A Theory of Asymmetric Price Adjustment

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Abstract

Empirical evidence suggests that 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.

We show that buyers have a greater incentive to search when they observe large price increases or small price decreases; and little incentive to search when prices increase by a little or decrease by a lot. This implies that small cost increases or large cost decreases are fully reflected on price; whereas small cost decreases and large cost increases are less then reflected in price. Specifically, sellers do not change price when cost decreases by a small amount.

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1 Introduction

Studies of various products and services, including gasoline, agricultural products, bank deposit rates, all find that prices are more likely to rise in response to input price increases than they are to decrease in the wake of cost reductions.[1] Recent work by Peltzman (200) significantly broadens the evidence for this asymmetrical price behavior. In a study of 77 consumer and 165 producer goods, he finds that on average the immediate response to a cost increase is at least twice the response to a cost decrease.

This phenomenon presents more than an interesting empirical regularity to explain. As Peltzman argues, it poses a real challenge to conventional economic theorizing. According to any static microeconomic model — whether monopoly, perfect or imperfect competition — prices should respond symmetrically to cost increases and cost reductions.

This paper presents a search theoretic model which is consistent with an asymmetric price adjustment. The idea is as follows. Suppose a consumer's regular vendor increases its price. Should he or she search for a lower price? If competing vendors' production costs are positively correlated (because they use the same or similar inputs in their production processes), then a price increase at one vendor is bad news to consumers about the entire industry: it is reasonable to suppose that competitors' costs — and hence competitors' prices — have also increased. If search is costly, it is reasonable for consumers to accept a moderate price increase rather than search. This suggests that sellers can increase prices moderately without losing customers in response to cost increases. The same reasoning does not apply to a moderate cost decrease. A price reduction at one firm is "good news" to consumers about the entire industry because it carries the possibility of even greater price reductions at other firms. Therefore a moderate price reduction runs the risk of encouraging customers to search elsewhere in the hope of finding still greater bargains. Hence, to avoid "rocking the boat" a seller's optimal response to moderate cost decreases is to keep prices unchanged.

The same logic implies a reverse asymmetry in the case of large cost changes. If prices decline by a lot, it is unlikely that further search will reveal even lower prices. Hence, large cost reductions may lead to commensurately large price reductions. By contrast, if search costs are not too high, a large price increase might well trigger consumer search because there is the likelihood that competitors' prices have risen by substantially less. Therefore, large cost increases may result in only moderate price increases.

[1] Karrenbrock (1991); Neumark and Sharpe (1992); Jackson (1997); Borenstein, Cameron and Gilbert (1997). There are more references which will be added later.

To be completed.

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 (Section 3). From here we move on to our general results (Section 4). Section 5 derives empirical testable implications and Section 6 discusses the results, namely in relation to previous literature. We conclude with Section 7.

2 Model

Our basic model consists of two firms competing over two periods, 0 and 1. At the beginning of period 0, firm i is endowed with constant marginal cost $c_i^0 \in \mathbb{R}_0^+$, $i = 1, 2$. The values of c_i^0 are common knowledge to firms and consumers. The firms then simultaneously set prices p_i^0. A continuum of consumers of mass 2 is equally divided between firms. Each consumer observes (for free) the price of the firm it is assigned to and must decide whether to pay a search cost s to observe the other price. Finally, each consumer purchases a quantity $q(p)$, where p is the lowest observed price.

At the beginning of the second period Nature generates c_i, firm i's cost, according to a commonly known stochastic process.[2] Only firm i observes c_i. The firms then simultaneously set prices p_i. Consumers are randomly re-assigned to sellers and, as before, observe one price for free and a second one at a cost s; and each consumer purchases a quantity $q(p)$, where p is the lowest observed price.

Let $\mu(p)$ be the consumer's surplus from buying at price p and $\pi(p, c)$ 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.

3 An example

In order to understand the main intuition, it helps to begin by considering a specific numerical example. Suppose that, in the first period, both firms have a cost of $c_i^0 = \frac{1}{2}$. With a probability $1 - \gamma$, second period cost is the same as in the first period. With probability γ, either both costs increase or both costs decrease. Given that costs change, they are independently and uniformly distributed in $[0, \frac{1}{2}]$ (if costs increase) or $[\frac{1}{2}, 1]$ (if costs increase). 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

[2] A more consistent notation would be c_i^1. However, since most of the paper focuses on solving the equilibrium in period 1, we drop the superscript to simplify notation.

