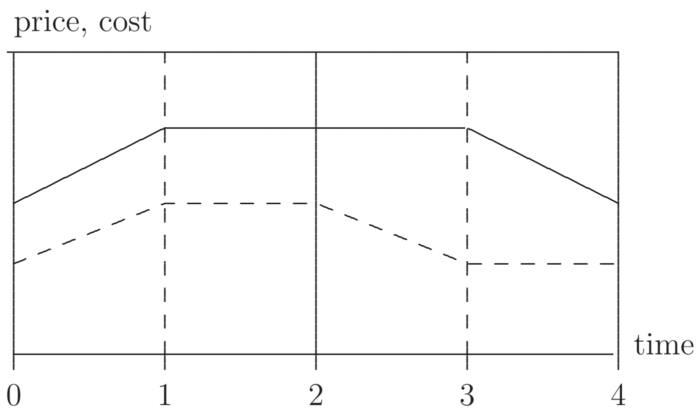

Figure 3: Cost changes and price changes.

a price increase; whereas a cost decrease results in a price decrease with a lag. Peltzman (2000) presents evidence that is consistent with the pattern illustrated by Figure 3.

□ **Correlation between cost changes and price changes.** A related empirical implication is that there is a greater correlation between cost changes and price changes on the way up than on the way down. Buckle and Carlson (1998) survey New Zealand businesses and ask them in separate questions whether prices were raised or lowered in a particular quarter; and whether costs increased or decreased. They find that price and cost increases paired more frequently in the same quarter than price and cost decreases.

□ **Frequency and size of price changes.** The example presented above suggests that price decreases are less frequent than price increases; and that the absolute value of price increases is smaller than the absolute value of price decreases.

Evidence for the Euro area seems consistent with the above predictions. Table 1 indicates that on a given month prices increase with probability 8% but decrease with probability of only 6%. The average price increase is 8%, whereas the average price decrease is 10%. Regarding the size of price changes in the U.S., Bils and Krivstov (2004) report average values of 13% (price decreases) and 8% (price increases).

Table 1: Frequency and size of price change in the Euro area. Source: Dhyne et al (2004).

	Product category					
	UPF	PF	EN	NEIG	SER	Total
Frequency (%)						
Increase	15	7	42	4	4	8
Decrease	13	6	36	3	1	6
Size (%)						
Increase	15	7	3	9	7	8
Decrease	16	8	2	11	9	10

Key: UPF: unprocessed food; PF: processed food; EN: energy; NEIG: non-energy industrial goods; SER: services

It is also interesting to notice the variation across classes of products. Again for the Euro area, Dhyne et al (2004) report that "price changes are very frequent for energy products (oil products) and unprocessed food, while they are relatively infrequent for non-energy industrial goods and particularly services" (p 16). The authors claim that the same result is obtained for the U.S. B.L.S. data used by Bils and Klenow (2004). While we don't have a complete explanation for this variation, it seems reasonable to assume that, for unprocessed foods and oil products buyers are better aware of cost variations. In our model, this would imply the absence of stickiness due to search costs.

Our theoretical model considers a zero-inflation environment. It is not clear how it should be adapted to take into account the fact there is a positive expected change in cost (and price). Dhyne et al (2003) regress the size of price increases and decreases on a variety of controls, including inflation, product dummies and country dummies. The constant for price increases is 0.043, and that for price decreases 0.057. Both are significant at the 5% confidence level. This seems broadly consistent with our theoretical prediction. Moreover, empirical evidence suggests that, in Europe and in the U.S., price volatility is fairly significant with respect to overall inflation. In this sense the situation may not be very far from the no-inflation reference point.

□ **Asymmetry in the small.** In the example above, the asymmetry in frequency of price changes results from the fact that small cost decreases lead to no change in price. More generally, we expect that the asymmetry in rates of price adjustment is particularly high for small cost changes. Levy et al (2005) present evidence that seems consistent with this prediction. Analyzing scanner data that cover 29 product categories over a eight-year period from a large Mid-western supermarket chain, they show that small price increases occur more frequently than small price decreases; no such asymmetry is found for larger price changes.

