Rockets and Feathers
Understanding Asymmetric Pricing

[Job Market Paper]

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Abstract

Prices rise like rockets but fall like feathers. This stylized fact of most markets is confirmed by many empirical studies. In this paper, I develop a model with competitive firms and rational partially-informed consumers where such asymmetric response to costs by firms emerges naturally. In contrast to public opinion and past work, collusion is not necessary to explain such result. Using a rich dataset of retail gasoline prices, I find the observed price dispersion pattern to be consistent with the model's prediction.

JEL Codes: D21, D40, L13.
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1 Introduction

Output prices do not react symmetrically to changes in input prices. According to Peltzman's comprehensive study of 165 producer goods and 77 consumer goods, *"In two out of three markets, output prices rise faster than they fall"* (Peltzman, 2000; p. 480). This pattern is also known as *rockets and feathers* and has sometimes been used interchangeably with the term *asymmetric pricing*.[1] Despite the abundance of empirical work confirming

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[1] To the best of my knowledge, Bacon (1991) was the first one to use the term *rockets and feathers* to describe the pattern of retail gasoline prices in the U.K.

this stylized fact, there has not been much progress in terms for theoretical explanations of this widespread phenomenon.

The first thing that comes to mind when talking about rockets and feathers is gas prices and collusion. Input and output prices are easily observable by everyone and the market is composed by only a handful of players. Asymmetric price variations are usually associated with collusive behavior by both government and the media.[2,3] However, Peltzman finds that the *rockets and feathers* pattern is equally likely to be found in both concentrated and atomistics markets. In this paper, I develop a consumer-search model that explains how an asymmetric response of prices to costs can arise in competitive markets.

According to traditional economic theory, homogeneous firms that compete on prices earn zero profit, and cost shocks are completely transferred to final prices.[4] The nature of this equilibrium changes drastically if consumers are imperfectly informed of market prices and a fraction of them has positive search costs. Competitive firms now profit from informational rents, and equilibrium is characterized by price dispersion instead of a single price. Still, for any given level of production costs, firms' optimal price margin is the same regardless of whether their cost shock was positive or negative. In order to obtain asymmetric pricing, the demand function faced by firms must be sensitive to previous cost realizations. This is indeed what happens when consumers don't observe firms' costs.

I introduce uncertainty over production costs in a *nonsequential* search model similar to Varian's model of sales (Varian, 1980). Given consumers' search intensity, firms maximize profit by choosing prices that are less dispersed under high than low production costs, since their scope to set prices -measured by the gap between marginal cost and the monopoly price- decreases. Rational consumers anticipate this and therefore search less when they expect costs to be high. Intuitively, when input cost shocks are not independent over time, consumers' expectations differ depending on whether cost was high or low in the previous period. This translates into different demand elasticities faced by firms when cost falls or rises and therefore, prices react asymmetrically to cost shocks as the firms' pass-through increases with the level of competition in the market.

[2] See Karrenbrock (1991; p. 20) for media and government representative quotations about gasoline price gouging.

[3] This perception, together with a lack of input substitution possibilities in gasoline production, influenced the focus of most empirical work (Bacon, 1991; Karrenbrock, 1991; Borenstein, Cameron, and Gilbert, 1997; Lewis, 2003; Deltas, 2004; and Verlinda, 2005 among others). Empirical research investigating asymmetric pricing in other markets includes Neumark and Sharpe (1992), Hannan and Berger (1991) in the banking sector; and Boyd and Brorsen (1998), and Goodwin and Holt (1999) in the food industry.

[4] Although firms with market power (and costlessly searching consumers) don't transfer all of their cost shocks to consumers, they still price symmetrically in that the price they optimally charge depends only on current cost realizations, not on previous costs. Therefore, the rate of change in prices is always the same (as a function of costs) regardless of previous prices, which annuls the possibility of rockets and feathers

The rockets and feathers pattern emerges under persistent cost realizations. Suppose that the current marginal cost is high. Consumers expect it will remain high, so they expect little price dispersion and search very little. If in fact the unexpected occurs and marginal cost drops, firms have little incentive to lower their prices because consumers aren't searching very much. On the other hand, if marginal cost is currently low, it is likely to stay low, so next period price dispersion is expected to be high, consumers search intensifies, and the response by firms to a positive cost shock is to raise prices significantly.

This paper links asymmetric pricing in competitive markets with consumer search. The main empirical implication of this link is price dispersion in the market even with homogeneous firms. Most markets actually involve product differentiation, which itself implies some price dispersion. However, the pattern of price dispersion is expected to differ in each case. In search models, firms with high prices today might have the lowest prices tomorrow while in models with product differentiation, this price dispersion is stable. I use a rich dataset of gasoline retail prices to separate price dispersion due to product differentiation from costly search behavior. Prices charged by stations that are across from each other should reflect only product differences since consumers are obviously informed about their prices. On the other hand, a model of search could play a role in explaining the prices of two distant stations in the same market. I obtain preliminary results on the effect of distance over rank reversals in prices and the stability of the price spreads between pairs of stations. They are consistent with the fact that the underlying model of price dispersion is a combination of product differentiation and costly search by consumers.

The contribution of this paper is in formalizing a model with rational agents that isolates the crucial features needed for asymmetric pricing to emerge in competitive markets. The most related work is represented by Lewis (2003). He develops a *reference-price* search model with homogeneous firms and consumers that form *adaptive* expectations about the current price distribution. Consumers search sequentially and their search strategies are optimal with respect to past *reference* prices, although not necessarily to actual prices. Firms then use this myopic behavior to their advantage and set prices to minimize search by consumers. If costs drop below past price, firms need to only decrease their prices a little to avoid search, while if cost increases above past prices, there is no option but to set prices at least as high as the new cost, which in equilibrium generates consumer search.[5] In this paper consumers use all available information to them. In that sense, the approach is similar to Benabou and Gertner (1993). They study the effect of inflation's uncertainty on efficiency in a market composed by consumers that search sequentially and *heterogeneous* firms that have their production costs composed of both an idiosyncratic (real) and a common (inflation) shock. Consumers behave rationally by updating their priors about the

[5] In this case, after visiting $n-1$ stores and observing $n-1$ identical prices, consumers would still choose to pay the cost and sample from the nth store since they believe that the prices in the market are normally distributed with a mean lower than the observed price.

common shock from observed prices. Under some parameters, more inflation uncertainty leads to more search and thus generate inefficiencies.[6,7]

This model shares the assumption that consumers are imperfectly informed with Benabou *et al.* (1993) and Lewis (2003). In contrast to their work, I assume firms are homogeneous (as Lewis), agents that form rational expectations (as Benabou *et al.*), and consumers searching nonsequentially. That is, each consumer decides -before observing any prices- between becoming informed about all market prices (and buying from the store with the lowest price) or remaining uninformed, in which case she buys costlessly from a random store. If a consumer were to search sequentially, after visiting a store she would decide whether to sample for another price or shop at the lowest price observed at that moment.[8]

The early literature on consumer-search models focused on *nonsequential* search protocols (Salop and Stiglitz, 1977; Braverman, 1980; and Varian, 1980), while more recently *sequential* search models have dominated the literature (Stahl, 1989 and 1996; and Benabou and Gertner, 1993). Both sequential and nonsequential search protocols can be optimal depending on the context of the decision problem (Morgan and Manning, 1985).[9] Nonsequential search tends to dominate when price quotes are not obtained instantaneously (insurance quotes, repair estimates, etc.), the opportunity cost of time is relatively high, and when there are economies of scale in the size of the price sample (online shopping). When price quotes are obtained easily and there are no economies of scale, sequential search tends to dominate nonsequential search protocols, since it allows consumers to stop searching as soon as they find a good bargain.[10]

The rest of this paper is organized as follows. In the next section I describe the model

[6] Borenstein *et al.* (1997) suggest a reinterpretation of this model to account for asymmetric pricing. If changes in the (common) production cost imply higher volatility, less search is related to higher and lower costs. Firms can charge a higher mark-up due to lower search and the cost pass-through is bigger if cost is increasing than decreasing.

[7] Other work on asymmetric pricing is Borenstein *et al.* (1997) and Eckert (2002). The former suggest a model of a tacit collusion with imperfect monitoring (as in Tirole, 1988; p. 264). With multiple equilibria, firms collude using the past-period price as a focal point. Decreases in production cost facilitate coordination on previous price, while if cost increases it is likely that past price is unprofitable, collusion breaks down and a higher price emerges as a new equilibrium. On the other hand, Eckert uses a model of Edgeworth cycles to explain gasoline price movements that are independent of cost shocks. This pattern has been observed in some Canadian cities.

[8] This is the case of sequential search with *perfect recall.* In the case of no recall, if the consumer stops searching, she must shop at the last observed price.

[9] Other search protocols have been used as well. Dana (1994) uses a mixture of sequential and nonsequential search. After a consumer observes a first price she needs to decide if she wants to pay to know the rest of the prices in the market. Burdett and Judd (1983)Burdett and Judd, 1983 assume a flexible sample-size nonsequential search protocol.

[10] The extension of this model to sequential search is part of my research agenda and preliminary results are available upon request.

and the static duopoly equilibrium. Next, the dynamic setting is introduced together with the rockets and feathers result. In section IV, I extend the result to markets with more than two firms. Section V, covers the empirical implications in the gasoline market. Section VI concludes.

2 The model

In this section I lay out a static duopoly model where firms compete choosing prices and consumers decide whether to search or not based on some prior over firms' production costs. The model is an extension of Varian's model of sales (Varian, 1980) where I endogenize consumers' search decisions and incorporate uncertainty over production costs. The two main results of this section are the following: First, the market equilibrium involves price dispersion and a fraction of informed consumers (proposition 2). Second, the search intensity in the market decreases with the expected production cost (lemma 2).[11] This static model serves as the stage game in a dynamic model that I introduce in the next section.

