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Consumer Search, Price Dispersion, and Asymmetric Pricing

A dissertation submitted in partial satisfaction
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by

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To my wife Florencia, my sons Felipe and Benjamín

and especially to my parents

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Abstract of the Dissertation

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This dissertation consists of a study of the consequences of consumers' imperfect information on market clearing prices. The traditional paradigm in economics assumes consumers have perfect information about the prices in the market. When this assumption is replaced by the more realistic one of costly information acquisition (consumer search) the predictions from the perfectly competitive market change radically. Price dispersion emerges even when firms are identical and sell homogeneous products. Moreover, profits or information rents are captured by the sellers in the long run.

In Chapter I, I explore the theoretical implications of consumer search on price dynamics. Previous empirical work established that in most markets "prices rise like rockets but fall like feathers." I show that a model with competitive firms and rational partially-informed consumers can generate such asymmetric response to costs by firms. In contrast to public opinion and past work, collusion is not necessary to explain such stylized fact.

In Chapter II, I analyze the price dispersion observed in the Californian retail

gasoline markets. The retail gasoline market presents a unique opportunity to identify the sources of price dispersion. The price differences between gas stations located in a single corner can only be related to product characteristics, while the price spreads between stations that are further appart can also be generated by costly consumer search. Using a rich and unique dataset on retail prices, I show that consumers' imperfect information is important in this market.

CHAPTER 1

Rockets and Feathers. Understanding Asymmetric Pricing.

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

The first thing that comes to mind when talking about rockets and feathers is collusion. A classical example is gasoline retailing, a market operated by a handful of players with output and input prices easily observable by everyone. Asymmetric gas price adjustments are usually associated with collusive behavior by both government and the media.[2,3] However, Peltzman finds that the *rockets*

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

[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 produc-

and feathers pattern is equally likely to be found in both concentrated and atomistic 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 the firms must be sensitive to previous cost realizations. This is indeed what happens when consumers don't observe firms' current production cost.

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

tion, 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) and 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 costless consumer search 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 eliminates the possibility of rockets and feathers

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.[5]

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 costly consumer search. A general characteristic of consumer search models is price dispersion. However, this pattern is also consistent with models of product differentiation in the market. Whether the widespread price dispersion observed in many markets is attributable to consumer search, product differentiation, or both is an empirical question. In Chapter 2, I show that the retail gasoline market (a market where evidence of rockets and feathers has been found many times) exhibits price dispersion consistent with both, product differentiation as well as costly consumer search.

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

[5]The extension of the model to the case of multiunit demands is analyzed in Appendix B.

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.[6] 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 with production costs composed of both an idiosyncratic (real) and a common (inflation) shock. Consumers behave rationally by updating their priors about the common shock from observed prices. Under some parameters, more inflation uncertainty leads to more search and thus generate inefficiencies.[7,8]

This model shares the assumption that consumers are imperfectly informed

[6] In this case, after visiting $n-1$ stores and observing $n-1$ identical prices, consumers would still choose to pay the search 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.

[7] 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 (smaller) if cost is increasing (decreasing).

[8] Other work on asymmetric pricing is Borenstein *et al.* (1997) and Eckert (2002). The former suggest a model of 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.

with Benabou *et al.* (1993) and Lewis (2003). In contrast to their work, I assume homogeneous firms (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.[9]

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).[10] 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.[11]

The rest of the chapter is organized as follows. In the next section I describe

[9] 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.

[10] 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) assume a flexible sample-size nonsequential search protocol.

[11] Appendix C contains an extension of the model for the case of sequential search. I show that a necessary condition for asymmetric pricing is the existence of heterogeneous search costs.

the model 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 concludes.

1.2 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 consumers choosing to become informed (Proposition 2). Second, the search intensity in the market decreases with the expected production cost (Lemma 2).[12] 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 production 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. To simplify the analysis, assume they each have a unit demand with a choke price v, and can obtain information about market prices through nonsequential search.[13] They decide -before observing any prices-

[12] 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 10).

[13] Consumers with unit demand is a simplifying assumption and is not critical for the rockets and feathers result. Intermediate results change for some demand functions and I discuss that

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.[14]

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 $\overline{s} > \upsilon$.

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

in the text. Appendix B extends the results to two other type of demands (linear and constant elasticity).

[14] Another example where nonsequential search is optimal is that of daily commuters deciding where to buy gasoline (see more in Chapter 2).

$i \in N^D = [0, 1]$ a consumer. Producers can be of either type c_L or c_H, where the probability of having high cost (type 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 $a_i \in A = \{0, 1\} = \{\text{don't search, search}\}$.[15] 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:

$$\pi_j (p_j, p_{-j}, a, c) = (p_j - c) \left\{ \frac{1+\mu}{2} \mathbf{I}_{\{p_j < p_{-j}\}} + \frac{1}{2} \mathbf{I}_{\{p_j = p_{-j}\}} + \frac{1-\mu}{2} \mathbf{I}_{\{p_j > p_{-j}\}} \right\} \tag{1.1}$$

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:

$$u_i (a_i, a_{-i}, p) = \upsilon - a_i (Min [p] + s_i) - (1 - a_i) \frac{1}{2} \sum_j p_j \tag{1.2}$$

Firm j's strategy profile is represented by all possible price distributions given a cost realization: $f_j (\cdot, c) = \{f_j (p_j, c)\}_{p_j \in P}$ 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 $\sigma^D = \{q_i (\cdot, s_i)\}_{i \in N^D}$ implies a value of $\mu \in [\lambda, 1]$.[16] Define a Nash Best Response $NBR (\mu, c)$ as a symmetric Nash Equilibrium strategy of the game $\Gamma = [N_J, P, \pi_{j \in N_J}]$ where π_j is defined in (1.1). That is, a NBR consists on the equilibrium price strategies in the duopoly game that are a best response to a given

[15] 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.

[16] 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 (1.2) by assuming they always search.

search intensity by consumers. A Symmetric Bayesian Nash Equilibrium (SBNE) or *market equilibrium* is composed of consumers' beliefs about the 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.[17]

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

[17]Note that SPE and pure strategy equilibrium are equivalent since *NBR* is defined to be a symmetric NE.

equilibrium.[18] 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:

$$\pi^{f}\left(p,c\right)=\frac{\left(1-\mu\right)}{2}\left(p-c\right) \tag{1.3}$$

$$\pi^{s}\left(p,c\right)=\frac{\left(1+\mu\right)}{2}\left(p-c\right) \tag{1.4}$$

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

$$\pi(\upsilon,c)=\frac{(1-\mu)}{2}(\upsilon-c) \tag{1.5}$$

This, places a lower bound on the prices considered by any firm. Even if a firm captured *all* the informed consumers, charging a price below p^{*} generates less profits than if it charged the monopoly price:[19]

$$p^{*}=\pi^{s\ -1}(\pi(\upsilon,c))=c+\frac{(1-\mu)}{(1+\mu)}(\upsilon-c) \tag{1.6}$$

Thus, a *NBR* consists of strategies over $\left[p^{*},\upsilon\right]$.

By the same argument used to ruled out any single price equilibrium, 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 $F\left(\cdot,c,\mu\right)$. A firm is indifferent between charging the monopoly price and a price that generates a similar expected profit:

$$\pi^{s}(p,c)(1-F(\cdot))+\pi^{f}(p,c)F\left(\cdot\right)=\pi(\upsilon,c) \tag{1.7}$$

[18] The perfect competition outcome will actually not arise as long as there is a proportion of consumers with positive search cost (not necessarily $>\upsilon$). This is because when $\mu=1$ firms set prices equal to the production cost. Then, since it would never pay to consumers with positive search cost to search (no price dispersion), $\mu=1$ is a contradiction.

[19] Note that by definition p^{*} cannot be a SPE.

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*

$$F(p, c, \mu) = \int_{p^*}^{p} f(x, c, \mu)\, dx = 1 - \left(\frac{(1-\mu)(\upsilon - p)}{2\mu(p - c)} \right) \tag{1.8}$$

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

Proof: See Appendix A.

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 1.6). 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 (1.8) as $F(\cdot.\mu')$ first-order stochastically dominates $F(\cdot.\mu)$ when $\mu' > \mu$.

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 in the market (price dispersion):

$$\begin{aligned} E\left[p - p_{\min}|\mu\right] &= E_c\left[\int_{p^*}^{v} p\left[1 - 2\left[1 - F\left(p, c, \mu\right)\right]\right] dF\left(\cdot, c, \mu\right)\right] = \\ &= \left(v - E\left[c\right]\right)\frac{(1-\mu)}{2\mu^2}\left[\log\left[\frac{1+\mu}{1-\mu}\right] - 2\mu\right] \end{aligned} \tag{1.9}$$

where the last equation is obtained using (1.8) 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 choosing prices 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.[20] For $\mu > \widehat{\mu}$, adding informed consumers reduces the spread between the expected price and minimum price since the firms increase the probability of choosing low prices while keeping the domain in (1.8) relatively fixed. The following lemma characterizes the price dispersion as a function of the search intensity (equation 1.9).

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 A.

[20] $E[p]$ 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 bigger μ's.

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 υ never search.[21] That also implies that there are at least λ informed and $(1-g(\upsilon))(1-\lambda)$ uninformed consumers in a market equilibrium. For the remaining consumers, 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:

$$E[p-p_{\min}|\mu=\lambda+(1-\lambda)\,g(\widetilde{s})]]-\widetilde{s}=0 \tag{1.10}$$

A market equilibrium when consumers have uniformly distributed search costs is shown in Figure 1.1. 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 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 (1.10) 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.

[21] See footnotes 18 and 16.

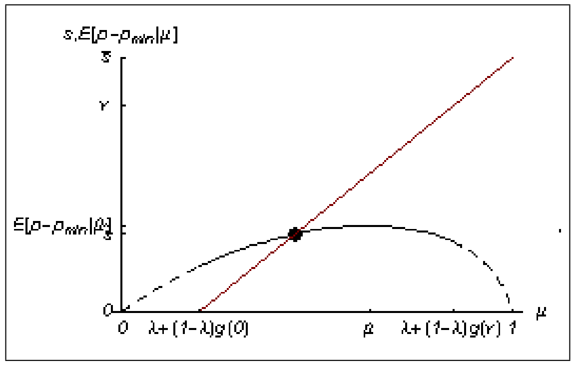


Figure 1.1: Equilibrium with uniformly distributed search costs

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 A.

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 $c = \upsilon$).[22] 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 (1.9). The gains from search $E[p - p_{\min}|\mu]$ are reduced as the probability of high cost α increases. Thus, the indifferent consumer has a lower

[22]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. See Appendix B for details.

search cost (equation 1.10) and the equilibrium search intensity decreases with α. The following lemma summarizes this result and is central for the findings in next section.

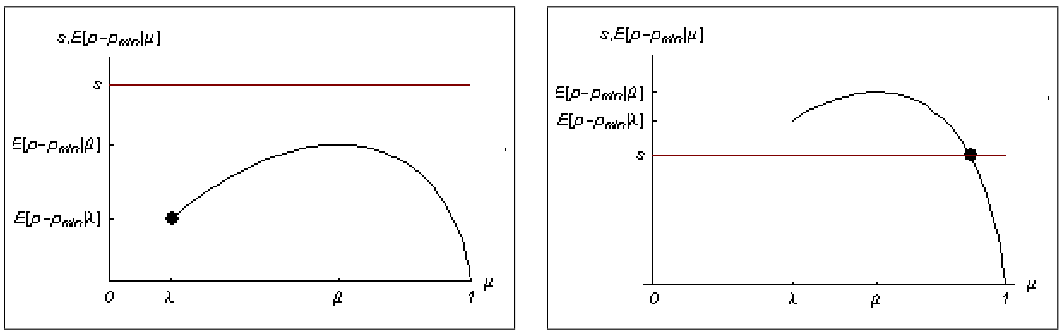
Lemma 2 *Search intensity decreases when consumers expect higher production cost:* $\frac{\partial \mu}{\partial \alpha} < 0$

Proof: See Appendix A.