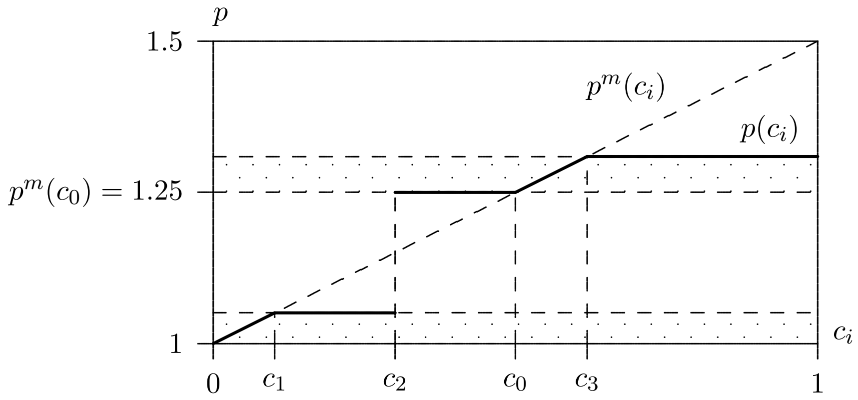

Figure 1: Equilibrium price as a function of cost in numerical example. Costs are uniformly distributed; demand is linear: $q = 2 - p$; initial cost is $c_0 = .5$ for both firms. The equilibrium cost thresholds are given by $c_1 = .102, c_2 = .301, c_3 = .619$.

results will also hold for small γ. Finally, suppose that demand is given by $q = a - p$ and the search cost is $s = 1/200$.

Let us first consider pricing in the first period. Suppose that second period strategies and beliefs do not depend on first period 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 $p_i^0 = 1.25$. 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 the second period. We will show that the following constitutes a Bayesian Equilibrium (see Figure 1 for a graphical representation). The sellers' pricing policy is as follows:

$$p = \begin{cases} p^m(c) & \text{if} \quad c \leq c_1 \\ p^m(c_1) & \text{if} \quad c_1 < c \leq c_2 \\ p_0 & \text{if} \quad c_2 < c \leq c_0 \\ p^m(c) & \text{if} \quad c_0 < c \leq c_3 \\ p^m(c_3) & \text{if} \quad c > c_3 \end{cases}$$

Regarding buyers, their strategy is as follows:

if	$p \le p^m(c_1)$	then do not search
if	$p^m(c_1) < p < p_0$	then search
if	$p_0 \le p \le p^m(c_3)$	then do not search
if	$p > p^m(c_3)$	then search

We first show that the buyers' strategy is optimal and their beliefs consistent. If price is very small, then the potential gains from search are also small, and thus for a given s search is not optimal.

Specifically, suppose buyers observe a very low price. Given the sellers' pricing strategy, buyers infer that costs have decreased, in particular that each seller's cost is independently and uniformly distributed in $[0, \frac{1}{2}]$. So, faced with a price $p = p^m(c)$, the expected surplus in case the buyer searches for the lowest price is given by

$$\frac{1}{c_0}\left(\int_0^c \mu\Big(p^m(x)\Big)\,d\,x + (c_0 - c)\,\mu\Big(p^m(c)\Big)\right).$$

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 $\mu\Big(p^m(c)\Big)$.

By not searching, the buyer receives 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

$$R(c) = \frac{c_0\,\Big(a^3 - (a - c)^3\Big)}{24\,c_0} - \frac{(a - c)^2\,c}{8\,c_0}.$$

The derivative of $R(c)$ with respect to c is given by $\frac{(a-c)\,c}{4\,c_0}$, which is positive. Moreover, $R(0) = 0$. It follows that there exists a positive value of c such that the net benefit from search is equal to the search cost. Let c_1 be such value, that is, $R(c_1) = s$. It follows that, for $p \le p^m(c_1)$, buyers are better off by not searching.

By the same token, if $p(c_1) < c < p_0$, then buyers prefer to search. In fact, $p < p_0$ signals that costs are uniformly distributed in $[0, \frac{1}{2}]$, as in the previous case; and since $R(c) > s$, it pays to search.