Consider two firms with the same marginal and average cost selling a homogeneous good. At the beginning of the period, Nature draws the cost for the industry, firms observe the cost realization and compete through prices. There is a continuum of consumers of measure one who only know the probability distribution of the marginal cost. They each have a unit demand with a choke price of υ, and can obtain information about market prices through nonsequential search. They decide -before observing any prices- between becoming informed and buying from the store with the lowest price, or shopping at a randomly selected store. Nonsequential search protocols are especially appealing to consumers when there are economies of scale in price sampling. Products that are advertised in weekly newspapers are a classical example of such advantages. More recent examples include specialized websites that aggregate and compare all the relevant information across online stores, and that save consumers the trouble of a sequential search.[12]

The cost of becoming informed is the search cost. Assume that a portion $\lambda \in (0,1)$ of the consumers has zero or negative search cost and I refer to them as *shoppers*. Shoppers can be interpreted as consumers who enjoy searching for prices or who have obtained price information unintentionally through advertising or while shopping for other goods. The remaining $(1-\lambda)$ consumers have positive search costs that are drawn from a continuous and differentiable *cdf* $g(s_i)$, with $s_i \in S = [0, \overline{s}]$ and $\overline{s} > \upsilon$.

[11] Dana (1994) analyzes the effects of consumer learning in a static model where with incomplete information about the firms' cost of production. For the duopoly case the search protocol used there by consumers is equivalent to sequential search (see footnote 9).

[12] As I describe in Section V, commuters buying gasoline can be thought of as searching nonsequentially.

Given the nature of the search protocol, consumers and firms decide their actions simultaneously. The search/no search decision by consumers will be affected by the expected price dispersion in the market and their search costs. So based on their priors about the marginal cost realization, consumers form rational expectations on firms' pricing strategies to forecast price dispersion. At the same time, firms set their prices anticipating the search intensity in the market.

More formally, firms and consumers play a simultaneous-move Bayesian game with $N = \left\{N^F \cup N^D\right\}$ players, where $j \in N^F = \{I, II\}$ denotes a firm and $i \in N^D = [0,1]$ a consumer. Producers can be of either type c_L or c_H, where the probability of the high cost c_H is α. Consumers' search costs (or their types) $s_i \in S$ are public knowledge. Firms choose prices p_j in the interval $P = [c_L, \upsilon]$ and consumers choose actions $a_i \in A = \{0,1\} = \{\text{don't search, search}\}$.[13] Letting $\mu = \int_0^1 a_i di$ represent the number of informed consumers, the profit of a firm j that charges a price p_j and has production cost c is given by:

$$\pi_j\left(p_j, p_{-j}, a, c\right) = \left(p_j - c\right)\left\{\frac{1+\mu}{2}\mathbf{I}_{\{p_j<p_{-j}\}} + \frac{1}{2}\mathbf{I}_{\{p_j=p_{-j}\}} + \frac{1-\mu}{2}\mathbf{I}_{\{p_j>p_{-j}\}}\right\} \tag{1}$$

where p_{-j} represents the price charged by firm j's competitor, and $\mathbf{I}$ is an indicator function. Meanwhile, the conditional utility of a consumer i with search cost s_i is:

$$u_i\left(a_i, a_{-i}, p\right) = \upsilon - a_i\left(Min\left[p\right] + s_i\right) - \left(1 - a_i\right)\frac{1}{2}\sum_j p_j \tag{2}$$

Firm j's strategy profile is represented by all possible price distributions given a cost realization: $f_j(\cdot, c) = \left\{f_j(p_j, c)\right\}_{p_j \in P}$ with $f_j(p_j, c) \geq 0$ for all $p_j \in P$ and $\int_P f_j(p, c)\, dp = 1$. Consumers on the other hand have strategy profiles $q_i(\cdot, s_i) \in \Delta(A)$ that include the possibility of randomizing between search and no search.

The interaction between consumers and firms can be summarized by the proportion of informed consumers μ. Any strategy profile for the consumers $\sigma^D = \left\{q_i(\cdot, s_i)\right\}_{i \in N^D}$ implies a value of $\mu \in [\lambda, 1]$.[14] Define a Nash Best Response $NBR(\mu, c)$ as a symmetric Nash Equilibrium strategy of the game $\Gamma = \left[N_J, P, \pi_{j \in N_J}\right]$ where π_j is defined in (1). That is, a *NBR* consists on the equilibrium price strategies in the duopoly game that are a best response to a given search intensity by consumers. A Symmetric Bayesian Nash Equilibrium (SBNE) or *market equilibrium* is composed of consumers' beliefs about the

[13] I ignore the decision between buying or not for the consumer by setting υ as the upper bound for p_j. This simplifies notation and does not affect any result.

[14] This is consistent with the definition of shoppers given above. If shoppers are thought of as consumers with zero search cost, I break any potential indifference in (2) by assuming they always search.

marginal cost, α and a strategy profile $\sigma = \left(\sigma^D, \sigma^F\right)$ such that *i)* σ^D is a best response to $\sigma^F = \left(f\left(p, c, \mu\right)\right)_{p \in P}$ and *ii)* σ^F is a $NBR\left(\mu\left(\sigma^D\right), c\right)$. In words, a market equilibrium is characterized by consumers that search optimally given the pricing strategies of the firms, and firms that set prices optimally given the number of consumers that become informed.

Start analyzing the supply side of the model by obtaining the firms *NBR*. A given number of informed consumers μ can be related to the expected elasticity of demand faced by each firm. This is clear when we examine the extreme cases of $\mu = 0$ and $\mu = 1$. The former corresponds to two separate monopolies. Each firm faces a completely inelastic demand and maximizes profits by extracting all the consumer surplus ($p = \upsilon$). On the other hand, when all consumers are informed about the market prices $(\mu = 1)$, firms face perfectly elastic demands which leave them no option but to price at marginal cost. In the rest of the cases ($0 < \mu < 1$), each firm faces an expected downward slopping demand. It is easy to verify that there is no single price equilibrium (SPE) since a store would capture the informed consumers μ by slightly undercutting its competitor.[15]

The assumptions made on consumers' search costs eliminate the possibility of monopoly or perfect competition outcomes. First, a lower bound on the number of informed consumers is given by the number of shoppers in the market ($\mu \geq \lambda$). On the other hand, as will be seen below, the existence of consumers with high search cost ($\overline{s} > \upsilon$) implies that there is always a mass of uninformed consumers in equilibrium. Therefore, given μ, a firm with cost c that sets a price p can either *fail* or *succeed* in capturing the informed consumers. Its profits are respectively:

$$\pi^f\left(p, c\right) = \frac{(1-\mu)}{2}\left(p - c\right) \tag{3}$$

$$\pi^s\left(p, c\right) = \frac{(1+\mu)}{2}\left(p - c\right) \tag{4}$$

By charging the highest possible price, a firm can always guarantee itself a positive profit equal to the surplus of its captive consumers:

$$\pi(\upsilon, c) = \frac{(1-\mu)}{2}(\upsilon - c) \tag{5}$$

This, places a lower bound on the prices considered by any firm:

$$p^* = \pi^{s\ -1}(\pi(\upsilon, c)) = c + \frac{(1-\mu)}{(1+\mu)}(\upsilon - c) \tag{6}$$

[15] Note that SPE and pure strategies equilibrium is the same since *NBR* is defined to be a symmetric NE.

Even if a firm captured *all* the informed consumers, charging a price below p^* generates less profits than if it charged the monopoly price.[16] Thus, a *NBR* consists of strategies over $[p^*, \upsilon]$.

By the same argument used to ruled out SPE, all mixing strategies that involve a positive mass over any price can be ignored. Denote the cumulative distribution implied by a particular strategy profile σ^F with $F(\cdot, c, \mu)$. A firm is indifferent between charging the monopoly price and a price that generates a similar expected profit:

$$\pi^s(p,c)(1 - F(\cdot)) + \pi^f(p,c)F(\cdot) = \pi(\upsilon, c) \tag{7}$$

High prices increase mark-ups per unit sold but decrease the expected market share by reducing the likelihood of being the cheapest firm in the market. The *surplus-appropiation* and *business-stealing* effects characterize the trade-off faced by firms, which induces price dispersion or the existence of *sales* (Varian, 1981).

Proposition 1 *There is a unique Nash Best Response σ^F. Given μ and c the cumulative distribution of market prices is*

$$F(p,c,\mu) = \int_{p^*}^{p} f(x,c,\mu)\,dx = 1 - \left(\frac{(1-\mu)(\upsilon - p)}{2\mu(p-c)}\right) \tag{8}$$

for all $p \in \left[p^* = c + \frac{(1-\mu)}{(1+\mu)}(\upsilon - c), \upsilon\right]$
Proof: See Appendix.

The share of informed consumers affects the pricing strategies of the firms in two ways. First, as μ increases, there is a smaller captive market for each firm and the profit made by charging the monopoly price decreases. This increases the equilibrium range of prices over which firms are willing to randomize in order to attract the informed consumers (equation 6). At the same time, a larger proportion of informed consumers makes the *business-stealing* effect more attractive, hence relatively more weight is placed on low prices. This can be seen in (8) as $F(\cdot.\mu')$ first-order stochastically dominates $F(\cdot.\mu)$ for $\mu' > \mu$.

On the demand side, consumers decide between becoming informed about the market prices (at a cost s_i) or buying from a random store. The market demand is composed of consumers whose individual choices a_i do not influence the search intensity in the market. Given the firms' *NBR* σ^F, the expected benefit for each consumer of being informed is measured by the difference between the expected price and the expected minimum price

[16] Note that by definition p^* cannot be a SPE.

in the market (price dispersion):

$$E\left[p-p_{\min}|\mu\right] = E_c\left[\int_{p^*}^{v} p\left[1-2\left[1-F\left(p,c,\mu\right)\right]\right]dF\left(\cdot,c,\mu\right)\right] = \tag{9}$$
$$= \left(v-E\left[c\right]\right)\frac{\left(1-\mu\right)}{2\mu^2}\left[\log\left[\frac{1+\mu}{1-\mu}\right]-2\mu\right]$$

where the last equation is obtained using (8) and integrating by parts.