□ **Price stickyness and asymmetric adjustment.** Our asymmetry results depend critically on the assumption of cost stickiness (specifically, that costs remain unchanged with probability $1 - \gamma$, where γ is small). Consider the opposite case: costs are independent across periods. In this case, equilibrium prices in period 1 do not depend on period 0 prices, rather are given by a smooth increasing price function; in particular, no asymmetry in prices will be observed. These two extreme results suggest that lower cost volatility is associated with greater price adjustment asymmetry. In an attempt to "fish out" for possible explanations for asymmetry in price adjustment, Peltzman (2000) regresses the degree of asymmetry on a series of correlates. One of the more robust predictors is the degree of input price volatility: a more volatile input price is correlated with lower asymmetry in price setting. This seems consistent with our theory.[3]

6 Conclusion

Much of the current literature on price rigidity is based on the idea of menu costs. However, in order to fit the stylized facts on price rigidity the required size of menus costs is rather high. In this paper, we present a consumer search theory of price rigidity that does not require menu costs. To some extent, one may reinterpret the idea of menu costs to include a decrease in seller profit resulting from price change. In this broad sense, our model does feature menu costs. However, such loose interpretation of menu costs is of

3. Also, Table 1 shows that the category for which there is greater volatility in prices is also the category where the pattern predicted by our model fails to hold.

little help: the size of such menu cost is not fixed as in the traditional physical menu cost case; in particular, it will be different depending on whether price increases or decreases.

Appendix

Proof of Proposition 1: The proof is divided into two parts. In the first part, we show that, across all BE, there exists a unique value c_1 (like the one derived in the example of Section 3) such that, for $c < c_1$, a firm is better off by setting $p = p^m(c)$. In the second part, we show that this implies that, for a small cost change from the initial cost, a firm strictly prefers not to change its price.

□ **Step 1.** First, let us show that, in a PBE, it must be that $p_i(c) \geq p^m(0)$. Suppose the opposite is true, that is, suppose the lower bound of seller i's pricing strategy, p_i', is such that $p_i' < p^m(0)$. Also suppose, without loss of generality, that $p_i' \leq p_j'$. Consider the critical value p_i'' given by

$$\mu\bigl(p_i'\bigr) - \mu\bigl(p_i''\bigr) = s.$$

Clearly, in such an equilibrium no search would take place if $p_i \leq p_i''$. If fact, even if the rival seller were to set the lowest price, p_i', with probability 1, it wouldn't pay to search. But then, regardless of cost, seller i is strictly better off by setting $p_i = \min\{p_i'', p^m(0)\}$ than by setting p_i'. By construction, seller i would not lose buyers; neither would it fail to gain any buyers from the rival seller: if the rival seller's buyers search, it must be that $p_j > p_i''$, in which case seller i captures those buyers equally well with p_i' and p_i''. Finally, given that the profit function is quasiconcave, p_i'' leads to higher profit per buyer than p_i'. We thus reach a contradiction and prove that the lower bound p_i' must be greater or equal to $p^m(0)$. In fact, we will next see that it is indeed equal.

Let c' be defined by

$$\mu\bigl(p^m(c')\bigr) - \mu\bigl(p^m(0)\bigr) = s.$$

If $p < p^m(c')$, then the buyers' best response is not to search. If fact, even if the rival seller were to set the lowest price, $p^m(0)$, with probability 1, it wouldn't pay to search. It follows that, if $0 < c < c'$, then it is optimal for sellers to set $p = p^m(c)$; and for $c > c'$, optimal price is greater or equal to $p^m(c')$. In particular, given that the profit function is quasiconcave, it does not pay to set a price lower than $p^m(c')$.

Consider a buyer who observes price p'. Let c' be such that $p' = p^m(c')$. Given the sellers' strategy, the buyer's expected utility from searching is given by

$$\int_0^{c'} \mu\big(p^m(x)\big)\, dx + (1 - c')\; \mu\big(p^m(c')\big)$$

Let c'' be defined by

$$\mu\big(p^m(c'')\big) - \left(\int_0^{c'} \mu\big(p^m(x)\big)\, dx + (1 - c')\; \mu\big(p^m(c')\big) \right) = s.$$

For the same reasoning as before, it follows that, if $0 < c < c''$, then it is optimal for sellers to set $p = p^m(c)$; and for $c > c''$, optimal price is greater or equal to $p^m(c'')$. In particular, given that the profit function is quasiconcave, it does not pay to set a price lower than $p^m(c'')$.