Now suppose that p is greater than, but close to, p_0. Given the sellers' pricing strategy, buyers infer that costs are uniformly distributed in $[\frac{1}{2}, 1]$. By searching, a buyer receives an expected surplus

$$\frac{1}{(1-c_0)}\left(\int_{c_0}^{c}\mu\Big(p^m(x)\Big)\,d\,x+(1-c_0)\,\mu\Big(p^m(c)\Big)\right).$$

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

$$R(c)=\frac{\Big((a-c_0)^3-(a-c)^3\Big)}{24\,c_0}+\frac{(a-c)^2\,(c_0-c)}{8\,(1-c_0)}.$$

The derivative of this expression with respect to c is given by $\frac{(a-c)\,(c-c_0)}{4\,(1-c_0)}$, which is positive. Moreover, $R(c_0)=0$. It follows that there exists a value of c greater than c_0 such that the net benefit from search is equal to the search cost. Let c_3 be such value, that is, $R(c_3)=s$. It follows that, for $p_0<p\le p^m(c_3)$, consumers are better off by not searching.

By the same token, if $p>p^m(c_3)$, then consumers prefer to search. The fact $p>p_0$ signals that costs are uniformly distributed in $[\frac{1}{2},1]$, 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. Next we show that the sellers' strategy is optimal given the buyers' strategy and beliefs.

First notice that, given the other seller's strategy as well as the buyers' strategies, in equilibrium the other seller's buyers do not search. It follows that a seller should not take into account the possibility of gaining more buyers, only the danger of losing buyers. Consequently, if c is such that $p^m(c)$ is in a price interval such that buyers do not search then it is optimal to set $p=p^m(c)$. This shows that the strategy for $0<c\le c_1$ and $c_0<c<c_3$ is indeed optimal.

Consider now the case when $c_1<c<c_0$. Setting any price between $p^m(c_1)$ and p_0 induces buyers to 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_2, which happens with probability $(c_0-c_2)/c_0$. Of all the price levels between $p^m(c_1)$ and p_0, 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

$$\frac{c_0-c_2}{c_0}\,\Big(a-p^m(c)\Big)\,\Big(p^m(c)-c\Big).$$

Since the profit function is quasi-concave, the best alternative price levels are $p^m(c_1)$ and p_0. We thus has the no-deviation constraints

$$\begin{aligned}\frac{c_0 - c_2}{c_0}\left(a - p^m(c)\right)\left(p^m(c) - c\right) &\leq \left(a - p^m(c_1)\right)\left(p^m(c_1) - c\right)\\ \frac{c_0 - c_2}{c_0}\left(a - p^m(c)\right)\left(p^m(c) - c\right) &\leq \left(a - p_0\right)\left(p_0 - c\right).\end{aligned}$$

We are not aware of a general analytical proof that these conditions hold. In the linear case, a sufficient condition is given by $a > \frac{1}{2}\left(1 + \sqrt{2}\right) c_0$, which holds for the particular parameters we consider in our example.[3]

Given that the seller does not want to price in the $\left(p^m(c_1), p_0\right)$ interval, we are left to determine whether it is best to pool at $p = p^m(c_1)$ or to pool at $p = p_0$. The seller prefers $p = p^m(c_1)$ if and only if

$$\left(a - p^m(c_1)\right)\left(p^m(c_1) - c\right) > \left(a - p_0\right)\left(p_0 - c\right).$$

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

$$\left(a - p^M(c_1)\right)\left(p^M(c_1) - c\right) - \left(a - p_0\right)\left(p_0 - c\right) = \frac{1}{2}\left(c_0 - c_1\right)\left(\frac{c_0 + c_1}{2} - c\right).$$

Let $c_2 \equiv \frac{c_0+c_1}{2}$. Clearly, the above difference is positive if and only if $c < c_2$. This confirms the seller's strategy for $c \in (c_1, c_0)$.

Finally, for $c > c_3$, any price greater than $p^m(c_3)$ induces search and zero demand. It follows that $p = p^m(c_3)$ is optimal so long as $p^m(c_3) > c$. In our example, $p^m(1) > 1$, and so the condition is satisfied.

■ **Uniqueness.** While we have shown that the above is a Bayesian Equilibrium (BE), we should also note that it is generically not the unique Bayesian Equilibrium. To see this, consider a perturbed version of the previous example whereby firm i's initial cost is ϵ higher than firm j's, where ϵ is a small number. By continuity, an equilibrium like to one we considered before exists, namely one where prices do not change if costs do not change.

Consider the following alternative BE. If costs do not change, then seller i increases price by ϵ^2, whereas seller j keeps the same price as before. If costs are in the $[c_2, c_0]$ interval, then each seller sets the same price as when costs do not change. Otherwise, the equilibrium price strategy is as before.