Expected market price dispersion is what drives consumer to search. At the same time, price dispersion depends on the amount of informed consumers. Starting from a monopoly situation with $\mu = 0$ and no price dispersion ($p = v$), as μ increases, firms start randomizing over a wider range of prices and placing relatively more likelihood on low prices. This has the effect that both, the expected price and the expected minimum price decrease. But they do it at different rates and there exists an amount of informed consumers $\widehat{\mu}$ at which the consumers' gains from search are maximized.[17] For $\mu > \widehat{\mu}$, adding informed consumers reduces the spread between the expected price and minimum price since the firms keep increasing the probability over low prices while keeping the domain in (8) relatively fixed. The following lemma characterizes (9).

Lemma 1 *The consumers' expected gains from search is a strictly concave function of the number of informed consumers. Furthermore, it has a maximum at* $\widehat{\mu} \in (1/2, 1)$.

Proof: See Appendix.

Consumers compare the benefits from becoming informed to their search costs. Thus, shoppers always search for low prices while consumers with search cost higher than v never search.[18] That also implies that there are at least λ informed and $(1-g(v))(1-\lambda)$ uninformed consumers in a market equilibrium. For the rest, the optimal search strategies are $q_i(s_i < \widetilde{s}) = 1$ and $q_i(s_i > \widetilde{s}) = 0$ where $\widetilde{s}$ is the search cost of the indifferent consumer:

$$E[p-p_{\min}|\mu = \lambda + (1-\lambda)\, g\left(\widetilde{s}\right)]] - \widetilde{s} = 0 \tag{10}$$

A market equilibrium for uniformly distributed search costs is shown in Figure 1. The proportion of informed consumers is measured on the horizontal axis, while the search costs and gains from search are on the vertical axis. The dashed and solid concave curve represents the gains from search to consumers. Each consumer compares her search cost

[17] $E[p]$ decreases at a decreasing rate for any μ while $E[p_{\min}]$ does it at an increasing rate for $\mu < 0.78341$ and a decreasing rate for $\mu > 0.78341$.

[18] See footnote 11.

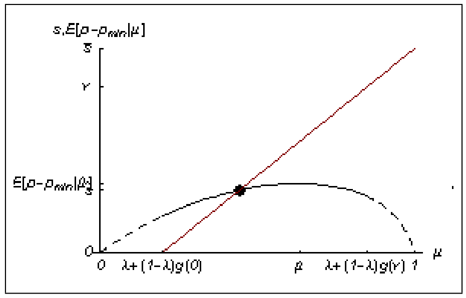


Figure 1: Equilibrium with uniformly distributed search costs

with the gains from search given the total amount of informed consumers. The straight line with positive slope represents the search cost of the marginal consumer that decides to search. The unique equilibrium is represented by the intersection of the two curves. Consumers with search cost lower than $\widetilde{s}$ search and those with higher cost choose to remain uninformed.

A unique equilibrium is obtained under any search cost distribution as long as there is a large number of shoppers ($\lambda > \widehat{\mu}$). When this is not the case, there could be more than one solution to (10) depending on the slope of the curves representing the search cost of the marginal consumer and the gains from search. The next proposition states the conditions required for a unique market equilibrium.

Proposition 2 *There is a unique market equilibrium if:*
a) $\lambda > \widehat{\mu}$*, or*
b) $0 < \lambda < \widehat{\mu}$ *and* $\frac{\partial g^{-1}}{\partial \mu} > \frac{\partial E[p - p_{\min}]}{\partial \mu}$ *over* $\mu \in [\lambda, \widehat{\mu}]$.

Proof: See Appendix.

The market equilibrium is characterized by price dispersion and consumer search. The intensity of this search is related to the expected production cost through its effect on price dispersion. Even though the level of the marginal cost does not affect the trade-offs faced by the firms when setting prices, it alters the range over which firms can choose those prices. In other words, the relative benefits and costs of attracting the informed consumers are the same under low and high costs. But, as production cost increases, the gap between the monopoly price and the minimum profitable price (p^*) decreases (the extreme case being $c = v$).[19] This implied negative relationship between price dispersion and production cost induces consumers to search less when they expect high costs. This can be seen in (9). The gains from search $E\left[p - p_{\min}|\mu\right]$ become flatter as the probability of high cost α

[19] This is true for the case of consumers having downward slopping demands as long as the absolute mark-up of a monopolist decreases with the marginal cost.

increases. Thus, the indifferent consumer has a lower search cost (see equation 10) and the equilibrium search intensity decreases with α. The following lemma summarizes this result and is central for the findings in next section.

Lemma 2 *Consumers search less when they expect higher production cost:* $\frac{\partial \mu}{\partial \alpha} < 0$

Proof: See Appendix.

As long as the demand is composed of informed and uninformed consumers, a market equilibrium implies price dispersion. This is not a result driven by the heterogeneity in search costs. The last part of this section is devoted to extend the results above to the case where g is degenerate and nonshoppers are homogeneous in their search cost ($s_i = s$). Intuitively, when the search cost is sufficiently high, the market equilibrium involves only shoppers searching.[20] For very low search cost, the gains from search are higher than its costs and everyone would want to search. But we know that the competitive outcome implies no price dispersion so it must be that if nonshoppers are searching in equilibrium, they are doing it with probability $q < 1$. In order to analyze the equilibrium properties better, let the number of shoppers be high or low; and the search cost be high, moderate or low:

Definition 1 *The number of shoppers* λ *is low (high) if* λ *is* $\leq$ $(>)$ *than* $\widehat{\mu}$*. Given* λ*, search costs are defined to be low if* $s < E\left[p - p_{\min} | \mu = \lambda\right]$*, moderate if* $E\left[p - p_{\min} | \mu = \lambda\right] \leq s \leq E\left[p - p_{\min} | \mu = \widehat{\mu}\right]$*, and high if* $s > E\left[p - p_{\min} | \mu = \widehat{\mu}\right]$*.*

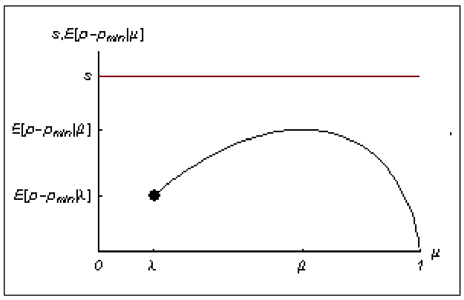
Figure 2 shows all possible equilibria. There is always a market equilibrium with only shoppers searching ($\mu = \lambda$) if the gains from search when only the shoppers do so are lower than the search cost $\left(E\left[p - p_{\min} | \mu = \lambda\right] < s\right)$. The rest of the equilibria imply search by all types of consumers ($\mu > \lambda$) and are determined jointly by the roots q (if they exist) of

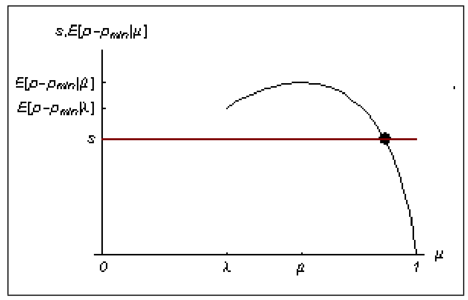
$$E\left[p - p_{\min} | \mu = \lambda + (1 - \lambda) q\right] = s \tag{11}$$

This possibility arises if there is a low number of shoppers and the search cost is low or moderate (Figure 2b and 2c). In the case of low search cost there are two equilibria where $\mu > \lambda$. The equilibrium with the smaller root q is unstable, while the other is locally stable (as well as the one with $q = 0$). Table 1 and the following corollary to proposition 2 summarize the equilibrium results.

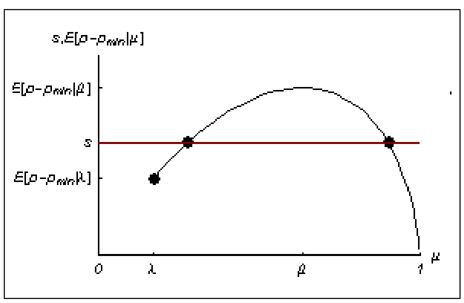
Corollary 1 *There can be one, two or three possible market equilibria when there are* λ *shoppers and* $(1 - \lambda)$ *consumers have positive search cost* s

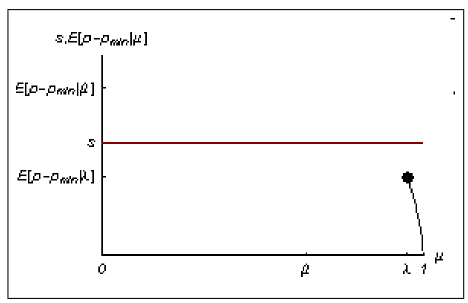
[20] The existence of an atom of shoppers is enough to eliminate the Diamond Paradox (Diamond, 1971) where firms charge the monopoly price and consumers don't search because there is no price dispersion.





(a) High search cost *(b) Low search cost*





(c) Moderate search cost

Figure 2: Equilibria with homogeneous search cost

	Shoppers (λ)	
Search Cost (s)	low	high
low	$\mu > \lambda$	$\mu > \lambda$
moderate	$\mu = \lambda, \mu_1 > \lambda, \mu_3 > \mu_2 > \lambda$	$\mu = \lambda$
high	$\mu = \lambda$	$\mu = \lambda$

Table 1: Equilibria with homogeneous search cost

If search cost is high: equilibrium is unique and $\mu = \lambda$
If search cost is low: equilibrium is unique and $\mu > \lambda$
If search cost is moderate
and the number of shoppers is high: equilibrium is unique and $\mu = \lambda$
and the number of shoppers is low, there are three equilibria: i) $\mu_1 = \lambda$*, ii)* $\mu_2 > \lambda$ *and iii)* $\mu_3 > \mu_2 > \lambda$.

Similarly to the case of heterogeneous search costs, consumers have less incentive to search if they expect higher production costs. However, the market search intensity only changes with α if the initial equilibrium involves searching by nonshoppers. When consumers expect higher production they search less since higher cost implies lower gains from search. The importance of this will be seen in the next section in which I present a dynamic setup where consumers' priors are based on past cost realizations.