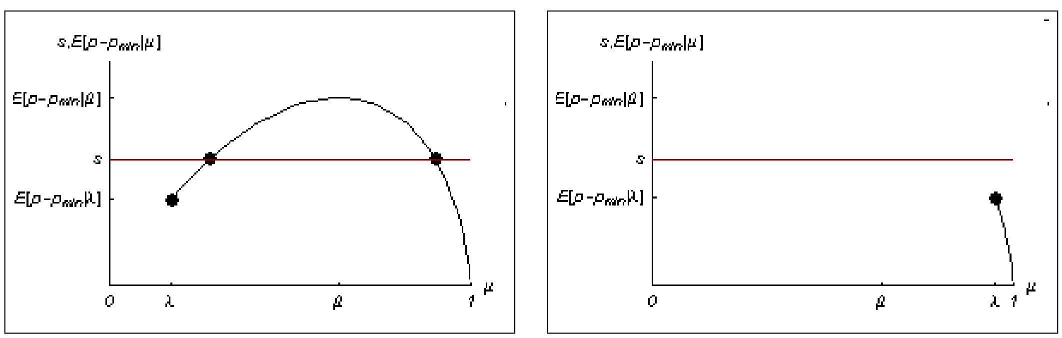
As long as the demand is composed of informed and uninformed consumers, a market equilibrium implies price dispersion. This is not a result driven by the heterogeneity in search costs. The last part of this section is devoted to extend the results above to the case where g is degenerate and nonshoppers are homogeneous in their search cost ($s_i = s$). Intuitively, when the search cost is sufficiently high, the market equilibrium involves only shoppers searching.[23] 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 non shoppers are searching in equilibrium, they are doing it with some 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 $s > E\left[p - p_{\min}|\mu = \widehat{\mu}\right]$.*

[23] 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 1.2: Market equilibrium with shoppers and homogeneous nonshoppers

Figure 1.2 shows all possible equilibria. There is always a market equilibrium with only shoppers searching ($\mu = \lambda$) if $E\left[p - p_{\min} | \mu = \lambda\right] < s$. That is, when the gains from search if only the shoppers do so are lower than the search cost of the nonshoppers (Figure 1.2a and 1.2c). The rest of the equilibria imply search by all types of consumers ($\mu > \lambda$) and the search intensity is determined by the roots q (if they exist) in

$$E\left[p - p_{\min} | \mu = \lambda + (1 - \lambda)q\right] = s \tag{1.11}$$

This possibility arises if there is a low number of shoppers and the search cost is low or moderate (Figure 1.2b and 1.2c). In the case of moderate 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 1.1 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 with homogeneous search cost $s > 0$*

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

	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 1.1: Market equilibrium with shoppers and homogeneous nonshoppers

search intensity only changes with α if the initial equilibrium involves searching by nonshoppers. When consumers expect higher production costs they search less since higher cost implies lower gains from search.[24] 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.

1.3 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 whether 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

[24]This is not the case in the unstable equilibrium that emerges when the number of shoppers is low search cost is moderate.

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).[25] In general, most tests of asymmetric pricing estimate a dynamic error-correction model of the following type:

$$\Delta y_t = \sum_{i=0}^{m} \beta_i^+ \left(\Delta x_{t-i}\right)^+ + \sum_{i=0}^{m} \beta_i^- \left(\Delta x_{t-i}\right)^- + \gamma \left(y_{t-1} - \delta_0 - \delta_1 x_{t-1}\right) + \varepsilon_t \qquad (1.12)$$

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 (1.12) 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.[26]

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

[26] In general, data restrictions prevent the econometrician from including a sufficient num-

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 atomistic 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.

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

ber of lags in (1.12) such that the CRF is estimated for all the periods it takes the price to accommodate to the cost change (Peltzman, 2000).

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:

$$P = \begin{bmatrix} \rho & 1-\rho & 0 & 0 \\ 0 & 0 & 1-\rho & \rho \\ \rho & 1-\rho & 0 & 0 \\ 0 & 0 & 1-\rho & \rho \end{bmatrix} \tag{1.13}$$

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.[27] 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 (1.12). 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

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

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:

$$\begin{aligned} E\left[\frac{\triangle p}{\triangle c^+}\right] &= \Pr(HL)\Pr(LH_t|HL_{t-1})[p_{LH}-p_{HL}]+ \\ &\quad \Pr(LL)\Pr(LH_t|LL_{t-1})[p_{LH}-p_{LL}] \end{aligned} \tag{1.14}$$

$$\begin{aligned} E\left[\frac{\triangle p}{\triangle c^-}\right] &= \Pr(LH)\Pr(HL_t|LH_{t-1})[p_{LH}-p_{HL}]+ \\ &\quad \Pr(HH)\Pr(HL_t|HH_{t-1})[p_{HH}-p_{HL}] \end{aligned} \tag{1.15}$$

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

$$E\left[\frac{\triangle p}{\triangle c^+}\right]-E\left[\frac{\triangle p}{\triangle c^-}\right]=\frac{-1}{2}\rho(1-\rho)[(p_{HH}-p_{HL})-(p_{LH}-p_{LL})] \tag{1.16}$$

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 (1.16) 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, (1.16) can be approximated by

$$\begin{aligned} E\left[\frac{\triangle p}{\triangle c^+}\right]-E\left[\frac{\triangle p}{\triangle c^-}\right] &\approx \frac{-1}{2}\rho(1-\rho)|\Delta c|\frac{\partial^2 p_t}{\partial c_t\partial c_{t-1}}= \\ &= \frac{-1}{2}\rho(1-\rho)|\Delta c|\frac{\partial^2 p_t}{\partial c_t\partial\mu}\frac{\partial\mu}{\partial\alpha}\frac{\partial\alpha}{\partial c_{t-1}} \end{aligned} \tag{1.17}$$

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 $\alpha' < \alpha''$).[28] 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 or constant elasticity, for example) allow for positive pass-through but still lower than one.[29]

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

[28] A potential unstable equilibrium is ignored.

[29] 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.

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

$$E\left[p|c\right] = \upsilon - \int\limits_{p^*}^{\upsilon} F(p,c)dp \tag{1.18}$$

where the price distribution $F(\cdot, c)$ is the market equilibrium distribution ($F(\cdot, c, \mu)$ in (1.8) with $\mu = \lambda + (1-\lambda)\, g\left(\widetilde{s}\right)$ from (1.10)). Integrating by parts and deriving:

$$\frac{\partial E\left(p|c\right)}{\partial c} = 1 - \frac{(1-\mu)}{2\mu} \log\left[\frac{1+\mu}{1-\mu}\right] \tag{1.19}$$

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.[30] The derivative of (1.19) with respect to μ confirms that the cost pass-through is higher as the market becomes more competitive.

Combining (1.19) and the fact that higher priors generate less search (Lemma 2), the sign of the asymmetry in (1.17) 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 A.

[30]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.

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, 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 Chapter 2. In the next section, I extend the results to markets with more than two firms.

1.4 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 (1.3) to (1.7) to account for $n > 2$, and solving (1.7) 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:*

$$F\left(p, c, \mu\right) = 1 - \left(\frac{(1-\mu)(\upsilon - p)}{n\mu(p-c)}\right)^{\frac{1}{n-1}} \tag{1.20}$$

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

The changes in $F(\cdot)$ are plotted in Figure 1.3. The presence of more stores in the market increases the likelihood of setting prices in the extremes of the distribution. This 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 strengthening 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

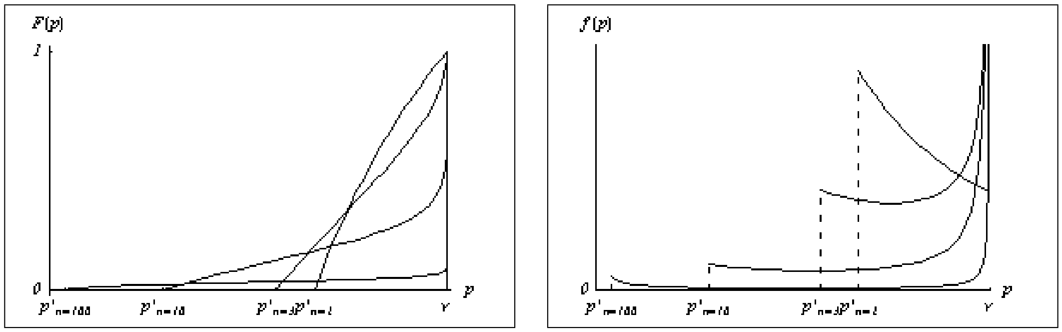


Figure 1.3: Equilibrium price distribution and number of stores ($c = 0, \mu = 0.2$)

distribution converges weakly to the monopoly price (Stahl, 1989; and Janssen and Moraga-Gonzlez, 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 (1.9), the expected gains from search are now:

$$E_c\left[E\left[p - p_{\min}|c, \mu, n\right]\right] = E_c \int_{p^*}^{v} \frac{p\,(v-c)\left(1 - n\left[1-F\left(p\right)\right]^{n-1}\right)}{(n-1)\,(p-c)\,(v-p)} \left[1 - F\left(p\right)\right] dp \tag{1.21}$$

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 :
$E\left[p - p_{\min}|c, \mu, n+1\right] > E\left[p - p_{\min}|c, \mu, n\right]$

Proof: See Appendix A.

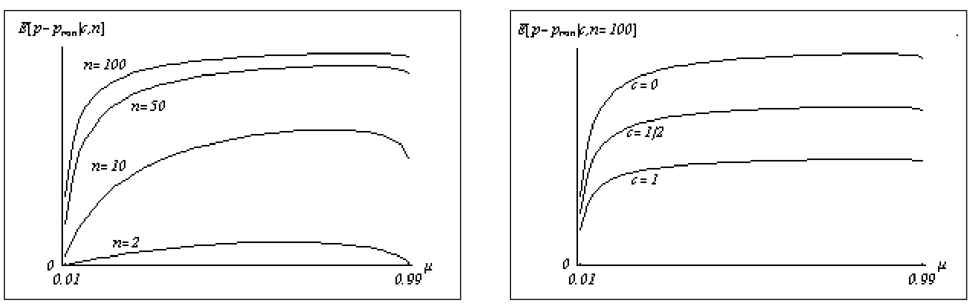
There are various ways to think about how competitive the market becomes when the number of sellers increases. As n grows, prices approach the monopoly price, but at the same time profits vanish. Furthermore, holding constant the number of firms, a larger number of informed consumers implies a more elastic demand faced by each firm. As μ increases, the market is more competitive and prices decrease regardless of the number of firms. From (1.20), $F(\cdot, \mu') > F(\cdot, \mu'')$ 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 (1.21) becomes less tractable and I need to rely on simulations to show its concavity. Table 1.2 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 toward zero. The plots in Figure 1.4(a) represent the first panel of Table 1.2 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 1.3.

With concavity guaranteed, Proposition 2 can be applied to the case of more atomistic 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.