It can be shown that this pricing strategy is consistent with a BE. Out-of-equilibrium beliefs are as before: any price p in the $\left(p^m(c_1), p_0 + \epsilon^2\right)$ interval (firm

[3]The condition $a > \frac{1}{2}\left(1 + \sqrt{2}\right) c_0$ is obtained by making $c = c_2$ and $c_2 = c_0/2$. It is necessary and sufficient if $c = c_2$ and $c_1 = 0$. For $c_1 > 0$ or $c \neq c_2$, it is sufficient.

i) or $\Big(p^m(c_1), p_0\Big)$ interval (firm j) leads to the beliefs that prices decreased, which in turn implies that search is the buyer's best response. This in turn implies that seller i is indeed better off by setting $p = p^m(c) + \epsilon^2$ even if cost does not change. In fact, keeping $p = p_0$ would lead to higher profits for a given number of buyers; but buyers would search and flock to the rival seller.

The only search-inducing deviation that seller i might want to follow is to undercut seller j's price. But since the price increase seller i is asked to follow is one order of magnitude lower than the price difference with respect to the rival implies that undercutting seller j makes seller i strictly worse off; in other words, the gap with respect to seller i's optimal price would be much greater.

In summary, we can construct a continuum of BE. Our next result shows that the equilibrium considered above is unique within a certain class of BE.

Proposition 1 *Consider the set of Baeysian equilibria such that (a) second period strategies and beliefs depend on first period costs but not on first period prices; (b) if costs do not change, then prices do not change either. If s and γ are sufficiently small, then the equilibrium derived above is unique among this set.*

Proof: See Appendix. ■

■ **Cost assumptions.** One of the interesting features of our model is that, starting from a symmetric cost process, we obtain an asymmetric price process. In other words, asymmetry is derived, not assumed. Having said that, the example we consider above seems to rely on a discontinuity at c_0: if seller i's cost is ever so slightly lower than c_0, then seller j's cost is uniformly distributed in $[0, c_0]$; whereas, if seller i's cost is ever so slightly higher than c_0 then seller j's cost is uniformly distributed in $[c_0, 1]$.

While we need sellers' costs to be positively correlated, it is not necessary for the cost distribution to be discontinuous at c_0. Consider a variation of the example above as follows: for $|\, c_i - c_0| > \epsilon$ and $|\, c_j - c_0| > \epsilon$, the same density as before applies. In the region where $|\, c_i - c_0| \le \epsilon$ or $|\, c_j - c_0| \le \epsilon$ we "smooth out" $F(c_i, c_j)$ so that marginal distributions are continuous at c_0.

The equilibrium of this variation of the example looks the same for values of c_i away from c_0. For values of c_i slightly greater than c_0, the seller pools at c_0. In fact, setting $p^m(c)$ would lead buyers to search: buyers would conclude seller i's cost increased by a little bit, in which case seller j's cost is distributed approximately uniformly. Since ϵ can be made arbitrarily small, the equilibrium price strategy can be made arbitrarily close to the one considered in the example above.

To be completed.

4 Main results

Our general results depend on some key assumptions regarding the stochastic process governing costs. In words, the assumptions below imply that (a) there is some stickiness in costs; (b) cost changes are positively correlated across firms, but not perfectly correlated. 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 two features (stickiness and imperfect positive correlation) are crucial. We return to this in Section 6.

Assumption 1 (cost inertia) *With probability* $1-\gamma$*, second period costs are identical to first period's costs.*

Assumption 2 (cost correlation) *If second period costs are different from first period costs, then either both costs increase or both costs decrease.*

Let $F^+(c_i, c_j \mid c_i^0, c_j^0)$ and $F^-(c_i, c_j \mid c_i^0, c_j^0)$ be the joint density of costs in the second period (conditional on costs moving up or down, respectively). Let $F_i^+(c_i \mid c_j, c_i^0, c_j^0)$ and $F_i^-(c_i \mid c_j, c_i^0, c_j^0)$ be the corresponding marginal distributions. Let $f^x(c_i, c_j)$ and $f_i^x(c_i)$ $(x \in \{+, -\})$ be the corresponding densities, where for simplicity we omit the second set of arguments.

Assumption 3 (conditional cost independence) *(a)* f^x *and* f_i^x *are continuous everywhere; (b) there exists a* $\rho < 1$ *such that* $1 - \rho \le \frac{f_i^x f_j^x}{f^x} \le 1 + \rho$ *for all* c_i, c_j*; (c) there exist* $\underline{f}, \overline{f}$ *such that* $0 < \underline{f} \le f_i^x \le \overline{f} < \infty$ *for all* i, x, c_i, c_j*.*

As we mentioned in the previous section, one can easily find multiple equilibria by conveniently manipulating buyer beliefs. We therefore restrict to equilibria satisfying certain reasonable properties. Specifically, we introduce the following definitions.