3 Dynamics and asymmetric pricing

In this section, I present a simple dynamic model that parses out the conditions under which asymmetric pricing in competitive markets holds. The main result is captured by proposition 3: firms react differently to positive cost shocks than to negative shocks as long as those shocks are not *iid*. When search decisions are linked to past cost realizations, firms face demands with different elasticities depending on wether the cost dropped or rose in the past period. Different demand elasticities are associated with different search intensity and imply asymmetric cost pass-through by the firms. Before getting to the model setup, I present a brief summary of how asymmetric pricing is defined and estimated in the literature.

Asymmetric pricing refers to the case where output prices react differently according to whether input prices have positive or negative changes. There is an abundant empirical literature that suggests that asymmetric pricing is more the norm than an anomaly. In particular, most studies find that prices react faster to positive than to negative cost shocks (*rockets and feathers* pattern).[21] In general, most tests of asymmetric pricing estimate a dynamic error-correction model of the following type:

$$\Delta y_t = \sum_{i=0}^{m} \beta_i^+ (\Delta x_{t-i})^+ + \sum_{i=0}^{m} \beta_i^- (\Delta x_{t-i})^- + \gamma (y_{t-1} - \delta_0 - \delta_1 x_{t-1}) + \varepsilon_t \qquad (12)$$

where y_t and x_t represent output and input prices, and Δ their change with respect to the

levels in the previous period. The model in (12) allows for different effects of positive and negative cost shocks on prices, and assumes that the output price adjusts completely to a cost shock after m periods. The last term in parenthesis is the error-correction-term that accounts for the current deviations from a long-run equilibrium relationship between the output and input prices. Hence, the parameter γ is expected to be negative.

By separating the effects of positive and negative cost changes, a *cumulative response function* (CRF) can be constructed for each type of shock. A CRF predicts the amount of the price adjustment completed after k periods from a one-time cost shock. Evidence of the rockets and feathers would consist on the CRF identified with positive shocks being greater than the one for negative shocks. If both cumulative functions are plotted against the number of periods away from the cost change, we would expect the difference to be important in the first periods after the cost changed and disappear as we approach to m.[22]

A simple model can be used to explain the rockets and feathers pattern. Consider a dynamic environment where the static game presented in the previous section is repeated over time. Assume that at the beginning of each period, nature chooses a high or low production cost with probabilities α and $(1 - \alpha)$. After that, each firm observes the cost realization and sets prices while consumers observe the previous period cost realization and decide whether to search or not. Once the market clears, Nature draws another production cost and the process is repeated. Since the main motivation for this model is to explain asymmetric pricing in markets with atomistics firms, I ignore the possibility of collusion among firms.

There are two sources of price variation over time in this setup. On the one hand, prices can change as a reaction to a change in the production cost. All else equal, a higher production cost implies higher expected prices in the market. But on the other hand, market prices can vary as a result of a change in consumers' priors. This is an indirect effect on prices that materializes through the variations on consumers' search intensity. Firms can anticipate this change in the search intensity and adjust prices accordingly.

[21] See footnote 3 in the introduction for references on empirical work.

[22] In general, data restrictions prevent the econometrician from including a sufficient number of lags in (12) such that the CRF is estimated for all the periods it takes the price to accommodate to the cost change (Peltzman, 2000).

The expected market prices are completely characterized by the current production cost level and the amount of search in the market. For simplicity, let the probability of high costs follow a Markov process $\alpha = h(c_{t-1})$ where $h(c_H) = \rho$ and $h(c_L) = (1-\rho)$ with $0 < \rho < 1$. It then follows that there is a one-to-one map between the previous period cost and the actual search intensity. Therefore, the state of the economy can be represented by past and current cost realizations. Denote the current state by $k = (c_{t-1}, c_t)$. Since production costs can only be low or high, the set of possible states is given by the set $K = \{LL, LH, HL, HH\}$ with $k_i = K(i)$. Given a current state k_i, the probability of moving to a new state k_j next period is denoted by the element P_{ij} in the following transition matrix:

$$P = \begin{bmatrix} \rho & 1-\rho & 0 & 0 \\ 0 & 0 & 1-\rho & \rho \\ \rho & 1-\rho & 0 & 0 \\ 0 & 0 & 1-\rho & \rho \end{bmatrix} \tag{13}$$

Thus, if the current state involves *low* actual and *low* past cost realizations ($k_1 = LL$), it can never happen that the next state indicates *high* as the previous cost ($P_{13} = P_{14} = 0$). Last, there is a unique invariant distribution for K and is represented by $\pi = \{\rho/2, (1-\rho)/2, (1-\rho)/2, \rho/2\}$.

In this simplified world, it takes only two periods for prices to fully adjust to an isolated cost change. After a shock, firms increase (decrease) prices reacting to bigger (lower) production costs. In the following period, assuming marginal cost does not change, firms adjust prices to be consistent with the new updated prior used by consumers. After two periods, the prices are in line with the new cost level, and the size of the price adjustment is the same, independent of the sign of the cost shock.[23] Therefore, asymmetric pricing, if any, has to be observed in the first period of adjustment to a cost shock.

We are interested in finding the conditions such that $\beta_0^+ \neq \beta_0^-$ in (12). First, consider β_0^+ and denote p_k as the average market price when the state of the economy is k. For a positive cost shock to occur, the previous cost realization has to be low. Thus, the previous state was either LL or HL and the new state is LH. Similarly for β_0^-; the state of the period in which the cost drops can only be HL while the previous state could have been either HH or LH. The expected change in prices to a positive and negative cost shock are, respectively:

$$E\left[\frac{\triangle p}{\triangle c^+}\right] = \Pr(HL)\Pr(LH_t|HL_{t-1})[p_{LH} - p_{HL}] + \Pr(LL)\Pr(LH_t|LL_{t-1})[p_{LH} - p_{LL}] \tag{14}$$

$$E\left[\frac{\triangle p}{\triangle c^-}\right] = \Pr(LH)\Pr(HL_t|LH_{t-1})[p_{LH} - p_{HL}] + \Pr(HH)\Pr(HL_t|HH_{t-1})[p_{HH} - p_{HL}] \tag{15}$$

[23] Moving from a state LL to HH implies the same price change than moving from HH to LL.

and using the transition and unconditional probabilities (P and π), the difference becomes

$$E\left[\frac{\triangle p}{\triangle c^{+}}\right]-E\left[\frac{\triangle p}{\triangle c^{-}}\right]=\frac{-1}{2}\rho\left(1-\rho\right)\left[\left(p_{HH}-p_{HL}\right)-\left(p_{LH}-p_{LL}\right)\right] \tag{16}$$

This last equation summarizes the conditions for asymmetric pricing. Note that the economy can not move from a state HL to a state HH, so $p_{HH}-p_{HL}$ represents the change in expected prices after an increase in production cost holding consumers' priors at $\alpha=\rho$. Likewise, $p_{LH}-p_{LL}$ represents the increase in prices if consumers' priors are $\alpha=1-\rho$. other words, $\beta_0^+\neq\beta_0^-$ if the the cost pass-through is sensitive to the priors held by consumers, and those priors are not *iid* ($\rho=1/2$).

Another way of seeing the drivers behind asymmetric pricing is by decomposing (16) into: *i*) The effect of past cost on consumers' priors, *ii*) the effect of those priors on the search intensity, and *iii*) the effect of the search intensity on the cost pass-through. That is, (16) can be approximated by

$$E\left[\frac{\triangle p}{\triangle c^{+}}\right]-E\left[\frac{\triangle p}{\triangle c^{-}}\right]\approx\frac{-1}{2}\rho\left(1-\rho\right)\left|\Delta c\right|\frac{\partial^2 p_t}{\partial c_t\partial c_{t-1}}=\frac{-1}{2}\rho\left(1-\rho\right)\left|\Delta c\right|\frac{\partial^2 p_t}{\partial c_t\partial\mu}\frac{\partial\mu}{\partial\alpha}\frac{\partial\alpha}{\partial c_{t-1}} \tag{17}$$

In the previous section, lemma 2 showed that a higher expected production cost generates less search by consumers. Lower gains from search are associated with higher costs since, as the gap between the marginal cost and the monopoly price is reduced, price dispersion decreases. Thus, the equilibrium pool of informed consumers μ decreases with α. This is also true when $g(\cdot)$ is degenerated and the equilibrium involves searching from nonshoppers (corollary 1) as the probability of a nonshopper searching increases ($q(s>0,\alpha')>q(s>0,\alpha'')$ with $\alpha'<\alpha''$).[24] If only shoppers are searching, the change in priors affects the benefits from search but it might not be enough to induce nonshoppers to search ($q=0$).

Now turn to the pass-through effect. An increase in the amount of informed consumers is similar to an increase in the expected demand elasticity faced by each firm. The limiting cases of perfect competition and monopoly are useful benchmark cases. In a perfectly competitive environment, prices are driven entirely by costs and a complete pass-through is expected after a cost shock. This is not the case for a monopolist where the interaction between the demand and cost determines market prices. In the case of consumers with homogeneous unit demands, a monopolist sets prices independently of the cost level and the corresponding pass-through is zero. Other assumptions on the demand function (linear

[24] A potential unstable equilibrium is ignored.

or constant elasticity, for example) allow for positive pass-through but still lower than one.[25]

From the previous analysis, it can be inferred that as the number of informed consumers increases, the market becomes more competitive and the link between costs and prices is stronger. In other words, firms compete more fiercely for the increasing mass of informed consumers by setting prices closer to marginal cost. As a result, the cost pass-through is expected to increase with μ.

The expected market price for a given cost realization c and prior α is given by

$$E\left[p|c\right] = \upsilon - \int_{p^*}^{\upsilon} F(p,c)dp \tag{18}$$

where the price distribution $F(\cdot, c)$ is the market equilibrium distribution ($F(\cdot, c, \mu)$ in (8) with $\mu = \lambda + (1-\lambda)\, g(\widetilde{s})$ from (10)). Integrating by parts and deriving:

$$\frac{\partial E\left(p|c\right)}{\partial c} = 1 - \frac{(1-\mu)}{2\mu} \log\left[\frac{1+\mu}{1-\mu}\right] \tag{19}$$

The pass-through effect is positive for any value of μ. Using L'Hopital rule, it can be checked that $\mu = 1$ implies a complete pass-through while if $\mu = 0$ there is no price adjustment.[26] The derivative of (19) with respect to μ confirms that the cost pass-through is higher as the market becomes more competitive.