	$\upsilon/c=2$			$\upsilon/c=5$			$\upsilon/c=10$		
$\mu \vert n$	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 1.2: Expected gains from search



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

Figure 1.4: Maximum expected gains from search and the number of firms

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

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 1.4.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 (1.17). 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-appropriation 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 (1.5), 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.

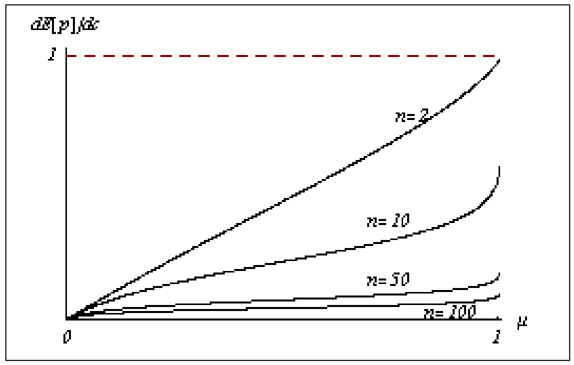


Figure 1.5: Cost pass-through

1.5 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 both 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 number of informed consumers in the market depends on the previous cost realization. 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 to identify the forces behind asymmetric pricing. The assumptions on both the cost process and consumers' learning of production cost could be modified to better approximate the quantitative properties of the observed rockets and feathers pattern in each market.

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. The next Chapter of this dissertation is a step in that direction.

Appendix A - Proofs

Proof of 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 (1.6).

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 $p_l < \widehat{p} - \varepsilon$:

$$\sum_{j=1}^{n-1} \binom{n-1}{j} F(\widehat{p} - \varepsilon)^j \left[1 - F(\widehat{p} - \varepsilon)\right]^{n-1-j} \left\{-\frac{(1-\mu)}{n}\varepsilon\right\} \tag{1.22}$$

If $p_l > \widehat{p}$:

$$-\varepsilon \left(\frac{(1-\mu)}{n} + \mu\right) \left[1 - F(\widehat{p})\right]^{n-1} \tag{1.23}$$

When $p_l = \widehat{p}$:

$$\sum_{j=1}^{n-1} \binom{n-1}{j} F(\{\widehat{p}\})^j \left[1 - F(\{\widehat{p}\})\right]^{n-1-j} \left\{\mu\left(1 - \frac{1}{j}\right)(p - c) - \left(\frac{(1-\mu)}{n} + \mu\right)\varepsilon\right\} \tag{1.24}$$

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

$$\sum_{j=1}^{n-1} \binom{n-1}{j} \left[F(\widehat{p}) - F(\{\widehat{p}\}) - F(\widehat{p}-\varepsilon)\right]^j \left[1-F(\widehat{p})\right]^{n-1-j} \left\{\mu(p-c) - \left(\frac{(1-\mu)}{n}+\mu\right)\varepsilon\right\} \tag{1.25}$$

As $\varepsilon \to 0$, (1.22) and (1.23) go to zero while (1.24) and (1.25) 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 of 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 (1.9),

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

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 $\mu = \widehat{\mu} \neq \{0,1\}$,

$$\log\left[\frac{1+\mu}{1-\mu}\right] = \frac{2\mu(2+\mu)}{(2-\mu)(1+\mu)} \tag{1.26}$$

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 $\widehat{\mu} > 0.5$.[31]

The second derivative of (1.9) 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 (1.26) 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 $\frac{\partial LHS}{\partial \mu} > \frac{\partial RHS}{\partial \mu} > 0$ ■

Proof of Proposition 2. Reexpress (1.10) using (1.9)

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

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 (1.10). 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 $(\lambda, \widehat{\mu})$ ■

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

Proof of Lemma 2. Let the equation in (1.10) be represented by G. Using (1.9):

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

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 of 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 (1.17). 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 (1.19) 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 (1.17) ■

Proof of Proposition 4. As long as the conditional gains from search increase with n, $\frac{\partial \widetilde{s}}{\partial n} > 0$ in (1.10) and $\frac{\partial q}{\partial n} \geq 0$ in a stable equilibrium of (1.11). The gains from search are:

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

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

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

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

$$\begin{aligned}
E\left[p-p_{\min}|n+1\right]-E\left[p-p_{\min}|n\right]&=\upsilon'\int\limits_{0}^{1}\left\{\frac{\left(n+1\right)z^{n}}{A_{n+1}}-\frac{nz^{n-1}}{A_{n}}\right\}dz=\\
&=\upsilon'\int\limits_{0}^{1}\frac{z^{n-1}\mu/\left(1-\mu\right)\left[n-\left(n+1\right)z\right]}{A_{n+1}A_{n}}dz=\\
&=\upsilon'\int\limits_{0}^{n/(n+1)}\frac{z^{n-1}\mu/\left(1-\mu\right)\left[n-\left(n+1\right)z\right]}{A_{n+1}A_{n}}dz-\upsilon'\int\limits_{n/(n+1)}^{1}\frac{z^{n-1}\mu/\left(1-\mu\right)\left[\left(n+1\right)z-n\right]}{A_{n+1}A_{n}}dz\geq\\
&\geq\frac{\upsilon'}{\left[1+\frac{\mu}{(1-\mu)}\left(n+1\right)\left(\frac{n}{n+1}\right)^{n}\right]\left[1+\frac{\mu}{(1-\mu)}n\left(\frac{n}{n+1}\right)^{n-1}\right]}\int\limits_{0}^{1}z^{n-1}\frac{\mu}{\left(1-\mu\right)}\left[n-\left(n+1\right)z\right]dz=0
\end{aligned}$$

■

Appendix B - Multiunit Demands

The model used in this paper assumes that consumers have unit demands. In this Appendix, I study the robustness of the results with respect to various demand assumptions. As it will become clear below, the characterization of the static equilibrium is not itself altered, but both the comparative statics of price dispersion with respect to the firms' production cost, and the expected cost pass-through with respect to the search intensity in the market are sensitive to the demand functional form. From (1.17) we know that these two effects are important in determining the existence of the rockets and feathers pattern since

$$sign\left(E\left[\frac{\triangle p}{\triangle c^{+}}-\frac{\triangle p}{\triangle c^{-}}\right]\right)=sign\left(-\frac{\partial\mu}{\partial\alpha}\frac{\partial^{2}p_{t}}{\partial c_{t}\partial\mu}\right) \tag{1.27}$$

With unit demands, consumers search less if they expect higher production costs ($\frac{\partial\mu}{\partial\alpha}<0$). The firms' cost pass-through increases as the market becomes more competitive ($\frac{\partial^{2}p_{t}}{\partial c_{t}\partial\mu}>0$). In what follows, I start by analyzing the duopoly Nash Best Responses for a general demand function and then restrict the analysis of price dispersion and search intensity to the cases of linear and constant elasticity demands.

Assume all consumers demand the final good according to the demand function $q\left(p\right)$ with $q'<0$, $\varepsilon=-\frac{\partial q}{\partial p}\frac{q}{p}$, and a unique price $p^{m}=\arg\max_{p}\left\{q\left(p\right)\left(p-c\right)\right\}$. Let $\psi\left(p\right)=q\left(p\right)\left(p-c\right)$ denote the profit per consumer for a firm that sets a price p. With multiunit demands, consumers not only decide whether to search or not, but also the number of units they'll buy once they observe a price. Thus, from the point of view of the firms, there are two price elasticity measures (ε and μ) since there are two channels by which setting a lower price increases the expected aggregate demand. First, the probability of attracting μ more consumers is greater, and second, each consumer that shows up in the store buys more units.

By the same argument used in Proposition 1, as long as there is a positive mass of informed and uninformed consumers, there is no pure strategy equilibrium and the unique mixed strategies equilibrium implies firms drawing prices from distribution function $F(\cdot)$. By charging any price in F's support a firm obtains the same expected profit as if they were setting the monopoly price. The equivalent to Equation (1.7) is:

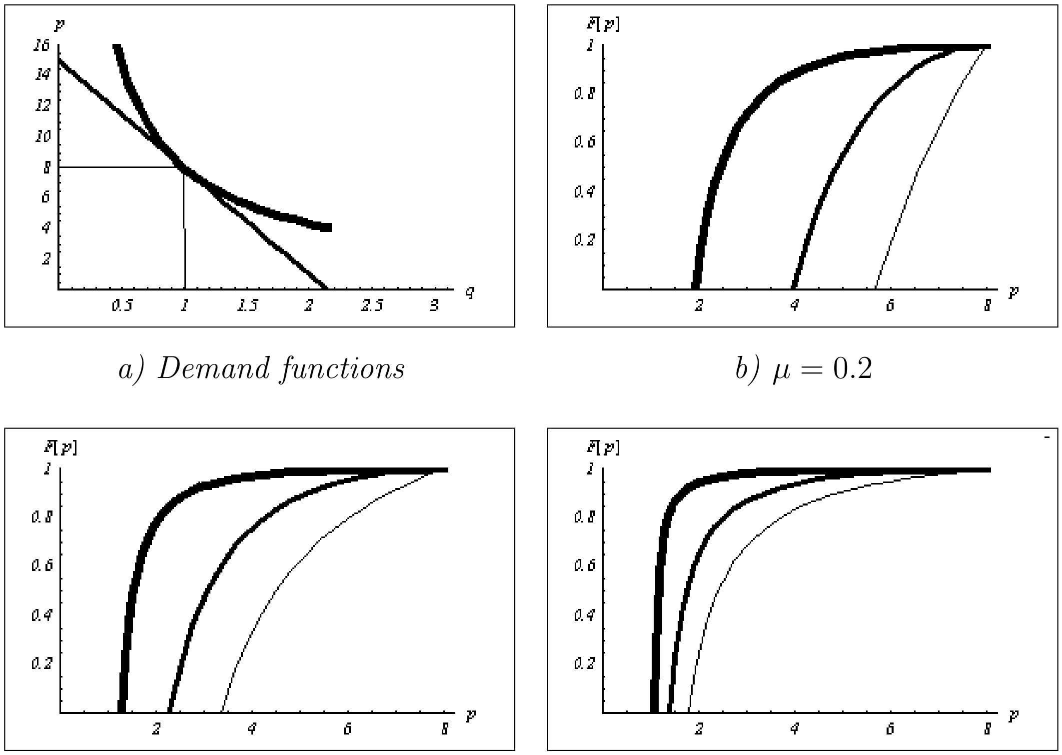
$$\pi(p^m) = \frac{(1-\mu)}{2}\psi(p)F(p) + \frac{(1+\mu)}{2}[1-F(p)]\psi(p)$$

substituting $\psi(p)$ and $\pi(p^m)$ and reorganizing

$$F(p) = \frac{(1-\mu)}{2\mu}\left[\frac{(1+\mu)}{(1-\mu)} - \frac{q(p^m)(p^m-c)}{q(p)(p-c)}\right] \tag{1.28}$$

$F(p)$ is concave since $\psi(p)$ is concave over the relevant range of prices ($\psi'(p) \geq 0$ for $p \leq p^m$) and its concavity increases with the elasticity of consumer demand (ε).[32] Both the *surplus-appropriation* and *business-stealing* effects explain the equilibrium in mixed-strategies. But -as opposed to the case of unit demands, when firms set prices below the monopoly price the loss of surplus is partially compensated with the fact that the uninformed consumers buy more units at lower prices. Thus, the support of the price distribution increases with ε. It can be checked that with unit demands (1.28) becomes (1.8). Figure 1.6 shows a comparison of the price distributions associated with three different demand functions *i)* linear, $q_l = a - bp$, *ii)* unit demand, $q_u = \mathbf{I}_{\{p<v\}}$, and *iii)* constant elasticity, $q_{ce} = K/p^{\theta}$, $\theta > 1$. The parameters $\{a, b, v, \theta, K\}$ were chosen such that the monopoly outcome is identical for the three cases (Figure 1.6 .a), and

[32]This is not the case when there are more than 2 firms in the market.



a) Demand functions *b)* $\mu = 0.2$

c) $\mu = 0.5$ *b)* $\mu = 0.8$

Figure 1.6: Consumer demand and firms' NBR

the elasticity at the monopoly price is the same for *i)* and *ii)*.[33] As equation (1.8) and Figure 1.6 makes visually clear, the differences in the price distributions are attenuated as the number of informed consumers (μ) in the market increases.