Definition 1 (Markov) *A Bayesian Equilibrium satisfies the Markov property is seller strategies and buyer beliefs in the second period only depend on history through first-period costs.*

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

Our results presume Assumptions 1–3 and are restricted to Bayesian Equilibria satisfying Definitions 1–2.

Definition 1 implies that equilibrium prices in the first period can be analyzed as part of a one-shot game. In fact, first period prices have no impact on future beliefs or strategies. We can then apply results from the previous literature:

Proposition 2 (Reinganum, 1979) *Suppose, without loss of generality, that* $c_i^0 \leq c_j^0$*. Equilibrium prices in the first period are given by*

$$
\begin{aligned}
p_i^0 &= p^m(c_i^0) \\
p_j^0 &= \min\left\{\widehat{p}_i(c_i^0), p^m(c_j^0)\right\},
\end{aligned}
$$

where $\widehat{p}(c_i^0)$ *is given by the equation*

$$\mu\Big(p^m\left(c_i^0\right)\Big) - \mu\Big(\widehat{p}\left(c_i^0\right)\Big) = s.$$

In words, Proposition 2 states that, if costs are similar, then both firms set their monopoly price. If however firm j's cost is much higher than firm i's cost, then firm j is "limit priced" by firm i, that is, firm j sets the highest price such that firm j's buyers have no incentive to search.

The main focus of our analysis is on second period prices.

Proposition 3 (large cost changes) *If* s *and* ρ *are sufficiently small, then*

(a) If c_i *is sufficiently lower than* c_i^0 *then* $p_i = p^m(c_i)$*.*

(a) If c_i *is sufficiently greater than* c_i^0 *then* $p_i < p^m(c_i)$*.*

Proof: See Appendix. ■

In words, Proposition 3 states that, if cost is close to the lower bound of its distribution then a firm is better off by setting monopoly price. In fact, no search will take place as consumers know that they can't get better than the current price. If however cost is close to the upper bound then low search cost buyers will search. In such a situation, a high cost firm will not set its monopoly price but rather a lower price.

The reason for the asymmetry between large cost decreases and large cost increases is that the latter lead to search, whereas the former do not. We next turn to the case of small cost changes, and conclude that something different happens: full adjustment to cost increases but no adjustment to cost decreases.

Proposition 4 (small cost changes) *There exist values of* ρ*,* γ*,* s *and* $|\, c_i^0 - c_j^0 \,|$ *sufficiently close to zero such that* *(a) If c_i is lower than, but close to, c_i^0, then $p_i = p_i^0$.*

(b) If c_i is greater than, but close to, c_i^0, then $p_i = p^m(c_i) > p_i^0$.

Proof: See Appendix. ■

In words, Proposition 4 states that small cost increases are fully reflected in cost. That is, the seller sets the price he would set if he were a monopolist with captive customer base; or equivalently, he sets the same price as if consumers could perfectly observe the sellers' costs. If costs decrease by a little bit, however, then price does not change.

The reasons for this asymmetry is that the news that costs have increased leads consumers not to search for a better price when they observe their seller increase its price by a little bit. If however consumers observe a small price decrease then they expect significant potential gains from search. It follows that the seller is better off by not changing price.

5 Empirical implications

In this section, we derive a series of empirical implications of our theoretical results. We also present empirical evidence that is consistent with these predictions.

■ **Speed of price response to cost changes.** Consider an extension of our theoretical model where all even periods are like period 0 and all odd periods like period 1; that is, consumers learn the sellers' costs every even period. The idea is that the odd periods represent short-run changes, whereas even periods represent the long run. The assumption that consumers know costs in the long run is a bit extreme—just as the assumption that consumers cannot observe any signal of costs in the short run. However, these assumptions seem a good approximation to the idea that it takes time for consumers to learn about shocks to the sellers' costs.

As Figure 2 illustrates, this extension of our model 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 in period 1, and then decrease by a bit in period 3. As mentioned in the introduction, Peltzman (2000) presents evidence that is consistent with the pattern illustrated by Figure 2.