Combining (19) and the fact that higher priors generate less search (lemma 2), the sign of the asymmetry in (17) is determined by the process behind α. The next proposition summarizes the result.

Proposition 3 *Asymmetric pricing occurs if cost is not iid. Moreover, prices rise faster than they fall under cost persistence* ($\rho > 1/2$).

Proof: See Appendix.

To summarize, asymmetric pricing occurs as a result of changes in the demand faced by each firm when cost increases than when it decreases. In the case of rockets and feathers,

[25] For demand functions where the monopolist pass-through is greater than one, the gap between monopoly price and marginal cost increases with c. Since this implies that consumers search more when cost increases, the combined effect of search intensity and cost pass-through does not change.

[26] Note that the response of prices to production costs doesn't depend on consumers' reservation price υ. This is important when analyzing the case of sequential search by consumers. Any equilibrium that involve firms setting low prices such that consumers prefer to buy instead of keep searching will not generate asymmetric pricing.

firms face a more inelastic demand if the marginal cost drops than when it goes up. Suppose that marginal cost is currently high, consumers expect it will remain high, so they expect little price dispersion and search very little. If in fact, marginal cost drops, firms have few incentives to lower their prices because consumers aren't searching very much. On the other hand, if marginal cost is currently low, it is likely to stay low, so next period's price dispersion is expected to be high, consumers search increases, and the response to a positive cost shock is to pass most of it to prices.

An empirical implication of this model is that price dispersion generated by costly consumer search is present at all times. Other models that have been suggested to explain asymmetric pricing imply firms playing pure strategies most of the time (see Lewis (2003) and Borenstein *et al.* (1997)). This feature is analyzed in the retail gasoline market in Section V. In the next section, I extend the results to markets with more than two firms.

4 More sellers

In this section, I extend the results of sections 2 and 3 to atomistic markets. The setup of the model is the same as the one presented above with the only exception that the number of firms n is allowed to be greater than two. The reason to present the results in a separate section is that I need to use simulations to characterize the equilibrium since the Nash Best Response for the firms become less tractable when as $n > 2$.

I again start by analyzing the firms' *NBR* of the static game. With more sellers in the market, the proportion of uninformed consumers that buy from each seller decreases. This lowers the expected profits per firm. At the same time, there are more firms disputing the mass of informed consumers. Thus, if a firm wants to charge the lowest price in the market, it has to set lower prices the larger the number of stores is. Restating equations (3) to (7) to account for $n > 2$, and solving (7) one can find the unique symmetric equilibrium for the firms. Given consumers' search intensity and marginal cost, the *NBR* implies firms pricing from the following *cdf:*

$$F(p, c, \mu) = 1 - \left(\frac{(1-\mu)(v-p)}{n\mu(p-c)} \right)^{\frac{1}{n-1}} \tag{20}$$

with support $\left[c + \frac{(1-\mu)(v-c)}{1+(n-1)\mu}, v \right]$. The proof of proposition 1 (in the Appendix) is done for $n > 2$ and follows Varian (1980).

The changes in $F(\cdot)$ are plotted in Figure 3. The presence of more stores in the market increases the likelihood of setting prices in the extremes of the distribution. This

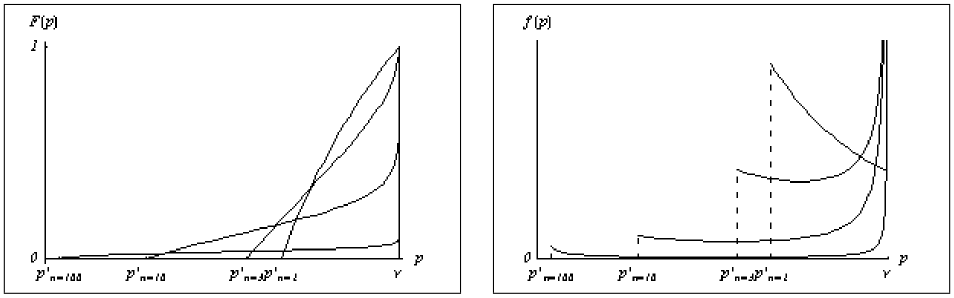


Figure 3: Equilibrium price distribution and number of stores ($c = 0, \mu = 0.2$)

is because the chances of being the lowest price in the market decrease with n and middle-range will never be enough to capture the informed consumers. But the strenghtening of the *business-stealing* and *surplus-appropriation* effects is not symmetric. As n increases, the probability of being the lowest price in the market decreases exponentially while the benefits from charging high prices decrease at a rate $1/n$. Thus, the surplus-appropriation effect becomes relatively more important than the business stealing effect and firms prefer to increase the likelihood with which they set prices close to the monopoly price than on low prices.

As the number of sellers increase, the *cdf* becomes flatter over low and medium-range prices and the expected price in the market increases. In the limit, the price distribution converges weakly to the monopoly price (Stahl, 1989; and Janssen and Moraga-González, 2004). Nevertheless, the support of the price distribution increases with n and its lower bound approaches marginal cost. That is, there is always a positive probability (for consumers) of finding very low prices.

In a market equilibrium, consumers decide endogenously their optimal searching strategy. The effect of the number of sellers on the equilibrium search intensity is determined by the effect of n on the expected price and expected minimum price. As in (9), the expected gains from search are now:

$$E_c\left[E\left[p - p_{\min}|c, \mu, n\right]\right] = E_c \int_{p^*}^{v} \frac{p\,(v-c)}{(n-1)\,(p-c)\,(v-p)} \left(1 - n\left[1 - F\,(p)\right]^{n-1}\right)\left[1 - F\,(p)\right] dp \tag{21}$$

It was claimed above that the expected price increases with n. Intuitively, the expected minimum price decreases with the number of sellers since the lower bound of the distribution support approaches the marginal cost. Therefore, consumers have more incentives to search in more atomistic markets than in duopolies.

Proposition 4 *Search intensity increases with* $n : E\left[p - p_{\min}|c, \mu, n+1\right] > E\left[p - p_{\min}|c, \mu, n\right]$

	$v/c=2$			$v/c=5$			$v/c=10$		
$\mu\|n$	10	50	100	10	50	100	10	50	100
0.1	0.268487	0.6282	0.75255	0.42958	1.005121	1.20408	0.483277	1.130761	1.35459
0.2	0.396569	0.744037	0.838856	0.634511	1.19046	1.34217	0.713825	1.339267	1.509941
0.3	0.472803	0.796879	0.875598	0.756486	1.275007	1.400956	0.851046	1.434383	1.576076
0.4	0.522712	0.827401	0.896187	0.83634	1.323841	1.4339	0.940882	1.489322	1.613137
0.5	0.556532	0.846985	0.909214	0.890452	1.355158	1.454743	1.001758	1.524553	1.636586
0.6	0.578868	0.860017	0.917898	0.926188	1.376027	1.468637	1.041962	1.54803	1.652216
0.7	0.591375	0.868404	0.923613	0.946199	1.389447	1.477781	1.064474	1.563128	1.662503
0.8	0.592896	0.872529	0.92676	0.948634	1.396046	1.482815	1.067214	1.570552	1.668167
0.9	0.575174	0.870377	0.92638	0.920279	1.392604	1.482208	1.035314	1.566679	1.667484

Table 2: Expected gains from search

n	2	102	202	302	402	502	602	702	802	902	1002
$\widehat{\mu}(n)$	0.6349	0.8471	0.8626	0.8704	0.8755	0.8792	0.882	0.8844	0.8863	0.888	0.8894

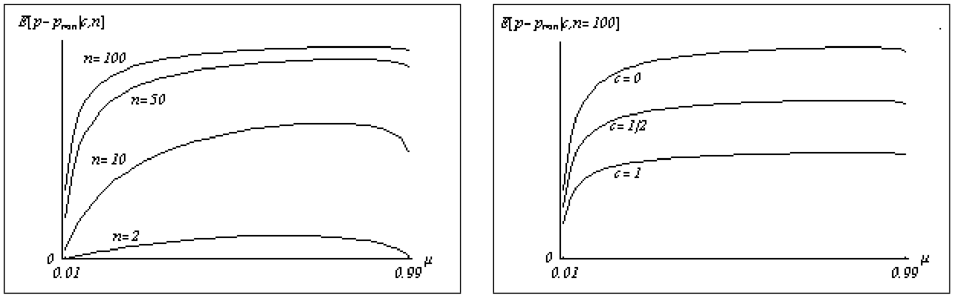
Table 3: Maximum $E[p - p_{\min}|c, n]$ and n

Proof: See Appendix.

There are various ways to think about how competitive the market becomes when the number of sellers increases. As n grows, prices approach the monopoly price, but at the same time profits vanish. Furthermore, holding constant the number of firms, a larger number of informed consumers implies a more elastic demand faced by each firm. As μ increases, the market is more competitive and prices decrease regardless of the number of firms. From (20), $F(\cdot, \mu') > F(\cdot, \mu'')$ if $\mu' > \mu''$.

The expected gains from search is a continuous function of μ, and -as with $n = 2$- it is zero when $\mu = 0$ (monopoly) or $\mu = 1$ (perfect competition) and increases as μ is away from those extremes. The conditions for unique market equilibrium in Proposition 2 are related to the concavity of the gains from search. Unfortunately, for markets with $n > 2$, the expression in (21) becomes less tractable and I need to rely on simulations to show its concavity. Table 2 shows the numerical values for $E[p - p_{\min}|c, \mu, n]$ as a function of different combinations of marginal cost values, amount of informed consumers, and number of firms in the market. It can be seen that the gains from search increase with μ at an increasing rate, reach a maximum and then decrease towards zero. The plots in Figure 4(a) represent the first panel of Table 2 and confirm the concavity assumption. Lastly, the effect of n on the amount of informed consumers that maximizes the expected gains is shown in Table 3.