To complete the characterization of the *market equilibrium*, we need to focus next on the search decisions made by consumers, given the firms *NBR*. Consumers are concerned about the price dispersion in the market since they would pay either the minimum price or a random price depending on whether they choose to search or not. Thus, given the number of informed consumers, the price dispersion in the market is defined as the difference between the average price and the minimum

[33]The parameter values are: $c = 1$, $v = 8$, $a = 2.14286$, $b = 0.1428$, $\theta = 8/7$ and $K = 10.7672$.

expected price. With linear demands, the average price is given by:

$$E\left[p|\mu,c\right]=E_c\left[\int_{p^*}^{v} pdF\left(\cdot,c,\mu\right)\right]=$$

$$=\frac{(1-\mu)}{4b\mu}\left\{\frac{2\left(a+bE\left[c\right]\right)}{(1-\mu)}-\left(a-bE\left[c\right]\right)\left[\frac{\left(2\mu\left(1+\mu\right)\right)^{1/2}}{(1-\mu)}+\frac{\Omega}{2}\right]\right\} \quad (1.29)$$

And the minimum expected price is:

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

$$=\frac{1}{32b\mu^2}\left\{16(a+bE\left[c\right])\mu^2+\left(a-bE\left[c\right]\right)\left[\left(6-14\mu\right)\left(2\mu\left(1+\mu\right)\right)^{1/2}+3\left(1-\mu\right)^2\Omega\right]\right\}$$

where $\Omega=\log\left[A/B\right]$, $A=(1+\mu)^{1/2}-(2\mu)^{1/2}$ and $B=(1+\mu)^{1/2}+(2\mu)^{1/2}$; hence $\Omega<0$.

The difference simplifies to:

$$E\left[p-p_{\min}|\mu,c\right]=\frac{\left(a-bE\left[c\right]\right)}{32b}\frac{(1-\mu)}{\mu^2}\left[-6\left[2\mu\left(1+\mu\right)\right]^{1/2}-\left(3+\mu\right)\Omega\right] \quad (1.30)$$

In the extreme cases of $\mu=0$ (monopoly) and $\mu=1$ (perfect competition) there is no price dispersion. It can also be checked that $E\left[p-p_{\min}|\mu\right]$ is a strictly concave function of μ (Lemma 1) and a unique market equilibrium exists under mild conditions (Proposition 2). Similar to the case of unit demands, the price dispersion has a linear and negative relationship with the production cost. The reason for this is that with higher production costs, the trade-offs faced by the firms when choosing prices are not affected, but the range of prices over which firms choose from shrinks and the new price distribution is rescaled.[34] The analog extreme case to $c\to v$ in the unit demand case is when $c\to a/b$.

[34] The bounds of the support are $p^m=\frac{a+bc}{2b}$ and $p^*=\frac{(a+bc)}{b}-\frac{(a-bc)}{b}\left[\frac{\mu}{2(1+\mu)}\right]^{1/2}$ with $\frac{\partial(p^m-p^*)}{\partial c}=-\frac{1}{2}\left(\frac{\mu}{1+\mu}\right)^{1/2}<0$.

But the negative relationship between price dispersion and production cost is not enough to characterize the new search intensity in the market. This is so because the search decision by consumers with multiunit demands depends not only on the gap between the mean and minimum prices (price dispersion) but also on the actual price *levels*. A change in the cost of production has two effects. First, as the cost increases, the gains from search *per unit* bought are lower (1.30). Second, as cost (hence prices) increases, consumers plan to buy less units and so their incentives to find a good deal are lower (less search). Therefore, the search decision is made by comparing the search cost to the expected gain in consumer surplus of paying the minimum price in the market instead of a random price:

$$E[CS(p_{\min}) - CS(p)|\mu, c] = \frac{E_c\left[(a-bc)^2\right](1-\mu)}{64b\mu^2A^2} r(\mu)$$

where $r(\mu) = 16\mu - 2(3+\mu)\left[2\mu(1+\mu)\right]^{1/2} - \left(1 + 3\mu - 2(2\mu(1+\mu))^{1/2}\right)\log\left[\frac{A^{(7+\mu)}B^{(1-\mu)}}{(1+\mu)^4}\right]$ is positive and has the properties $r(0) = 0$ and $r(1) = 0$.

As expected, increases in the production cost generate less consumer search, $\frac{\partial\mu}{\partial\alpha} < 0$. In other words, when higher production costs are expected, the indifferent consumer will have a lower search cost because a) she expects to buy fewer units, and b) the gains from search per unit decrease. Figure (1.7) shows the total gains from search under low and high cost as well as the difference between the gains from search and the price dispersion ($E[CS(p_{\min}) - CS(p)|\mu, c]$ and $E[p - p_{\min}|\mu, c]$ respectively).[35]

In order to obtain the rockets and feathers result, we need to verify that the cost pass-through increases with the search intensity. This is done by differenti-

[35] The parameters values are: $\{a = 10, b = 1, c_H = 2, c_L = 1\}$

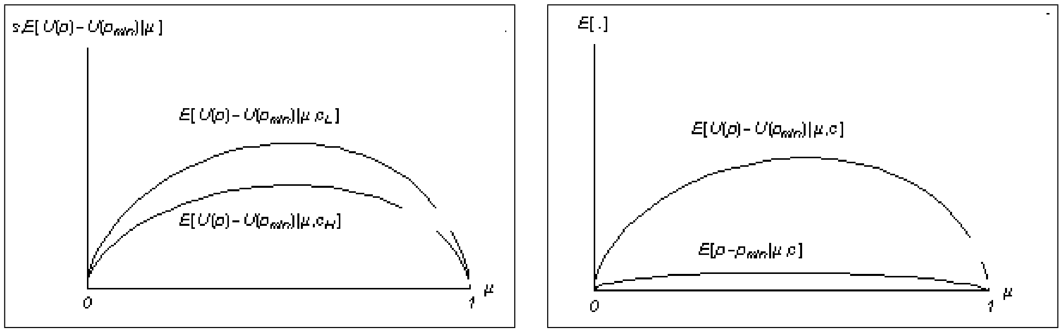


Figure 1.7: Gains from search and price dispersion with linear demands.

ating (1.29) twice:

$$\frac{\partial^2 E\left[p\right]}{\partial c \partial \mu} = \frac{1}{8\mu^2}\left[\Omega - 2\left(\frac{2\mu}{1+\mu}\right)^{1/2}\right] > 0 \tag{1.31}$$

Starting with the monopolist cost pass-through ($\frac{\partial p^m}{\partial c} = \frac{1}{2}$), as the search intensifies, the pass-trough approaches the competitive outcome (full pass-through). This result is related to the effect of expected production cost on price dispersion. For some demand functions (linear and unit demand), the monopolist absolute mark-up decreases with the production cost. This is in fact what makes the support of the price distribution to shrink ($\frac{\partial p^m - p^*}{\partial c} < 0$) and lowers the gains from search to consumers. At the same time, if the monopolist absolute mark-up decreases with the production cost, it must be that the monopolist cost pass-trough is less than one (the competitive pass-through).

To summarize, demand functions for which the monopolist absolute mark-up decreases with the cost of production generate the same qualitative effects (equation 1.31) as the unit demand case and the rockets and feathers result is guaranteed.

Contrary to the linear demand case, when the mopolist absolute mark-up increases with c, higher production costs imply more price dispersion. For example, when consumers' demands is of the form $q_{ce} = K/p^{\theta}$, $\theta > 1$. Following the same argument as before, the price support (hence price dispersion) should expand with the cost of production. Unless $\theta = 2$, there is no explicit solution for the lower bound of the price support. Using the IFT in (1.28),

$$\frac{\partial p^*}{\partial c} = -\left.\frac{\frac{\partial F(p)}{\partial c}}{\frac{\partial F(p)}{\partial c}}\right|_{p=p^*} = -\left.\frac{p^{1+\theta}\left(\frac{c\theta}{\theta-1}\right)^{-\theta}\left(c-(p-c)\,p^{-\theta}(\theta-1)\left(\frac{\theta c}{\theta-1}\right)^{\theta}\right)}{c\,(p-c)\,(\theta-1)\left(1-\frac{\left(\frac{\theta c}{\theta-1}\right)^{1-\theta}}{p^{-\theta}(p-c)\theta}\right)}\right|_{p=p^*}$$

using the fact that expected profits are the same for p^* and p^m and simplifying[36]

$$\frac{\partial p^*}{\partial c} = \frac{p^*}{c} > 1$$

$$\frac{\partial\left(p^m - p^*\right)}{\partial c} > 0$$

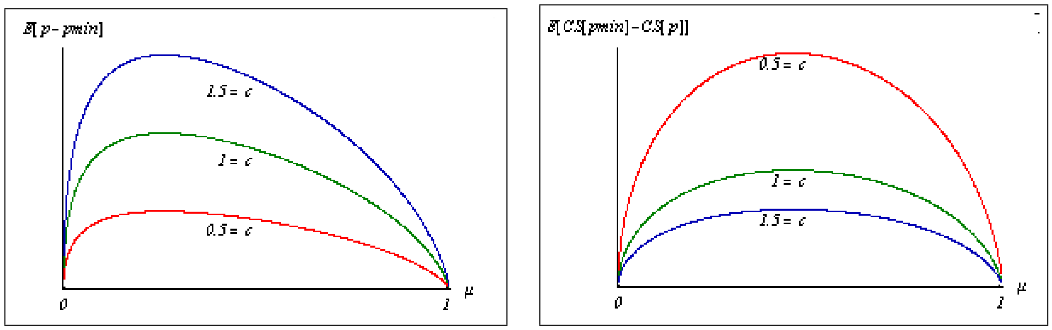
since $p^* < p^m = \frac{c\theta}{\theta-1}$.

Together with the expansion of the price support, the gains from search per unit increase with the expected cost of production (unlike the in the unit and linear demand cases). On the other hand, since consumers expect to buy less units when the production cost increases, the final effect on the gains from search is not clear.