■ **Correlation between cost changes and price changes.** A related empirical implication of our results 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

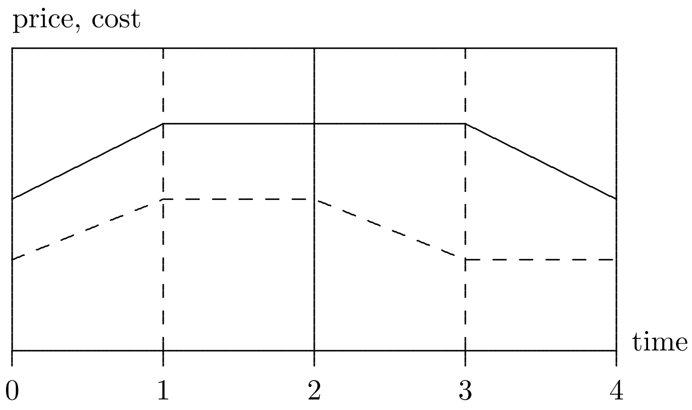

Figure 2: Cost changes and price changes.

(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.** Proposition 4 and in particular the example presented in Section 3 suggest 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).

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

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

	Product category					Total
	UPF	PF	EN	NEIG	SER	
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

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.

In our model, the asymmetry in frequency of price changes results from the fact that small cost changes lead to no change in price. More generally, our results imply 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.[4]

■ **Cost correlation and asymmetric adjustment.** Our assumptions regarding the cost stochastic process amount to a combination of correlation and independence: if there is a change in costs, then costs move in the same direction, but conditionally on moving up (or down) costs are approximately independent. The extreme cases regarding the correlation between costs are (a) conditionally on changing, costs are independent; and (b) conditionally on changing, costs are perfectly correlated. The latter case is easy to solve. In fact, the results in Reinganum (1979) apply, and consequently $p_i = p^m(c_i)$, which in turn implies no asymmetry in price adjustment. What about case (a)? In this case, if a firm slightly changes its price then consumers know that costs have changed. For a small enough value of s, the net benefit from search is strictly positive. We conjecture that the seller's optimal strategy is then not to change price.

We conclude that the two extremes, (a) and (b), feature no asymmetry in price adjustment to small cost changes, in one case because prices do not adjust at all, in the other because prices perfectly adjust to cost changes. This suggests two empirical predictions regarding the relation between correlation between costs and price adjustment: (a) the degree of price adjustment is increasing in the correlation between costs; and (b) the relation between cost correlation and asymmetry of price adjustment is non-monotonic, first increasing and then decreasing.

■ **Price dispersion.** See Tappata's paper. To be completed.

6 Related literature

There are various possible explanations for price rigidity and the asymmetry of price responses to cost changes. Two of the more popular explanations consider the role of market power and menu costs.

In 1999, *The New York Times* reported an instance of asymmetry in price adjustment to cost changes: "The Great Pork Gap; Hog Prices Have Plummeted. Why Haven't Store Prices?" The story states that "allegations of price-gouging

[4] 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.

are being leveled against the meatpackers that turn hogs into pork products." The economics literature has also proposed collusion as an explanation for asymmetric price adjustment; see for example Borenstein, Cameron and Gilbert (1997). However, Peltzman (2000) finds little evidence for the effect of market power on the incidence of asymmetric price adjustment.

In an inflationary context, the optimal policy is to respond less promptly to cost reductions that to cost increases; see Ball and Mankiw (1994), Sheshinski and Weiss (1993). However, just like market power, Peltzman (2000) finds little evidence for the effect of menu costs on the incidence of asymmetric price adjustment.

Regarding buyer search models, we are only aware of three formal models that focus on asymmetric price adjustment: Lewis (2005), Tappata (2006), and Yang and Ye (2006). Lewis (2005) develops a reference price search model with homogenous sellers and buyers that form adaptive expectations about the current price distribution. In his model, buyers search sequentially and optimally with respect to past prices but not necessarily with respect to actual prices.

Tappata (2005) develops a non-sequential search model a la Varian with homogenous sellers and rational buyers. When buyers expect costs to be high, they expect less price dispersion and search less, giving sellers more market power. When buyers expect costs to be low, they expect greater price dispersion, search more intensively and sellers price more competitively. Now suppose that past costs were high. Then, buyers expect current costs to be high as well and thus search less. In this context, if costs drop then sellers have a low incentive to lower prices. In fact, doing so would lead buyers to search and make the market more competitive. So, while Tappata's search model is quite different from ours, it shares the feature that sellers are reluctant to lower price as this induces greater search by buyers.

Yang and Ye (2006). To be completed.

7 Conclusion

We propose a consumer search theory of asymmetric price adjustment. The basic intuition for our theory is that consumers have a greater propensity to search when they observe a large cost increase or a small cost decrease; and have no incentive to search when costs increase by a little or decrease by a lot. This implies that firms are reluctant to change prices when costs decrease by a little bit; and don't fully reflect on price large costs changes.