With concavity guaranteed, proposition 2 can be applied to the case of more atom-



(a) Number of firms $(\upsilon/c = 2)$ *(b) Cost variation* $(n = 100,\ \upsilon = 2)$

Figure 4: Maximum expected gains from search and the number of firms

istic markets. Given the production cost and consumers' priors, there is a unique market equilibrium that is characterized by price dispersion and active search by consumers. Consumers search because they expect price dispersion, and firms generate price dispersion because consumers are searching. The amount of search in equilibrium is influenced by the expectations over the marginal cost. Note that when marginal cost is high, the expected price, as well as expected minimum price, increase. Since the latter effect is stronger than the former (see lemma 2), the expected price dispersion in the market decreases with the marginal cost. This is shown in 4.b for parameter values $n = 100$ and $\upsilon = 2$.

The last step needed for the asymmetric pricing and rockets and feathers results is to show that the pass-through increases with the amount of search by consumers. That is, $\frac{\partial^2 E(p)}{\partial c \partial \mu} > 0$ in (17). For the reasons explained above, it is expected that for a given level of search, the pass-through in a duopoly is bigger than in a market with more firms. Start assuming that $\mu = 0$. In this case, each firm is a monopolist over half of the consumers in the market. The pass-through is zero independent of the number of firms. But as consumers become informed, the surplus-appropiation effect is stronger in more atomistic markets. That is, firms prefer high prices to low prices, and average prices are further from the marginal cost as the number of firms increases. The fact that in atomistic markets each firm is more concentrated on its captive consumers explains why the incentives to adjust prices to cost changes are lower. In Figure (5), the pass-through effect is drawn for markets with different numbers of firms and parameters $\upsilon = 2$ and $c = 0$. The pass-trough approaches 1 as the proportion of informed consumers dominates the market, but for $n > 2$, this convergence occurs only when the market is very close to perfectly informed.

To conclude, the rockets and feathers result can be extended to markets with more than n firms since all the conditions found in the duopoly hold. Namely: i) consumers search less if they expect a higher cost, and ii) the cost pass-through by firms increases with the amount of informed consumers. Under persistence in the cost shocks, the asymmetric pricing takes the form of the rockets and feathers pattern.

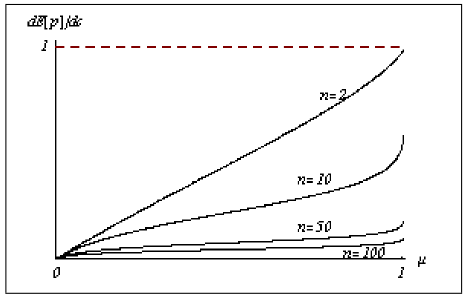


Figure 5: Effect of n on the pass-through

5 Empirical implications

The model in the previous sections links the rockets and feathers pattern to the search intensity in the market. Costly consumer search has major implications in the firms' pricing strategies. As long as there is a fraction of informed consumers, firms find optimal to randomize between high and low prices and there is no pure strategy equilibrium. In this section, I analyze the price dispersion observed in the gasoline market looking for evidence of whether it is due to product differentiation, or also to costly consumer search.

There are many reasons to choose the gasoline market for this analysis. First, most of the empirical work on asymmetric pricing found evidence of the *rockets and feathers* in retail gasoline prices.[27] Second, the characteristics of the market suggest that the assumptions used in the theoretical model apply directly. The demand faced by a station is mainly composed by commuters. Since they drive the same route twice a day, it is optimal for them to search nonsequentially. After realizing that the stock of gasoline in her car is close to the reserve level, a commuter has enough time to look for prices while driving to or from home and buy from the station with the lowest price in the next trip.[28] Since gasoline stations post their prices such that each driver can look at them from their cars, the decision between becoming informed or not is based mostly on the cost associated with remembering and comparing prices (information cost) and not with any physical or transportation activity.[29] At the same time, consumers have some information on past input prices. Last, as I will explain below, the test proposed in this section could hardly be carried out in other markets.

[27] See footnote 3.

[28] Stations in general don't change prices during the day.

[29] The problem faced by non commuters is different and sequential search might be the optimal search protocol for them. When consumers search sequentially, firms change slightly their pricing strategies, but price dispersion is still a characteristic of the market. The extension of the rockets and feathers result to the case of sequential search is part of my research agenda and preliminary results are available upon request.

The gasoline sold at any gas station is not a perfectly homogeneous good. The only difference between gasoline from two different branded stations is in the additive applied by each refinery in the last chain of the production process (when the fuel is delivered from the terminals to the stations). Independent of whether additives have real effects on the car's performance, consumers might believe so and show brand loyalty. There are other dimensions in which gasoline stations differentiate themselves. The most relevant is geographic location, but the availability of convenience stores, payment method accepted, car wash and other ancillary services might also be important.[30]

Since gasoline is a differentiated product, the fact that price dispersion is observed can not be used to validate a consumer-search model. However, there are differences in the dispersion patterns generated under each model. Even though the characteristics of a station are in the set of choice variables for a firm, the choices over such dimensions remain fixed for a much longer period of time than prices. If this is the case, we should expect to observe a fairly stable price dispersion across time when product differentiation is the only driver of price dispersion. Under search models instead, price ranks across stations are expected to revert as frequently as firms change prices. Rank reversions in prices might not be observed if product differentiation and costly consumer search happen together. But the size of the spread between any pair of stations is then expected to shrink and expand over time.

In other words, stable price dispersion should be associated to product differentiation models while unstable patterns can not reject the coexistence of product differentiation and costly consumer search. I first analyze the stability of the price dispersion pattern in the gasoline market by looking at price rank reversals and the variance over time of the price spread between different pairs of stations.

I constructed a dataset of retail gasoline prices for more than 2000 stations in Southern California during the period March 2003 - September 2005. Even though the dataset includes prices for all four grades of gasoline, I concentrate on *regular unleaded* (87 octanes grade) since it is the product that accounts for half of the observations.[31] The panel is unbalanced in every sense. Not all the stations have prices for the same days nor have the same number of observations. From the original set of 2367 stations I was able to obtain reliable geographic information for 83% of them. Since distance is a key element in the analysis that follows, I discarded any suggested geocoding with low precision score.[32] Table 4 summarizes the structure of the dataset.

[30] Studies on the effect of product differentiation and market power in the gasoline market include Shepard (1991 and 1993), Png and Reitman (1994).

[31] The dataset was constructed from public online information. The prices are originally collected daily by Oil Price Information Service (OPIS, http//:www.opisnet.com) from credit card transactions and reported together with brand, address and city of each gas station.

[32] Addresses are not accurate since information is missing or incorrect. I mapped stations using a GIS geocoding service. I ignored stations that were geocoded with a geocoding score of less than 70%.

			Station level	
	N	**T**	**Mean**	**sd**
Stations*	1949	338 days	45 days	34.9
Market coverage	117.017sq. miles			
	Mean	**Min**	**Max**	**sd**
Price	\$2.442	\$1.499	\$3.499	\$0.309
Rank reversal**	0.1121	0	0.5	0.1574
Spread1= $p_{it} - p_{jt}$, $i \neq j$	7.28cts	0	108	5.8918
Spread2=$\sum (p_{it} - p_{jt}) / T_{ij}$	6.899cts	0	78	6.1895

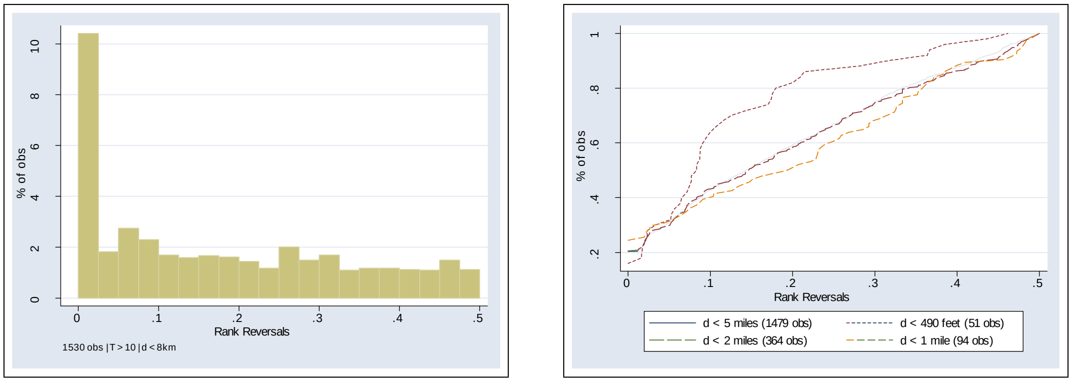
* Successfully geocoded stations with regular unleaded prices.

** Given a pair of stations (i, j), if most of the time $p_i \leq p_j$ then a rank reversal of x means that $p_j > p_i$ $100x\%$ of the time.

Table 4: Summary Statistics

A simple way to analyze the stability of price dispersion is to couple stations and study the behavior of their prices over time. Let s_{ij} be a vector of the price spread between two stations (i, j) across T_{ij} periods, such that $p_{it} > p_{jt}$ is observed most of the time. A measure of instability can be given by the number of times $p_{jt} > p_{it}$. The average *rank reversals* in prices observed in the dataset is 0.11 (Table 4). That means that from the price observations within a pair of gas stations, the station that usually has the the lowest price had a high price 11% of the time. By definition, a rank reversal can never be higher than 0.5. Figure 6(a) shows a histogram of the rank reversals in prices for all possible pairs of stations that are separated by at most 5 miles from each other. As it can be seen, for more than 50% of the stations in the sample, the spread is reverted at least 10% of the time. This is a sign of instability on the price dispersion pattern and is consistent with a model of costly consumer search.