In what follows, I concentrate on the case of $\theta = 2$ and provide numerical results for different values of the price-elasticity. The total gains from search are

$$E[CS(p_{\min}) - CS(p)|\mu, c] = \frac{(1-\mu)}{32\mu^2}E\left[\frac{1}{c}\right]\left[(3+\mu)\log\left[\frac{(1-\mu)}{1+3\mu-2C}\right] - 6C\right]$$

[36] $p^{*-\theta}\left(p^* - c\right)(1+\mu) = \frac{(1-\mu)}{\theta}\left(\frac{c\theta}{\theta-1}\right)^{1-\theta}$



(a) Price dispersion *(b) Gains from search*

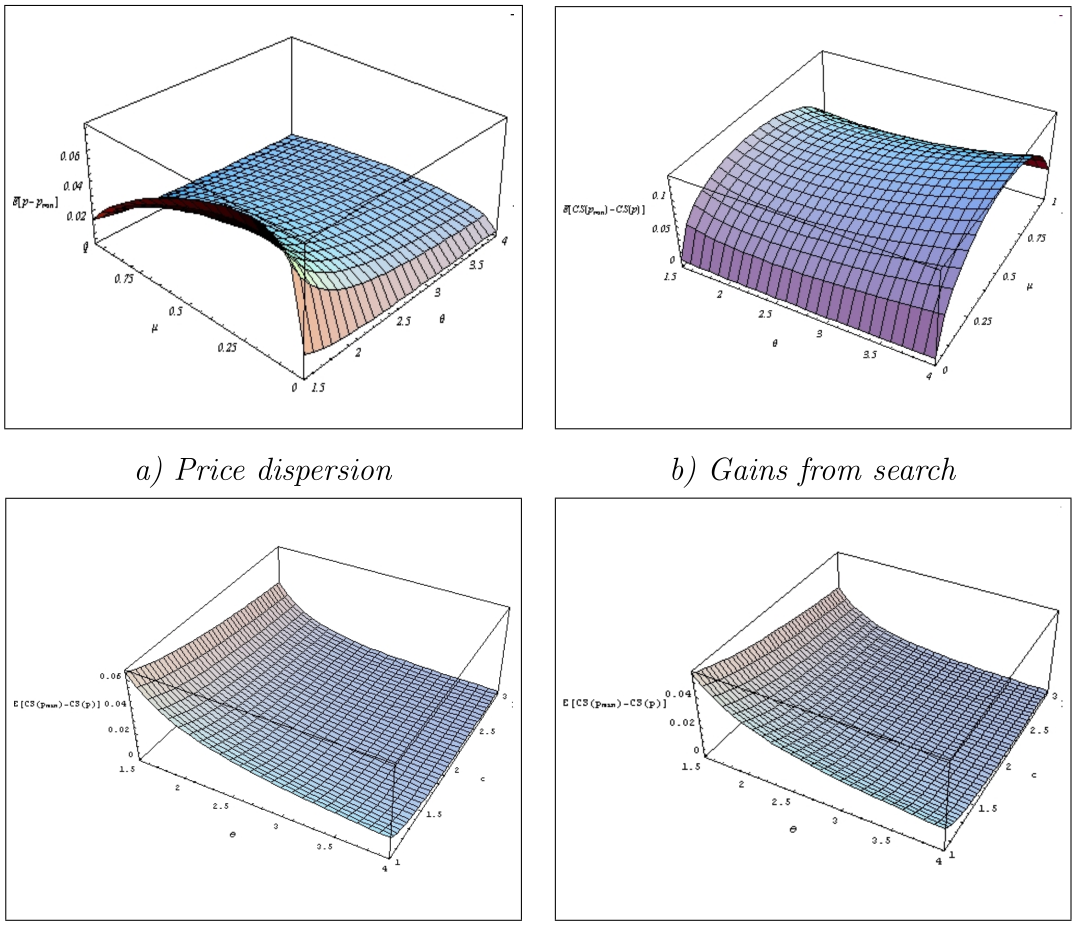
Figure 1.8: Higher production costs. Constant elasticity demands.

where $C = (2\mu(1+\mu))^{1/2}$.[37] It is easy to see that increases in the production cost implies less search. That is, even though the price dispersion increases with the cost of production, consumers choose to search less because the number of units they expect to buy is smaller. Figure 1.8 shows this for $\theta = 2$ and $K = 1$ although the same properties hold for different parameter values.

Given that consumers with constant elasticity demands search less when they expect higher production costs ($\frac{\partial \mu}{\partial \alpha} > 0$), the rockets and feathers result will only hold if the cost pass-through increases as the market becomes more competitive (see 1.27). But from the previous discussion we know that this is unlikely since the monopolist' pass-trough is higher than 1. In fact, the expected pass-trough in the market decreases as the number of informed consumers increases:

$$\frac{\partial^2 E[p]}{\partial c \partial \mu} = \frac{1}{8\mu^2(1-\mu)^2}\left[8\mu^2 + C(1-5\mu) - (1-\mu)^2 \log\left[\frac{(1-\mu)}{1+3\mu-2C}\right]\right] < 0$$

[37] $CS(p) = \int_p^\infty \frac{1}{x^\theta} dx$.



a) Price dispersion

b) Gains from search

c) $\mu = 0.25$

d) $\mu = 0.75$

Figure 1.9: Numerical simulations for $\theta > 1$

The same qualitative result is found for other values of θ (Figure 1.9) and this implies *feathers and rockets* instead of *rockets and feathers*. However, the quantitative effects are of a smaller order than in the case of unit or linear demands since both the unitary gains from search as well as the quantity demanded by each consumer change in the same direction when a higher cost of production is expected.

Appendix C - Sequential Search

In this appendix, I explore the implications of changing the search protocol used by consumers from nonsequential to sequential search. A consumer that searches sequentially observes (costlessly) a price at the first store she visits and then decides whether to visit (costly search) another store or go ahead and buy at the observed price. As discussed in Section 1.1, sequential search can be optimal when the search technology does not allow for significant economies of scale in the sample size.

All else equal, sequential search is more desirable than nonsequential search if consumers are uncertain about production costs. After observing a price, consumers are able to update their prior beliefs about the cost realization and therefore the distribution from which market prices are drawn from. As it is shown below, the rockets and feathers result is not robust to the search protocol used by consumers. The reason is that when consumers are either shoppers or nonshoppers with homogeneous search cost, the equilibrium implies that only shoppers search. Thus, changes in the cost of production don't change the search intensity in the market. Drawing from this insight, a necessary condition for rockets and feathers points toward the heterogeneity in non shoppers' search costs.

The change in the search protocol used by consumers modifies the stage game presented in Section 1.2. It is now a sequential-move instead of simultaneous game. After nature draws a production cost $c \in C$, firms choose their prices simultaneously and commit to them for one period. Once prices are set, each consumer visits a random store and decides between buying at the price observed p_0 or searching (with a cost s_i) for a better price in the remaining store. A consumer that decides to search buys from the store with the lowest price (perfect recall). To simplify the analysis, assume that the distribution of search costs $g(\cdot)$ is degenerate at $s >> 0$. Thus, the market demand is composed by λ shoppers and $(1-\lambda)$ consumers with homogeneous search cost s. [38]

Consumers randomly choose the first store they visit. Keeping the notation used in (1.1), a consumer i that visits a store j has conditional utility

$$u_{ij}(a_i, a_{-i}, p) = v - a_i [Min[p] - s_i] + (1-a_i) p_j \tag{1.32}$$

Let μ_j be the proportion of the consumers with positive search cost $\left(\frac{1-\lambda}{2}\right)$ that visits store j and decides to sample another price. Thus, given a price vector $p = (p_j, p_{-j})$, the number of consumers that visit the two stores is $\psi = \lambda + (\mu_j + \mu_{-j})\left(\frac{1-\lambda}{2}\right) < 1$. Firm $j's$ payoff becomes

$$\pi_j(p_j, p_{-j}, a, c) = (p_j - c)\left[\psi \mathbf{I}_{\{p_j < p_{-j}\}} + \frac{1}{2}\mathbf{I}_{\{p_j = p_{-j}\}} + \left(\frac{1-\lambda}{2}\right)(1-\mu_j)\mathbf{I}_{\{p_j > p_{-j}\}}\right]$$

A consumer strategy is a function $q_i(\cdot, p_0, s_i) \in \Delta(A)$ of the observed price $p_0 \in P$ and search cost $s_i \in \{0, s\}$. Since shoppers always visit both stores, $q_i(\cdot, p_0, s=0) = 1$ (search) for any p_0.[39] Firm *j's* strategy profile is represented by all possible price distributions conditional on the cost realization: $f_{jc}(\cdot) = (f_{jc}(p))_{p\in P, c\in C}$.[40] A SBNE (symmetric bayesian Nash equilibrium) or *market equilibrium* consists on a strategy profile $\sigma = (\sigma^D, \sigma^F)$ and consumers' beliefs $\alpha'(p_0, \sigma^F)_{p_0 \in P}$ such that *i)* $\sigma^D = (q_i(\cdot, 0), q_i(\cdot, s))_{i\in N^D}$ is a best response to

[38]The equilibrium characterization of the nonsequential search case with degenerated $g(\cdot)$ is done by Definition 1 together with Corollary 1.

[39]Note that an equilibrium where $\psi = 1$ is not feasible. If consumers visit both stores, the firms compete aggressively on prices and the competitive outcome results $p = c$. But then, nonshoppers don't want to search.

[40]For expositional reasons, the cost realization now is expressed as a subindex of the strategy profile instead of an argument of it.

$\sigma^F = \left(f_c\left(p, \sigma^D\right)\right)_{p \in P,\ c \in C}$, *ii)* σ^F is a Nash Best Response (*NBR*) to σ^D, and *iii)* $\alpha' = \Pr\left(c_H | p_0, \alpha, \sigma^F\right)$ is the Bayesian update of prior α for each observed price consistent with σ^F.

An intuitive and desired property for the optimal search rule is that it preserves the *reservation price property* (RPP). That is, consumers decide to search only if the observed price is above a certain reservation price. In such a case, q would be a step function with $q\left(p_0 \leq \widetilde{v}, s\right) = 0$ (don't search) and $q\left(p_0 > \widetilde{v}, s\right) = 1$ (search) where $\widetilde{v} \leq v$ is the reservation price. Given a certain distribution of prices, consumers that sample a high price have more incentives to pay the search cost and visit the second store since it is likely that they will sample a better price. But the *RPP* is not guaranteed in models that involve consumers searching sequentially from an *unknown* price distribution. A consumer that observes a low price p_0 might now consider that the cost realization for the firms was low and decide to continue searching for lower prices. If she observes a high price, the fact that high cost is more likely might make p_0 a bargain. As it is shown below, the *RPP* is satisfied if the cost shocks meet some requirements..

Assume that the equilibrium *NBR* for each production cost level are represented by $F_H\left(p, r\right)_{p \in \left[p_H^*, r\right]}$ and $F_L\left(p, r\right)_{p \in \left[p_L^*, r\right]}$ with $F_L\left(p, r\right) > F_H\left(p, r\right)$ for all p and $p_H^* > p_L^*$. The parameter r is -for the moment- an exogenous upper bound for the prices selected by the firms. The expected benefit of sampling one more price for a consumer that observes p_0 is the expected price at the remaining store, conditional on it being lower than p_0.

$$\begin{aligned} EG(p_0, r) &= \alpha' \int\limits_{p_H^*}^{p_0} (p_0 - p)\, f_H(p, r)\, dp + (1 - \alpha') \int\limits_{p_L^*}^{p_0} (p_0 - p)\, f_L(p, r)\, dp = \\ &= \alpha'(p_0) \int\limits_{p_H^*}^{p_0} F_H(p, r)\, dp + (1 - \alpha'(p_0)) \int\limits_{p_L^*}^{p_0} F_L(p, r)\, dp \qquad (1.33) \end{aligned}$$

where the second equality is obtained integrating by parts. A monotonic EG implies a unique (if there is one) reservation price $\widetilde{v}$ such that $EG(\widetilde{v}, r) = s$. Two effects take place after a price p_0 is observed: a *direct* and a *learning* effect. The former is the standard effect when a consumer samples from a known distribution. High observed prices imply a higher probability of sampling a lower price next time. The learning effect isolates the new information contained in p_0 about the unknown sampling distribution. Higher observed prices could be due to higher costs of production hence the gains from search are lower. Since the learning and direct effects go in opposite direction, EG can be non-monotonic and the RPP violated.