Notice that $c'' > c'$. This process can be repeated, obtaining a strictly increasing, bounded sequence $c', c'', c''', \ldots$ which converges to a value c_1 given by:

$$\mu\big(p^m(c^\ell)\big) - \left(\int_0^{c_1} \mu\big(p^m(x)\big)\, dx + (1 - c_1)\; \mu\big(p^m(c^\ell)\big) \right) = s.$$

□ **Step 2.** Definition 1 implies that pricing in period 0 can be analyzed as a one-shot game. From Diamond (1971), we know that, if costs are approximately equal (specifically, if $|\, p^m(c_i) - p^m(c_j)\, | < s$), then in equilibrium each firm sets its monopoly price. In the second period, suppose that any price out of the equilibrium path leads consumers to believe there has been a cost change. Assumption 1 implies that the expected gain from from search is strictly positive. It follows that, if s is small enough, then consumers will search. Finally, since $p_i^0 = p_i^m(c_0)$ and c_i is close to c_i^0, the envelope theorem implies that the profit increase firm i can hope for by adjusting its price is of second order, while the expected loss if consumers search is of first order.

Finally, we need to justify the assumption that any out-of-equilibrium price leads buyers to believe there has been a cost change and therefore search. Let us now consider the possibility of alternative off-the-equilibrium beliefs. Whatever those beliefs are, suppose that no consumer searches following p' off the equilibrium path. Then a seller with cost $c' = (p^m)^{-1}\,(p')$

would strictly prefer to set that price — a contradiction. Alternatively, suppose that buyers' beliefs are such that they are indifferent between searching and not searching, and search with some probability $\alpha \in (0, 1)$. If no seller ever sets such price, then we get the same equilibrium (modulo different out-of-equilibrium beliefs) as before. If however seller c' sets that price with strictly positive probability, then consumers beliefs must be that costs have changed, and thus buyers must strictly prefer to search — a contradiction. ■

■ **Large cost differences.** Proposition 1 assumes that firms' costs are sufficiently close that at period 1 each firm's equilibrium price is its monopoly price. We now consider the case in which they are not. The following proposition has been proved by Reinganum (1979):

Proposition 2 *Consider a period t in which consumers are perfectly informed about firms' costs. Suppose $c_i^t > c_j^t$ and (implicitly) define $\hat{p}$ by*

$$\mu\big(p^m(c_j)\big) - \mu\big(\hat{p}_i\big) = s$$

Then $p_j^t = p^m(c_j)$ and $p_i^t = \min\{\hat{p}_i, p^m(c_i)\}$.

Thus if $c_i - c_j$ is sufficiently large, $p_i < p^m(c_i)$ at period 1 (suppose for convenience that $k = 3$, as in the example in Section 3). Suppose first that there is no cost change at period 2. Then of course firm j has no incentive to change its price, but firm i does. This can be ruled out if consumers' hold the belief that any price change indicates a cost change. In that case, under the same assumptions as before, if firm j increases its price its consumers will search and will definitely find a lower price, since costs have not changed. Thus, as in the case of similar costs, there exist equilibria in which the price doesn't change when the cost doesn't change. Consider the equilibrium when costs really do change. Consider first the low cost firm, firm j. As before, for small cost changes its gain from a price change is of second order while under our assumptions of in Section 4 its expected loss if consumers search is of first order. So with respect to the low cost firm, our previous analysis is essentially unchanged. Things are less clear cut with respect to the high cost firm because, conditional on not losing its customers, its gain from raising its price to its monopoly price may be of first order. An additional assumption on the joint probability distribution can rule that out. Specifically, assume that, conditional on a cost shock at period 2, the firm whose cost was lower at period 1 continues to be lower cost than its competitor at period 2 with probability λ. If firm i changes its price, which causes its customers to search, then, if, λ is sufficiently high, the probability that firm i it will lose its searching customers (because firm j's price turns out to be lower than firm i's price) is sufficiently high that it is optimal for firm i to keep its price unchanged.

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