On the other hand, rank changes could be argued to be generated by models with product differentiation and uncorrelated shocks in demand or idiosyncratic costs. If that is the case, firms facing a positive demand shock increase their prices (and eventually the rank changes) relative to other firms that did not receive a demand shock. In general, a demand shock is thought of as affecting a whole market rather than a station. In Figure 6(b), the cumulative empirical distributions of rank reversals are plotted for groups of stations that differ in the distance separating the stations in each pair. First, the set of stations having at least one competitor within 390 feet were selected. Then, for each distance bound or market area, all pairs involving one of those stations were formed. It can be seen that the pattern of rank reversals don't differ too much when the distance bound is 1, 2 or 5 miles, but are notably different when stations are separated by at most 390 feet. The price dispersion is more stable between stations that are very close to each other than those that,



(a) $d_{ij} < 5$ miles (b) Cumulative rank reversals and distance

Figure 6: Rank reversals in prices

while being in the same market, are more distant.[33]

Another possible reason for unstable price dispersion is the existence of idiosyncratic cost shocks at the station level. Then, from Figure 6(b) we should expect the correlation in the cost shocks between two stations to decrease with the distance separating them. This is very unlikely at the market level. Also, since the main cost component of a gasoline station is the wholesale cost (rack price) it is expected that stations serving the same brand have cost shocks that are highly correlated. But given that stations with the same brand are never located one across each other, the correlation in the cost shocks (if any) should increase with the distance separating the stations thus, the group of nearby stations should present more rank changes than the group of stations that are separated by more than a block.

Now assume that a model of costly consumer search and product differentiation together are a good description of the retail gasoline market. Then, a consumer that decided to buy gasoline in station i at price p_i is either uninformed or informed. If she is informed, it means that -after accounting for product differentiation spreads- there is no better deal in the route she travels daily than p_i. If she is uninformed, station i was picked randomly from the set of stations (presumably many) she drives by. But, when stations i and k are in front of each other, consumers are obviously informed of their prices and price differences can only reflect product differentiation.[34] Stations i and k coordinate to set prices and compete for the informed consumers with other distant stations. In other words, rank reversals in prices are expected to happen less frequently for stations that are close from each other than

[33]Industry expert as well as most of the empirical papers that deal with retailing gasoline agree in considering the market for one gasoline station to be the area within 1 mile from the station (Hastings, 2002)

[34]See Png and Reitman (1994) for evidence of product differentiation across stations with similar location.

	D	*p-value*
$\text{H}_0 : F_c\,(rc) < F_1\,(rc)$	0.0847	0.626
$F_c\,(rc) > F_1\,(rc)$	-0.3387	0.001
$F_c\,(rc) = F_1\,(rc)$	0.3387	0.001
$\text{H}_0 : F_c\,(rc) < F_2\,(rc)$	0.0570	0.751
$F_c\,(rc) > F_2\,(rc)$	-0.2501	0.004
$F_c\,(rc) = F_2\,(rc)$	0.2501	0.008

Notes: c=490 feet.

Table 5: Kolmogorov-Smirnov equality of distributions test

for stations that are nearby but further apart.[35] The equality of the observed frequencies in Figure 6(b) can be tested using a Kolmogorov-Smirnov test. This non parametric test rejects the null hypothesis of samples coming from the same populations if there exists a point for which the cumulative empirical distribution of two independent samples are significantly different. Table 5 presents the results. D represents the maximum distance separating the cumulated empirical distribution of rank changes (rc) for stations located close to each other ($F_c\,(rc)$) with the distribution for stations within 1 or 2 miles ($F_1\,(rc)$ and $F_2\,(rc)$ respectively). In both cases, the null hypothesis of equal distributions can be rejected and lower rank reversals are observed in the group of clustered stations ($F_c > F_1$ and $F_c > F_2$).

If product differentiation is an important factor in the gasoline sector, the study of rank reversals might underestimates the presence of costly search in the market. A better measure of the stability of price dispersion could be related to the *size* of the price spread over time between every couple of stations. In a market that has constant demand and cost shocks, spreads are expected to be constant over time when only product differentiation is the reason for price dispersion. When costly search comes into the scene, only the spread between stations sufficiently close should remain constant. The rest is assumed to vary. Denote $\sigma_{ij}\,(d_{ij})$ the standard deviation of $(p_{it} - p_{jt})$ over the days for which i and j have prices (T_{ij}), where d_{ij} is the distance separating the two stations. A test of consumer search would consist on testing if $\sigma_{ij}\,(d_{ij})$ increases with d_{ij}. There are other factors that affect the search intensity in each market and influence σ_{ij}. For example, income is a proxy of consumers' search cost (both, because of income effects and as the opportunity cost of time). Also, the area (business district or residential zone) and the day of the week reveals information about the type of consumer buying gasoline and hence, the type of search protocol used.

[35] Not all stations that are about 400 feet apart are visible to consumers. At the same time, there is some measurement error in the mapping of the stations and setting a radius below 400 feet might eliminate stations that are actually facing each other. Thus positive rank reversals could actually be observed within this group of stations even without idiosyncratic cost shocks.

The study of the stability of the price dispersion is part of my ongoing research. Later versions of this paper will include the estimation of the effect of distance on the stability of price dispersion.

6 Conclusion

This paper develops a model that explains the widely observed rockets and feathers price pattern. The model links the firms' asymmetric response to cost shocks to the fact that consumers are imperfectly informed about market prices and the industry's production cost. Consumers' search decisions affect the elasticity of the expected demand faced by firms and therefore their cost pass-through. If production cost shows serial correlation, the amount of informed consumers in the market depends on the previous cost realization and as a result, the cost pass-through exercised by firms is different when the cost drops than when it raises. The simplicity of the model helps identify the forces behind asymmetric pricing. Both the assumptions on the cost process and consumers' learning of marginal cost could be modified to better approximate the quantitative properties of the observed rockets and feathers pattern.

Contrary to public opinion and previous work suggesting that collusive behavior was the cause behind asymmetric pricing, this paper shows that it can well be the outcome of a competitive market. This finding reinforces the importance of consumer search models in explaining actual markets functioning. By using a dataset of retail gasoline prices -a market where there is abundant evidence of rockets and feathers-, I find that the observed price dispersion pattern is consistent with costly consumer search. Gasoline stations located across each other (ie, consumers are informed about each price) present a more stable price dispersion over time than gas stations that are nearby but further apart.

The extent to which price dispersion is explained by consumer search models has important policy implications. Dispersed prices have different effects on welfare when there is product differentiation than when consumer search is costly. Under product differentiation, more variety (hence higher price dispersion) in the market is associated with higher welfare. It is not the same when consumer search is costly: higher price dispersion implies more search by consumers and the effect on welfare depends on the relative size of the search costs and the deadweight loss. It is thus evident the importance of more empirical work aiming at detecting the underlying model of price dispersion in the market.

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7 Appendix

Proof. [Proposition 1] This proof is done for the n firms case since it is also used in Section III. Therefore, $p^* = c + \frac{(1-\mu)(\upsilon-c)}{1+(n-1)\mu}$ in (6).

To show that $F(\cdot, c, \mu)$ is a unique symmetric NR the proof is divided in three steps (to simplify notation, ignore the fact that F is conditional on (c,μ)). First, it shows that there are no point masses in the equilibrium *pdf*. Second, for $\varepsilon > 0$, $F(p^* + \varepsilon) > 0$ and $F(\upsilon - \varepsilon) < 1$. Last, there are no gaps in the support of $F(p)$

1. Assume there exist a price $\widehat{p} \in (p^*, \upsilon]$ such that $\Pr(p = \widehat{p}) \equiv F(\{\widehat{p}\}) > 0$ (by definition, $F(\{p^*\}) = 0$). Then, there is an arbitrary small ε such that $F(\{\widehat{p} - \varepsilon\}) = 0$.A firm could deviate from $F(\cdot)$ by applying $F^d(\cdot)$ similar to $F(\cdot)$ with the exception that $F^d(\{\widehat{p}\}) = 0$ and $F^d(\{\widehat{p} - \varepsilon\}) = F(\{\widehat{p}\})$. The expected gains for the deviator can be decomposed to four scenarios, depending on the prices charged by the other firms. Let p_l be their lowest of the n prices in the market. If $p_l < \widehat{p} - \varepsilon$:

$$\sum_{j=1}^{n-1} \binom{n-1}{j} F(\widehat{p} - \varepsilon)^j [1 - F(\widehat{p} - \varepsilon)]^{n-1-j} \left\{ -\frac{(1-\mu)}{n} \varepsilon \right\} \tag{22}$$

If $p_l > \widehat{p}$:

$$-\varepsilon \left(\frac{(1-\mu)}{n} + \mu \right) [1 - F(\widehat{p})]^{n-1} \tag{23}$$

When $p_l = \widehat{p}$:

$$\sum_{j=1}^{n-1} \binom{n-1}{j} F(\{\widehat{p}\})^j [1 - F(\{\widehat{p}\})]^{n-1-j} \left\{ \mu \left(1 - \frac{1}{j}\right)(p-c) - \left(\frac{(1-\mu)}{n} + \mu \right) \varepsilon \right\} \tag{24}$$

Lastly, if $p_l \in (\widehat{p} - \varepsilon, \widehat{p})$, the expected gains are:

$$\sum_{j=1}^{n-1} \binom{n-1}{j} [F(\widehat{p}) - F(\{\widehat{p}\}) - F(\widehat{p} - \varepsilon)]^j [1 - F(\widehat{p})]^{n-1-j} \left\{ \mu (p-c) - \left(\frac{(1-\mu)}{n} + \mu \right) \varepsilon \right\} \tag{25}$$

As $\varepsilon \to 0$, (22) and (23) go to zero while (24) and (25) remain positive.

2. Suppose $F(\upsilon - \varepsilon) = 1$. Then at setting $p = \upsilon$ generates an increase in profits (with respect to $\upsilon - \varepsilon$) and no loss in customers. Similarly, if $F(\widehat{p} + \varepsilon) = 0$, it has to be that $\pi(\widehat{p} + \varepsilon) = \pi(\upsilon)$. By charging $p = \widehat{p} + \varepsilon/2$, profits are bigger: $\pi(\widehat{p} + \varepsilon/2) > \pi(p^*) = \pi(\upsilon)$.

3. Suppose there exists an interval (p_1, p_2) such that $F(p_1) = F(p_2)$. Then, by placing some density on $\widehat{p} \in (p_1, p_2)$, a firm will gain by increasing its markup. There is no expected loss since by part 1 of the proof, there are no ties at p_1.