As it is usual in the literature of optimal sampling from unknown distributions, assumptions are made to preserve the reservation price property. When the price distribution is exogenous, assumptions rely on $F(\cdot)$ (Rothschild, 1974). If the price distribution is endogenously determined, assumptions on either the production cost structure or the number of shoppers guarantee a weak learning effect.[41] I will assume that, for a given search cost s, the gap between the two

[41] For example, Benabou et. al. (1993) assume low correlation in firm's marginal costs. In their model, firms have production costs composed of both an idiosyncratic (real) and a common (inflation) shock. A consumer that observes a low price knows that the firm has a low cost and needs to infer the cost of the remaining producer in order to decide to sample another price. When costs have low correlation, the learning effect is dominated by the direct effect and EG is monotonic.

possible production costs $(c_H - c_L)$ is sufficiently low.[42] That is, I assume the learning effect to be smaller than the direct effect so higher prices imply increasing gains from search. Given the assumption on the cost gap, consumer strategy profiles are restricted to the type:

$$\begin{aligned}
\sigma^D &= \left(q_i\left(\cdot,0\right), q_i\left(\cdot,s\right)\right)_{i\in N^D} \qquad (1.34)\\
q_i\left(p_0,0\right) &= 1 \text{ for all } p_0\\
q_i\left(p_0,s\right) &= \begin{cases} 1 \text{ for } p_0 > \widetilde{v} \\ 0 \text{ otherwise} \end{cases}
\end{aligned}$$

Shoppers always search while nonshoppers only if the price is above their reservation value $\widetilde{v}$. As in the case of nonsequential search, the existence of an atom of shoppers eliminates the possibility of a Single Price Equilibrium (Stahl, 1989). Furthermore, the upper bound for any price distribution is $\widetilde{v}$ instead of the monopoly price v.

Lemma 3 *Firms' NBR imply $f_c\left(v\right) = 0$ and $F_c\left(\widetilde{v}\right) = 1$.*

Proof. Given non-shoppers' reservation price $\widetilde{v}$, assume that firms draw prices from a *cdf* $F_c\left(\cdot\right)$ with upper bound $\widehat{p}$. It is not possible that $\widehat{p} < \widetilde{v}$ since a firm could deviate and increase its revenues (keeping the same number of consumers) by setting $p = \widetilde{v}$. Suppose $\widehat{p} > \widetilde{v}$. A firm that charges $p = \widehat{p}$ would not capture any customers while, with $p = \widetilde{v}$ the customers are at least $\frac{(1-\lambda)}{2}$. Thus, the only possibility left is $\widehat{p} = \widetilde{v}$ ■

A consequence of this lemma is that in any market equilibrium, consumers with positive search cost never observe a price above their reservation value, and

[42]Below, I show that there is no *NBR* for the firms if the search rule does not satisfy the RPP.

therefore they don't search ($\mu_j = 0$). As in Proposition 1, there is no pure strategy equilibrium for the firms and the price distribution does not present any mass points or gaps on the support $[p_c^*, \widetilde{v}]$. A firm that sets a price $\widetilde{v}$ sells to $\frac{1-\lambda}{2}$ captive consumers while if it charges lower prices, the likelihood of capturing the informed consumers increases. In equilibrium, the firm is indifferent between the reservation price and lower prices that generate the same expected profit:

$$\pi_j(p_j, c) = \left[\lambda\left(1 - F_c\left(p_j, \widetilde{v}\right)\right) + \frac{(1-\lambda)}{2}\right](p_j - c) = \frac{(1-\lambda)}{2}\left(\widetilde{v} - c\right) = \pi_j\left(\widetilde{v}, c\right) \tag{1.35}$$

with $c \in \{c_L, c_H\}$. Solving for $F(\cdot)$, we obtain the following lemma:

Lemma 4 *Given the number of shoppers and consumers search rule σ^D from (1.34), there is a unique Nash Best Response σ^F:*

$$F_c(p, \widetilde{v}) = 1 - \left(\frac{(1-\lambda)(\widetilde{v} - p)}{2\lambda(p - c)}\right) \quad p \in [p_c^*, \widetilde{v}], \quad c \in \{c_L, c_H\} \tag{1.36}$$

with $p_c^* = c + \frac{(1-\lambda)(\widetilde{v}-c)}{1+\lambda}$.

On the demand side, consumers choose their optimal search strategies by comparing the gains from search (1.33) given σ^F and production cost prior α. Using (1.36) and Bayes' rule, the posterior probability of high cost becomes

$$\alpha' = \begin{cases} 0 & p_0 < p_H^* \\ \frac{\alpha F'_H}{\alpha F'_H + (1-\alpha)F'_L} & p_0 \geq p_H^* \end{cases} \tag{1.37}$$

Thus, when prices are very low ($p_0 < p_H^*$) consumers know that the cost realization was low and $EG\left(p_0 < p_H^*, \widetilde{v}\right)$ increases with prices observed. When the price observed is supported by both, low and high cost of production ($p_0 \geq p_H^*$), α' possesses the following properties:

$$\alpha'\left(p_0 \geq p_H^*\right) = \frac{\alpha\left(\widetilde{v} - c_H\right)\left(p_0 - c_L\right)^2}{\alpha\left(\widetilde{v} - c_H\right)\left(p_0 - c_L\right)^2 + \left(1-\alpha\right)\left(\widetilde{v} - c_L\right)\left(p_0 - c_H\right)^2} > \alpha$$

$$\alpha'\left(p_H^*\right) = \alpha + \frac{\alpha\left(1-\alpha\right)\left(c_H - c_L\right)}{\widetilde{v} - \left(\alpha c_L + \left(1-\alpha\right)c_H\right)}$$
$$\frac{\partial \alpha'\left(p_0 \geq p_H^*\right)}{\partial p_0} < 0$$

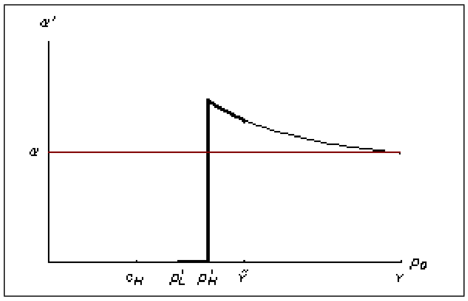
The updated probability jumps from zero to its highest value when $p_0 = p_H^*$ and decreases as the observed price is higher. Higher prices are relatively more likely to be observed when the cost of production is low than when the cost is high. That is, except at $p_0 = p_H^*$, the learning effect reinforces the direct effect and $EG\left(p_0 > p_H^*, \widetilde{v}\right)$ is also monotonic in p_0.

To characterize the *market equilibrium*, the optimal reserve price has to be consistent with the firms' *NBR*. Uninformed consumers are indifferent between searching or not when the observed price is equal to the reservation price. At the same time, firms anticipate $\widetilde{v}$ correctly and set prices accordingly. Thus, an equilibrium is characterized by

$$EG(p_0 = \widetilde{v}, \widetilde{v}) \leq s \tag{1.38}$$

Figure 1.10 shows an example with a unique equilibrium.[43] Even though EG is not monotonic in p_0, the assumption of small $c_H - c_L$ relative to s guarantees a unique reservation price. Intuitively, the closer c_H is to c_L, the closer p_H^* is

[43]The parameters used are $v = 2, \alpha = 0.5, s = 0.15, c_L = 0, c_H = 0.5$, and $\lambda = 0.2$.



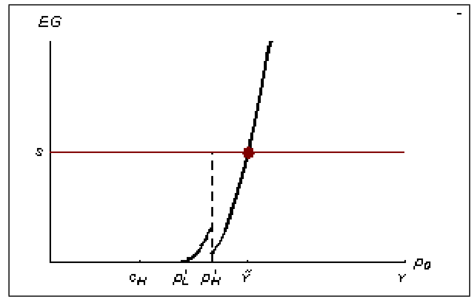


Figure 1.10: Updated prior and unique reservation price

to p_L^* and the array of possible observed prices revealing low cost realization are never high enough to motivate searching. From the point of view of the firms, the relevant reservation price is any root in (1.38) that is below v and over c_H. The next proposition characterizes the market equilibrium.

Proposition 5 *Under sequential search and assuming RPP ($c_H - c_L$ sufficiently small), there is a unique market equilibrium given by (1.34), (1.36) and (1.37) and* $\widetilde{v} = Min\left\{\arg\text{solve}(1.38), v\right\}$

Proof. Assume *wlg* $c_L = 0$ and any reservation price $\widetilde{v} > p_H^*$. From (1.33) and Lemma 4, the upper bound for $EG\left(p_0 < p_H^*, \widetilde{v}\right)$ is given by

$$\underset{p_0 \to p_H^*}{Lim} EG\left(p_0 < p_H^*, \widetilde{v}\right) = \frac{1}{2\lambda}\left\{2\lambda c_H + \widetilde{v}\left(1-\lambda\right) Log\left[\frac{\widetilde{v}\left(1-\lambda\right)}{\widetilde{v}\left(1-\lambda\right)+2c_H\lambda}\right]\right\}$$

This limit increases with c_H. Assuming c_H sufficiently low, $EG\left(p_0 < p_H^*, \widetilde{v}\right) < s$ and thus $\widetilde{v} > p_H^*$. For high observed prices ($p_0 > p_H^*$), using $p_0 = \widetilde{v}$ in (1.33),

$$EG\left(\widetilde{v}, \widetilde{v}\right) = \frac{\widetilde{v}\left(\widetilde{v} - c_H\right)}{2\lambda\left[\widetilde{v} - c_H\left(1-\alpha\right)\right]}\left[2\lambda + \left(1-\lambda\right) Log\left[\frac{1-\lambda}{1+\lambda}\right]\right] \tag{1.39}$$

The expression in brackets is positive for any value of λ and there are two roots that solve $EG\left(\widetilde{v}, \widetilde{v}\right) = s$. The smaller one can be ignored since it implies a reservation price below c_H. ■

If the assumption on low $c_H - c_L$ is relaxed, the possibility of non-monotonic search rules arises (RPP is violated). This can be easily seen in Figure 1.10. As the gap between the high and low production costs increases, the gap between the lower bounds for the prices under each cost also increases and the gains from search could cut the search cost twice. Consider then the case where $(1-\lambda)$ uninformed consumers have a search rule q consisting of two reservation prices $(\widetilde{v}_L, \widetilde{v}_H)$:

$$q = \begin{cases} 0 & p_0 \leq \widetilde{v}_L < \widetilde{p} \\ 1 & \widetilde{v}_L < p_0 < \widetilde{p} \\ 0 & \widetilde{p} \leq p_0 \leq \widetilde{v}_H \\ 1 & \widetilde{v}_H \leq p_0 \end{cases}$$

with $\widetilde{p} > c_H$. A firm chooses prices given (λ, q) and -when cost realization is low- takes into account that the $(1-\lambda)/2$ potentially captive consumers search if $p \in (\widetilde{v}_L, \widetilde{p})$ are chosen.