To be completed.

Appendix

Proof of Proposition 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 $p_i' < p_0$. Also suppose, without loss of generality, that $p_i' \leq p_j'$. Consider the critical value p_i'' given by

$$\mu\Big(p_i''\Big) - \mu\Big(p_i'\Big) = s.$$

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 $p_i = p_i''$ than by setting p_i'. By construction, seller i would not lose buyers with respect to p_i'; 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

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

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 $p^m(c')$.

Given the sellers' strategy, an upper bound to a buyer's expected utility from switching sellers is given by

$$\frac{1}{c_0}\left(\int_0^{c'} \mu\Big(p^m(x)\Big)\, dx + (c_0 - c')\, \mu\Big(p^m(c')\Big)\right).$$

Let c'' be defined by

$$\mu\Big(p^m(c'')\Big) - \frac{1}{c_0}\left(\int_0^{c'} \mu\Big(p^m(x)\Big)\, dx + (c_0 - c')\, \mu\Big(p^m(c')\Big)\right) = s.$$

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^ℓ given by:

$$\mu\Big(p^m(c^\ell)\Big) - \frac{1}{c_0}\left(\int_0^{c^\ell} \mu\Big(p^m(x)\Big)\,dx + (c_0 - c^\ell)\,\mu\Big(p^m(c^\ell)\Big)\right) = s. \tag{1}$$

But this is exactly the value c_1 derived above.

Consider now the case of higher values of p, that is, $p > p^m(c_1)$. An important result states that, along the equilibrium path, sellers whose cost increases cannot decrease their price:

Lemma 1 *There exists no PBE satisfying Definition 2 such that prices decrease when costs increase.*

(The proof appears after the current proof.)

Suppose that p is higher than $p^m(c_1)$ but lower than p_0, and let c be the cost that would lead to the price as optimal monopoly price: $p^m(c_1) < p^m(c) < p_0$. If such a price occurs along the equilibrium path, then it must be set by a seller whose cost is lower than c_0. But then by Lemma 1 buyers' belief must be that costs have decrease, in which case they have an incentive to search, in which case the analysis in the text applies, implying that $p^m(c_1)$ or p_0 are better options for the seller.

Suppose that $p^m(c)$ does not occur along the equilibrium path. Notice that Lemma 1 implies no restrictions regarding off-the-equilibrium-path beliefs. Suppose that beliefs are such that no search takes place. Then a seller with cost c would set $p = p^m(c)$, which contradicts the hypothesis that $p^m(c)$ does not occur along the equilibrium path. Finally, suppose that beliefs are such that search takes place. Then the analysis in the text applies, implying that $p^m(c_1)$ or p_0 are better options for the seller.

Consider now the case of prices higher than p_0. First notice that, if costs are lower than c_0, then any price above p_0 is dominated by p_0: no additional buyers would be gained by increasing price, and profit per buyer would be lower with a higher price. Then the analysis for prices lower than p_0 also applies, leading to uniquely to the equilibrium derived in the text. ■

Proof of Lemma 1: Suppose that seller i prices below p_0 with positive probability (conditional on costs increasing). Let $F_i(p)$ be the distribution of seller i's prices induced by its equilibrium strategy; S_i the lowest connected set of seller i's prices such that $f_i(p) > 0$ and buyers search; p'_i and p''_i the infimum and supremum of S_i; and let $F_j(p)$, S_j, p'_j, p''_j the corresponding objects for seller j. First notice that the measure of S_j, as defined by $F_j(p)$, must be positive. If that were not the case, then seller i would never capture any of seller j's buyers, that is, it would only stand to lose buyers, in which case p_0 dominates any lower price (regardless of seller i's cost).

Suppose that $p''_j < p_0$. Then seller i would never price in the $(p''_j, p''_j + \epsilon)$ interval as this would not attract seller j's buyers. But then seller j would also prefer to increase price from p''_j. Now suppose that $p'_j > p_0$. Then seller i would gain nothing from pricing below p_0. In fact, setting p_0 would give seller i as many buyers as a lower price; and seller i would get a higher profit per buyer. We thus conclude that $p'_j \leq p_0 \leq p''_j$.