Given, 1, 2, and 3 above, the only function that satisfies

$$\pi_s(p)(1 - F(p))^{n-1} + \pi_f(p) F(p) = \pi(\upsilon)$$

is:

$$F(p) = 1 - \left(\frac{(1-\mu)(\upsilon - p)}{n\mu(p-c)} \right)^{\frac{1}{n-1}}$$

■

Proof. **[Lemma 1]** I first show that there exists a unique global maximum $\widehat{\mu}$ for $E[p - p_{\min}]$ and strict local concavity around $E[p - p_{\min} | \mu = \widehat{\mu}]$. Then, concavity everywhere is provided. From (9),

$$\frac{\partial E[p - p_{\min}]}{\partial \mu} = \frac{(\upsilon - c)(2-\mu)}{2\mu^3} \left\{ \frac{2\mu(2+\mu)}{(2-\mu)(1+\mu)} - \log\left[\frac{1+\mu}{1-\mu}\right] \right\}$$

with $\underset{\mu \to 0}{Lim} \frac{\partial E[\cdot]}{\partial \mu} \to \frac{\upsilon - c}{3}$ and $\underset{\mu \to 1}{Lim} \frac{\partial E[\cdot]}{\partial \mu} \to -\infty$. The term in curly brackets determines the sign of this expression. Critical points are at $\mu = \widehat{\mu} \neq \{0, 1\}$,

$$\log\left[\frac{1+\mu}{1-\mu}\right] = \frac{2\mu(2+\mu)}{(2-\mu)(1+\mu)} \tag{26}$$

At $\mu = 0$, $LHS = RHS$. The difference in slopes between RHS and LHS is:

$$\frac{\partial LHS}{\partial \mu} - \frac{\partial RHS}{\partial \mu} = -\frac{4\mu^2(1-2\mu)}{(1-\mu)(2+\mu(1-\mu))^2}$$

which is positive (negative) for $\mu < (>)\, 1/2$. Since at $\mu = 1$, $LHS > RHS$, there is a unique critical point at $\widehat{\mu} > 0.5$.[36]

The second derivative of (9) is:

$$\frac{\partial^2 E[p - p_{\min}]}{\partial \mu^2} = \frac{-(\upsilon - c)}{(1-\mu)(1+\mu)^2 \mu^4} \left\{ \frac{2\mu(3+\mu(2-\mu(3+\mu)))}{(3-\mu)(1-\mu)(1+\mu)^2} - \log\left[\frac{1+\mu}{1-\mu}\right] \right\}$$

Using (26) and rearranging, at $\widehat{\mu}$,

$$\frac{\partial^2 E[p - p_{\min}]}{\partial \mu^2} = \frac{2(\upsilon - c)\widehat{\mu}^3(1-2\widehat{\mu})}{(1-\widehat{\mu})(2-\widehat{\mu})(1+\widehat{\mu})^2 \widehat{\mu}^4} < 0$$

For concavity everywhere,

$$\frac{2\mu(3+\mu(2-\mu(3+\mu)))}{(3-\mu)(1-\mu)(1+\mu)^2} \geq \log\left[\frac{1+\mu}{1-\mu}\right]$$

At $\mu = 0$, both expressions are equal to zero. For $\mu > 0$, it can be verified that $\frac{\partial LHS}{\partial \mu} > \frac{\partial RHS}{\partial \mu} > 0$ ■

[36] Numerically, the maximum can be shown to be $\widehat{\mu} \approx 0.634816$

Proof. **[Proposition 2]** Reexpress (10) using (9)

$$(\upsilon - E[c])\frac{(1-\mu)}{2\mu^2}\left[\log\left[\frac{1+\mu}{1-\mu}\right] - 2\mu\right] = g^{-1}(\frac{\mu-\lambda}{1-\lambda})$$

At $\mu = \lambda + (1-\lambda)\,g(0)$, the RHS is zero while the LHS is positive. By Lemma 1, LHS is concave and lower than υ. Thus, g^{-1} cuts from below the expected gains from search at least once. If $\lambda > \widehat{\mu}$, it is easy to see that there is a unique solution to (10). If $\lambda < \widehat{\mu}$, the possibility of multiple solutions is eliminated if g^{-1} has steeper slope than the LHS for any value of μ in the range $(\lambda, \widehat{\mu})$ ■

Proof. **[Lemma 2]** Let the equation in (10) be represented by G. Using (9):

$$G = (\upsilon - E[c])\frac{1-\widetilde{\mu}}{2\widetilde{\mu}^2}\left[\log\left[\frac{1+\widetilde{\mu}}{1-\widetilde{\mu}}\right] - 2\widetilde{\mu}\right] - g^{-1}\left(\frac{\widetilde{\mu}-\lambda}{1-\lambda}\right)$$

where $\widetilde{\mu} = \lambda + (1-\lambda)\,g(\widetilde{s})$. Then, by the IFT,

$$\frac{\partial \widetilde{s}}{\partial \alpha} = -\frac{\frac{\partial G}{\partial \alpha}}{\frac{\partial G}{\partial \widetilde{s}}}$$

The numerator is negative since α increases $E[c]$. The denominator is

$$\frac{\partial G}{\partial \widetilde{s}} = (1-\lambda)\frac{\partial g}{\partial \widetilde{s}}\left(\frac{\partial E[p - p_{\min}|c, \widetilde{\mu}]}{\partial \mu} - \frac{\partial g^{-1}}{\partial \widetilde{\mu}}\right) < 0$$

Since at $\widetilde{s}$ the inverse *cdf* cuts the expected price differential from below, the term in parenthesis is negative.

The same argument applies to the case of degenerate $g(\cdot)$. $E[p - p_{\min}|\mu = \lambda + (1-\lambda)\,q] = s$ could have one or two roots q depending on the size of λ and s. The stable equilibrium has $E[\cdot]$ cutting s from above. As α increases, $E[\cdot]$ gets flatter and q (hence μ) decreases ■

Proof. **[Proposition 3]** If cost is *iid* consumers would not update priors ($\frac{\partial \alpha}{\partial c_{t-1}} = 0$) and there is no asymmetric pricing in (17). When cost is persistent, $h(c_H) > h(c_L)$ so $\frac{\partial \alpha}{\partial c_{t-1}} > 0$ and $\rho > 1/2$. The derivative of the pass-through (19) w.r.t. μ

$$\frac{\partial^2 E(p|c)}{\partial c \partial \mu} = \frac{1}{2\mu}\left[\log\left[\frac{1+\mu}{1-\mu}\right] - \frac{2\mu}{(1+\mu)}\right]$$

is positive since $\log\left[\frac{1+\mu}{1-\mu}\right] > 2\mu$. Therefore, $\underset{(+)}{\frac{\partial^2 p_t}{\partial c_t \partial \mu}}\underset{(-)}{\frac{\partial \mu}{\partial \alpha}}\underset{(+)}{\frac{\partial \alpha}{\partial c_{t-1}}} < 0$ and $E\left[\frac{\triangle p}{\triangle c^+}\right] - E\left[\frac{\triangle p}{\triangle c^-}\right] > 0$ in (17) ■

Proof. **[Proposition 4]** As long as the conditional gains from search increase with n, $\frac{\partial \tilde{s}}{\partial n} > 0$ in (10) and $\frac{\partial q}{\partial n} \geq 0$ in a stable equilibrium of (11). The gains from search are:

$$E\left[p - p_{\min}|c, n\right] = \int_{p^*}^{v} pn\left[1 - F\left(p\right)\right]^{n-1} f\left(p\right) dp = \int_{p^*}^{v} \frac{p(v-c)}{\left(n-1\right)\left(p-c\right)\left(v-p\right)} n\left[1-F\left(p\right)\right]^{n} dp$$

Define $z = 1 - F\left(p\right)$. Then, $p = \frac{v(1-\mu)+cn\mu z^{n-1}}{(n-1)(p-c)(v-p)}$ and $dp = -\frac{(1-\mu)\mu n(n-1)(v-c)z^{n-1}}{\left(z(1-\mu)+\mu z^{n}\right)^{2}} dz$. Changing variables,

$$E\left[p - p_{\min}|c, n\right] = \int_{0}^{1} nz^{n-1}\left[\frac{v(1-\mu)+c\mu nz^{n-1}}{(1-\mu)+\mu nz^{n-1}}\right] dz = v' \int_{0}^{1} \frac{nz^{n-1}}{1+\frac{\mu}{(1-\mu)}nz^{n-1}} dz$$

wlg, the marginal cost can be normalized to 0 and v adjusted to v'. Define $A_{n+1} = 1 + \frac{\mu}{(1-\mu)}\left(n+1\right) z^{n}$ and $A_n = 1 + \frac{\mu}{(1-\mu)} nz^{n-1}$:

$$E\left[p - p_{\min}|n+1\right] - E\left[p - p_{\min}|n\right] = v' \int_{0}^{1} \left\{\frac{\left(n+1\right) z^{n}}{A_{n+1}} - \frac{nz^{n-1}}{A_n}\right\} dz =$$

$$= \quad v' \int_{0}^{1} \frac{z^{n-1}\mu/\left(1-\mu\right)\left[n-\left(n+1\right)z\right]}{A_{n+1}A_n} dz =$$

$$= \quad v' \int_{0}^{n/(n+1)} \frac{z^{n-1}\mu/\left(1-\mu\right)\left[n-\left(n+1\right)z\right]}{A_{n+1}A_n} dz - v' \int_{n/(n+1)}^{1} \frac{z^{n-1}\mu/\left(1-\mu\right)\left[\left(n+1\right)z-n\right]}{A_{n+1}A_n} dz \geq$$

$$\geq \quad \frac{v'}{\left[1+\frac{\mu}{(1-\mu)}\left(n+1\right)\left(\frac{n}{n+1}\right)^{n}\right]\left[1+\frac{\mu}{(1-\mu)}n\left(\frac{n}{n+1}\right)^{n-1}\right]} \int_{0}^{1} z^{n-1}\frac{\mu}{\left(1-\mu\right)}\left[n-\left(n+1\right)z\right] dz = 0$$

■