Proposition 6 *There is no (symmetric) market equilibrium when consumers have non-monotonic search rules with two reservation prices.*

Proof. By Lemma 3 above, $p \leq \widetilde{v}_H$. A firm setting a price p should expect profits to be greater than charging the highest reservation price: $\pi(p) \geq (\widetilde{v}_H - c)(1-\lambda)/2$. As in Proposition 1, an equilibrium can not consist on pure strategies (Single Price Equilibrium) nor the price distribution have mass points or gaps over $[p^*, \widetilde{v}_L] \cup (\widetilde{p}, \widetilde{v}_H]$. Also, $F(\widetilde{v}_H - \varepsilon) < 1$ as well as $F\left(p^*_{c_H} + \varepsilon\right) > 0$. Assume first that $F(p') = F(\widetilde{v}_L)$ for $p' \in (\widetilde{v}_L, \widetilde{p})$. The expected profits are

$$\pi(\widetilde{v}_H) = (\widetilde{v}_H - c)(1-\lambda)/2 \tag{1.40}$$

$$\pi(p) = (p-c)\{(1-\lambda)/2 + \lambda[1-F(p)]\} \quad p \in [p^*, \widetilde{v}_L] \cup (\widetilde{p}, \widetilde{v}_H] \tag{1.41}$$

$$\pi(\widetilde{p}) = (\widetilde{p} - c)\{(1-\lambda)/2 + \lambda[1-F(\widetilde{p})] + F(\{\widetilde{p}\})\lambda/2\} \tag{1.42}$$

and there is no $F(p)$ that satisfies (1.40), (1.41) and (1.42). If $p' \in (\widetilde{v}_L, \widetilde{p})$ are considered, expected profit is

$$\pi(p') = (p' - c)\left\{\left(\frac{1-\lambda}{2} + \lambda\right)\left[1 - F(p') + \frac{1-\lambda}{2}\left[F(\widetilde{p}) - F(p')\right]\right]\right\}$$

Clearly, $\underset{p' \to \widetilde{p}}{Lim} F(p') < F(\widetilde{p})$ and thus an atom of probability is needed at $\widetilde{p}$ (contradiction). ■

Summarizing, given the cost gap assumption, consumers' search strategies satisfy the RPP and the firms find optimal to set low prices rather than charging higher prices and observe all the consumers shop around.[44] The search intensity in the market is given by λ and is not affected by changes in the cost of production or consumers' prior α. That would lead us to discard any possibility for the rockets and feathers result. However, consumers play a critical role when shaping the *NBR* since their reservation value is a function of the expected prices in the market hence on α. An increase in α doesn't affect the search gains when low prices are observed $EG(p_0 < p_H^*, \widetilde{v})$ but decreases $EG(\widetilde{v}, \widetilde{v})$. Assuming $c_L = 0$,

$$\frac{\partial EG(\widetilde{v}, \widetilde{v})}{\partial \alpha} = \frac{-c_H}{\widetilde{v} - c_H(1-\alpha)} EG(\widetilde{v}, \widetilde{v}) < 0$$

Therefore the reservation price that equates (1.38) is higher when a higher production cost is expected: $\frac{\partial \widetilde{v}}{\partial \alpha} > 0$. This could be interpreted as lower search intensity in the market since high reservation prices allow the firms to charge higher prices.

The rockets and feathers result found in Section 1.3 depends on *i* the stochastic process for the production cost, *ii* the response on the search intensity (reservation price now) to higher expected costs, and *iii* the change on the expected

[44]This is also a consequence of restricting the search cost heterogeneity.

cost pass-through by the firms when the search intensity in the market increases. The equivalent to equation (1.17) would be:

$$E\left[\frac{\triangle p}{\triangle c^{+}}\right]-E\left[\frac{\triangle p}{\triangle c^{-}}\right]=\frac{-1}{2}\rho\left(1-\rho\right)\frac{\partial^{2}p_{t}}{\partial c_{t}\partial\widetilde{v}}\frac{\partial\widetilde{v}}{\partial\alpha}\frac{\partial\alpha}{\partial c_{t-1}} \tag{1.43}$$

I now turn to the analysis of the change in the expected cost pass-through as the reservation price increases. Using 1.36, the expected price is

$$E\left[p|c\right]=\widetilde{v}-\int\limits_{p^{*}(\widetilde{v})}^{\widetilde{v}}F(p,c)dp \tag{1.44}$$

and for a given reservation price, the jump in prices as cost increases is:

$$E\left[p|c_{H}\right]-E\left[p|c_{L}\right]=\left(c_{H}-c_{L}\right)\left(1-\frac{(1-\lambda)}{2\lambda}\log\left[\frac{1+\lambda}{1-\lambda}\right]\right)>0 \tag{1.45}$$

The cost pass-through is not sensitive to consumer's reservation price and that means that there is no room for rockets and feathers when nonshoppers are homogeneous and search sequentially. The following proposition summarizes the result

Proposition 7 *There is no price asymmetry when consumers search sequentially and have search cost* $s\in\{0,s\}$.

The result in the Proposition above is not as negative as it seems. It implies that a necessary condition for the rockets and feathers under sequential search is heterogeneity in the search cost of the nonshoppers. Intuitively, in equilibrium, the nonshoppers with the lower search cost will search (so $mu > lambda$) and the search intensity changes with the expected production cost. As in the nonsequential case, the cost pass-through by the firms is sensitive to the search intensity in the market (see equations 1.45 and 1.19). Therefore, extending the sequential search model to more general distributions of search costs across consumers is likely to generate the result.[45]

[45] Another possibility (as Jim Dana suggested to me) is to assume a search protocol where consumers observe the first price for free and then decide whether to search for k more prices. This protocol is a combination of Dana (1994) and Burdet and Judd (1983) protocols, and more than two firms in the market are required.

CHAPTER 2

Price Dispersion and consumer search. The Retail Gasoline Markets.

2.1 Introduction

Price dispersion (as opposed to the law of one price) characterizes most final good markets. With few exceptions, the traditional empirical approach to the study of this phenomena assumes that product heterogeneity is responsible for the observed price differences. More recently, findings of significant price dispersion in *almost* homogeneous goods markets expose the need for other potential explanations and the old theoretical models of costly consumer search were rescued by empirical economists.[1] There is no doubt that the assumptions of these models (consumers's imperfect information and positive search cost) are quite appropriate to most markets, but researchers have been always skeptic about the unappealing equilibrium property of firms using mixed-strategies to choose prices. This paper vindicates the importance of consumers' imperfect information to explain the price dispersion observed in retail gasoline markets.

Theoretically, both models of product differentiation and costly consumer search predict price dispersion in equilibrium. However, the dynamic implications

[1] Figure 2.4 in the Appendix shows the growth in the number of articles on information, search and price dispersion published in main journals (AER, JPE and Econometrica) during the period 1960-2005.

of each model are different. In search models, a firm with a high price today might have the lowest prices tomorrow while in models of product differentiation, this price dispersion is stable as long as the characteristics of the products don't change over time.

The retail gasoline market presents a unique opportunity to identify whether search is important to explain the observed price dispersion. Gasoline prices are posted outside each station and many street corners are populated with more than one of them. The price differences (if any) between gas stations located on a single corner (control group) can only be related to product differentiation since consumers are obviously informed about their prices. Moreover, this dispersion is expected to be stable over time since stations' characteristics don't change in the short run. On the other hand, the price dispersion between stations that are further apart -but still in the same market- can be generated by both product differentiation and costly consumer search. If that is the case, we can expect a more unstable price dispersion for this second group.

This paper provides a simple test of the dynamic stability of price dispersion in both groups. The price reversals between gas stations in the same corner are indistinguishable from zero, as a model of product differentiation would predict. Conversely, and consistent with an underlying model of costly consumer search, the price reversals are frequent and important when stations are located in different corners. Previous empirical work that links price dispersion to costly consumer search do so by analyzing prices after controlling for product heterogeneity. This poses the problem that unobservable characteristics can be behind the dispersion not explained by observable characteristics. To overcome this potential pitfall, I use a control group of prices not influenced by search.

In Chapter 1, I use a theoretical model of consumer search to explain the asymmetric pricing puzzle (*rockets and feathers*) observed in many markets. This asymmetric cost pass-through by the firms is explained by the fact that the search intensity in a market changes with the past cost realizations. Interestingly, the rockets and feathers pattern has been found systematically in almost every study of the retail gasoline market.[2] Thus, the findings in this chapter provide additional support to the theory presented in the previous chapter.

The empirical relevance of costly consumer search has important policy and academic implications. Outcomes like the rockets and feathers that were thought to be generated by collusive behavior and requiring government intervention can well be the consequence of imperfect consumer information. On the academic side, it emphasizes the need to generalize the traditional structural empirical models that started with Berry, Levinson and Pakes (1995) to allow for consumer search. Also, recent work by Klenow and Willis (2006) has shown that traditional general equilibrium models used to explain price rigidities can not account for the high frequency of relative prices changes within industries. The main reason could be found in the fact that such models assume product differentiation only and ignore the possibility of consumers with imperfect information.

The paper is organized as follows. In the next section, I describe the existing literature on consumer search and price dispersion. In section 2.3 I describe the aspects of the gasoline industry that are relevant to this study. Section 2.4 describes the dataset and results. Section 2.5 concludes.

[2] See Geweke (2004) and Deltas (2004) for surveys of the literature on asymmetric pricing in gasoline markets.

2.2 Consumer Search and Price Dispersion

An abundant theoretical literature on price dispersion and consumer search was developed after Stigler's seminal paper on economics of information (Stigler, 1961). In that article, Stigler asserts that the price dispersion in the market is a function of the amount of search conducted by consumers, which at the same time depends on the nature of the commodity traded. Thus, he argued that search would be more intense when *i)* goods represent a larger fraction of the consumers' expenditures, *ii)* the fraction of repetitive consumers is bigger, *iii)* the geographic size of the market is smaller (lower search costs). As Rothchild (1974) pointed out, in Stigler's model, consumers decided to search taking a certain distribution of prices in the market as given, and ignored the fact that the price distribution is endogenous since firms anticipate consumer behavior and set prices optimally.[3] Following Rothschild's criticism, several economists developed *complete* models of costly consumer search that are able to generate price dispersion as a stable equilibrium although not necessarily the same comparative statics Stigler anticipated. In this section, I review the different theoretical approaches to consumer search and the empirical work that link price dispersion to these models.

There are many models of consumer search in the literature and their main results are most of the time driven by the modeling assumptions chosen. However, the mechanism that generates price dispersion in equilibrium is always the same. As long as some consumers don't become completely informed, the firms are indifferent between high and low prices. By setting high prices, they can sell to the few consumers with a high search cost (*surplus appropriation* effect) while

[3]Another flaw in Stigler's analysis was ignoring the change in the marginal benefit of a next search by consumers that observe different prices.

setting low prices could give them the opportunity to gain market share (*business stealing* effect). Table 2.3 in the Appendix provides a summary of the main differences between the models used in the literature.

One way to explain price dispersion can be by assuming cost dispersion. The models where firms have heterogeneous cost of production escape from the Bertrand result where only the most efficient firm serves the market since consumers don't know the cost realizations and have positive search costs (MacMinn, 1980; Carlson and McAfee, 1983; Benabou and Gertner, 1993). But different firms' costs is not necessary to generate dispersion. Burdett and Judd (1983) were the first to show that the law of one price is not true even when firms *and* consumers are completely homogeneous.

Models differ in the method used when obtaining the equilibrium. Stahl (1996) identifies the Stackelberg and Nash paradigms. Under the Stackelberg approach, consumers are assumed to know the "market distribution" of actual prices being charged but do not know which store is charging which price.[4] Under the Nash paradigm, consumers have less information before search and decide their strategies based on the Nash Equilibrium pricing strategies of the firms. The early work on search followed the Stackelberg paradigm (Salop and Stiglitz, 1977; Braverman, 1980; Rob, 1985; Stiglitz, 1987) but the Nash paradigm as replaced it as the preferred modeling choice.