Consider now the interval $\omega = (p_0 - \epsilon, p_0)$. If $\omega \notin S_i$, then seller j would be better off by pricing at p_0 than just under p_0: lowering the price does not attract any seller i's buyers and lowers seller j's profit per buyer. If $\omega \in S_i$, then firm i is better off by pricing at p_0 than just under p_0: lowering the price increases additional buyers at a rate of order ϵ; but it risks inducing search and losing buyers at a rate greater than ϵ.

We thus conclude that seller i cannot price below p_0 with positive probability. But if seller i were to price below p_0 with probability zero, then seller j would stand go gain nothing from encouraging buyers to search; and so any price below p_0 would be dominated by p_0; in which case seller i would also prefer to price at p_0. ■

Proof of Proposition 3: By an argument analogous to the proof of Proposition 1, we can show that, in equilibrium, $p_i \geq p^m(0)$. Suppose that $c_i = 0$ and firm i sets $p_i = p^m(0)$. The potential gain from search is zero, since seller j's price is greater or equal to $p^m(0)$. If follows that there is no search by seller i's buyers. This in turn implies that seller i is doing its best by setting $p_i = p^m(0)$. In fact, seller i does not lose any of its buyers. Moreover, the only case when firm j's buyers would search is when p_j is strictly greater than $p^m(0)$, in which case seller i would capture those buyers by setting $p_i = p^m(0)$. Since the above inequalities are strict, the result follows by continuity for c_i sufficiently close to zero.

Consider now the case of a large cost increase. First we show that no seller sets a price above its monopoly price, that is, $p_i \leq p^m(c_i)$. If $p_i > p^m(c_i)$, then by lowering p_i the seller would get a greater profit from each buyer; it would be more likely to attract searchers from the rival seller; and it would be less likely to lose its own customers. The latter proposition follows from the fact that, since costs are approximately independent (conditional on increasing), seller i's customers follow a simply threshold rule for deciding whether or not to search, that is, they search if and only if firm i's price is greater than some threshold value.

If $c_i > p_i^0$, then it must be that $p_i(c_i) > p_i^0$ as no seller would set a price below cost. If search costs are sufficiently small, then the buyer's net expected payoff from search is positive. But if buyers search, then $p_i(c_i) < p^m(c_i)$. To see why, consider a seller with the highest possible cost. For such a seller, pricing at the monopoly level would lead to zero profits as no customer would buy from them. To the extent that there are other cost types who would price above the highest cost, it would pay to reduce price. If no other cost types price above the highest cost, the result also follows. ■

Proof of proposition 4: First notice that, if costs do not change, then it is a best response for sellers not to change prices. In fact, for a given s, if γ is sufficiently close to zero then the buyers' expected net benefit from search is negative. Changing price would give the seller a (strictly) lower profit per buyer and would (weakly) increase the probability that seller i's customers search. Moreover, given that the rival firm does not change its prices, seller i's price has no effect on the probability of capturing buyers from the rival seller.

Suppose that $c_j = c_j^0 - \epsilon$. The line of argument in Lemma 1 applies here, and so a lower price by firm j is interpreted by consumers as a lower cost by firm i. Assumption 3 and the first part of Proposition 3 imply that the expected benefit from search is strictly positive. If s is sufficiently small, then consumers would prefer to search. If that is the case, then firm j prefers not to change its price: even if no consumers were to move away from firm j, the gain in adjusting price would be of second order; but the potential loss of consumers is a first-order effect. In fact, by keeping price constant no search will take place: if γ is sufficiently close to zero (for given values of ρ and s) then by Assumption 1 buyers rightly believe that most likely no change in cost has taken place and so the expected net gain from search is negative. Finally, notice that an increased price is also a dominated strategy. By instead keeping price constant the seller gets a (striclty) higher profit per buyer, (weakly) decreases the probability that buyers will search, and (weakly) increases the probability of attracting searchers from the other seller.

Consider now the case when $c_i = c_i^0 + \epsilon$ and suppose that firm i sets its new monopoly price: $p_i = p^m(c_i^0 + \epsilon)$. In the initial period, the net expected gain from search was strictly negative (cf Proposition 2 and the assumption that c_i^0 is close to c_j^0). The news that firm i's cost increased is bad news regarding firm j's price. In fact, from the previous paragraph we know that if cost decreases price cannot increase. It follows that, if ϵ is small enough, then the net expected gain from search is now strictly negative. This implies that firm i is doing its best. In fact, firm

i's customer base is independent of price (in the relevant range). The only case in which firm i might increase its customer base is when firm j's customers search. But this only happens when firm j prices at a higher level than firm i's current price, in which case firm i's price increase has no impact on the number of consumers, only on sales per consumer. ■

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