Another dimension in which models can be grouped is the search protocol

[4]For example, if there are N stores whose symmetric mixed-strategy is to draw a random price from a probability distribution $F(p)$, these N independent random draws give N actual prices, and the frequency distribution of these actual prices, say $M(p)$, is called the market distribution. Note that given a finite number of stores, $M(p)$ can be quite different from $F(p)$. Consumers are assumed to know $M(p)$ and to choose optimal search rules with respect to $M(p)$.

used by consumers. A consumer that searches *non-sequentially* needs to decide -before observing any prices- between becoming informed about a fixed number of 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. As it is well known, both sequential and non-sequential search rules have their own advantages and disadvantages (Morgan and Manning, 1985). Varian's *model of sales* (Varian, 1980) uses non-sequential search where the sample size is the number of firms in the market. Others allow for flexible sample size (Burdett and Judd, 1983) or introduce alternative protocols (Dana, 1994; Janssen, Moraga-Gonzlez, and Wildenbeest, 2004).[5] On the sequential search side, Stahl (1996) provides the characterization of the equilibrium in a model with heterogeneous search costs.

Lastly, the distribution of consumers' search costs has important implications for the equilibrium properties. For example, the existence of a mass of consumers with zero search cost (also called *shoppers*) eliminates the possibility of a monopoly equilibrium or Diamond Paradox (Diamond, 1971): all the firms in the market charge the monopoly price and not searching is the optimal response by consumers. Alternatively, models with sequential search where consumers have the same positive search cost imply no search since firms prefer to decrease the competition by setting prices below the unique reservation price for consumers (see Appendix C in Chapter 1).

On the empirical side, the approach taken by most of these studies consists of

[5]Baye et al. (2004, 2005) show how the non-sequential search model can be thought of as a particular case of a "clearinghouse" model of equilibrium price dispersion.

two steps. First, they show that after controlling for product heterogeneity, there is significant price dispersion that needs to be explained. Second, they test some of the comparative statics (effect of the number of firms and consumer search costs on the price levels and dispersion) generated by one the theoretical search models described above, and use that as evidence that the price dispersion in the first step is indeed generated by consumer search. For example, Sorensen (2000) finds that the price dispersion and price-cost margins are lower for pharmaceutical drugs that require repeated purchases than for those that are used infrequently. Barron *et al.* (2004) find that increasing the number of sellers decreases price levels and price dispersion of gasoline prices. Dahlby and West (1986) find also that the dispersion in insurance premiums is lower for consumers associated with higher incentives to search. Borenstein and Rose (1994) show that dispersion in airline fares on a route is higher when more competitors serve the route.[6]

The problem with most of these studies is that there are always unobserved characteristics that could explain the corrected or "clean" (from product characteristics) price dispersion. Moreover, the fact that a particular model of search supports the comparative statics found in the data should not be considered as additional evidence of search. Almost each theoretical model of search has different predictions regarding the response of price dispersion to the number of firms, search cost level, and other exogenous variables.

The approach taken in this paper is different from previous studies. Due to the special characteristics of the retail gasoline market, the evidence that search plays a role in explaining price dispersion is found by comparing the dispersion pattern generated by a model of product differentiation with one where *a priori* we are uncertain about the underlying model. The former group is composed by the

[6] Baye (2005) provides a comprehensive survey of the empirical work on price dispersion.

gasoline stations that are located in a same corner. Clearly, if there is any price dispersion in this sub market it can not be explained by costly consumer search. The latter group is composed by all the gasoline stations in a particular market. We know that product differentiation (at least location) is important to explain price differences in this market, but are uncertain about search. The key to identify whether search plays an important role is to compare the stability of the price dispersion in the two groups. Stable price dispersion is generated by firms playing pure strategies (product differentiation) but this is not the case when they use mixed-strategies (costly consumer search).[7] Before showing the results, the next section describes the industry structure that will help to understand the key assumptions in the econometric analysis.

2.3 The gasoline market

The industry is characterized by refineries that produce gasoline from crude oil and send it to a main distribution center (distribution rack) to be delivered to its final destination, the gas station. Gasoline stops being a homogeneous good when an additive corresponding to the brand of the refiner is mixed with the fuel right before it is taken for delivery to the gas station. The potential for further differentiation is then increased since gas stations can differ in other dimensions such as location, capacity, convenience store, car wash, repair facilities, full service, and methods of payments available to consumers (credit cards, ATM, payment inside or at the pump). Some studies have measured the importance of these characteristics and found that the main difference in prices are between branded stations (Texaco, Shell, BP, Exxon-Mobil) and stations that sell unbranded gasoline or

[7] As it will be argued in the next section, gas stations have fairly homogeneous costs and therefore an equilibrium where firms set pure strategies can not be supported by costly consumers search.

independents (Lewis, 2003; Hastings, 2004).[8]

Besides different product characteristics, another reason for potential price dispersion in a similar geographical market is the vertical relationship between the stations and refiners. Table 2.5 in the Appendix summarizes the industry's vertical chain. Branded stations can have three basic vertical contract types with the branded refiner. The first type is a company operated station (*company-op*). The refiner owns the station and an employee of the refiner manages the station. The refiner sets the retail price directly and pays the employee a salary. The second type of station is called a *lessee dealer*. In this case the refiner owns the station and leases it to a residual claimant. The lessee is responsible for setting the retail price, but has to purchase wholesale gasoline directly from the refiner at a price called the Dealer Tank-Wagon price (DTW).[9] At the third type of branded station, a *dealer owned* station, the retailer owns the station property and signs a contract with a branded refiner to sell its brand of gasoline. The retailer can either be supplied directly by the refiner in which case they pay a DTW, or the dealer can be supplied by an intermediate supplier called "jobber". The jobber purchases gasoline at the distribution rack and pays a wholesale price called the rack price. That is the refiner's posted price for branded gasoline at the distribution rack, and it is the same price for any jobber purchasing at that rack.[10] Independent stations on the other hand can purchase gasoline from any refiner (branded or unbranded) that sells at the distribution rack.

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

[9]The DTW is set by the refiner for a particular zone and includes delivery costs. The refiner also sets volume discounts, the lease rate, and other operation stipulations for the station.

[10]One jobber often supplies, and possibly owns, many different branded and unbranded stations. Jobbers can purchase branded gasoline and supply it to independent stations if it is cheaper than the unbranded price (the rack prices are "inverted"), but the independent station cannot post the name of the brand that they are selling.

Summarizing, excluding consumers imperfect information, two reasons could explain differences in prices between two gas stations: product differentiation and the degree of vertical integration. The last effect implies that firms have different maximization problems when setting prices and that the wholesale costs (DTW and branded and unbranded rack prices) could be different across contracts. In any of these two cases, the price differentials should be constant over time unless changes in the contracts occur. Shepard (1993) finds that the contract choice is mainly influenced by the agency costs associated with the characteristics of different stations. Also, there is evidence that final prices are not affected by the vertical relations between stations and refiners. Hastings (2004) studied the acquisition of the independent gasoline retail chain Thrifty by ARCO in Southern California and finds that the observed increment in prices after the merger was due to the independents' lower market share and not a consequence of the change in contracts (from no integration to partial and full integration).

2.4 Price dispersion analysis

I constructed a unique dataset of retail gasoline prices for more than 2000 stations in Southern California during the period March 2003 - September 2005. The dataset was downloaded from public online information where prices are reported together with the brand, address and city of each gas station.[11] Even though the dataset includes prices for all four grades of gasoline (regular, midgrade and premium unleaded, and diesel), I concentrate on *regular unleaded* (87 octanes grade) since it is the product that accounts for half of the observations. From the original set of 2367 stations I was able to obtain reliable geographic information

[11] The source of the information is Oil Price Information Service (OPIS, http//:www.opisnet.com). They collect the price information daily from credit card transactions in each store of the sample.

	N	T	Station level Mean	sd
Stations*	1949	338 days	45 days	34.9
Market coverage	117.017miles^2			
	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 2.1: Summary Statistics

for 83% of them. Distance is a key element in the analysis that follows so I discarded any suggested geocoding with a low precision score.[12] The panel is unbalanced in every sense. Not all the stations have prices for the same days nor have the same number of observations. Table 2.1 summarizes the structure of the dataset and provides some summary statistics.

A simple measure of price dispersion is the high standard deviation observed in prices. Also, the average daily price spread between any two gas stations in the sample is 8cts although it can be as high as one dollar. As explained before price dispersion can not be used to validate a consumer-search model since gasoline is also a differentiated product. However, there are differences in the dispersion

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

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 pattern across time when product differentiation is the only driver of price dispersion. Instead, when the underlying model involves consumer search, price ranks across stations are expected to revert as frequently as firms change prices.

The more straightforward 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) over T_{ij} days, 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 2.1). 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 2.1 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 that could not be explained by a model where firms have homogeneous costs and sell differentiated products. But it 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 idiosyncratic costs and demand shocks. If demand shocks are important, firms facing a positive demand shock increase their prices (and eventually the rank changes) relative to other firms that did not re-

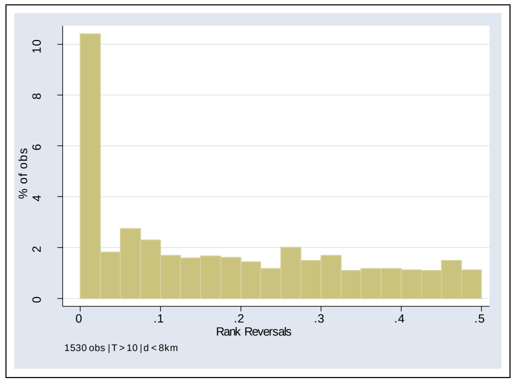


Figure 2.1: Rank reversals in prices

ceive a demand shock. In general, a demand shock is thought of as affecting a whole market rather than a particular gas station or corner. Thus, if demand shocks explanained rank reversals we would observe that gas stations in the same market (less than 1 or 2 miles apart) have lower reversals than those further apart. In Figure 2.2, 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 490 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 490 feet.[13] The price dispersion is more stable between stations that are very close to each other than those that, while being in the same market, are more distant.[14]

The remaining potential explanation (besides consumer search) for unstable

[13]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)

[14]To avoid the possibility of localized demand shocks like basketball games and other events, only weekday prices were analyzed.

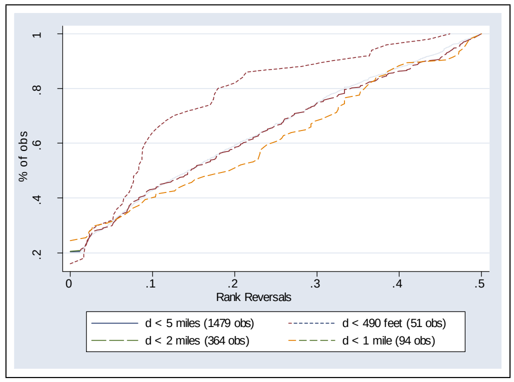


Figure 2.2: Cumulative rank reversals and distance

price dispersion is the existence of idiosyncratic cost shocks at the station level. A profit maximizer gas station owner would always use the opportunity cost of gasoline as the relevant cost for setting prices. As explained in the previous section, the differences in wholesale costs for two stations are irrelevant in terms of final prices. But even when they exist, they do for stations that are in different markets ("zone" prices and delivery costs) and are stable over time since the contracts with refiners do not change frequently. So wholesale costs are expected to be highly (if not perfectly) correlated across stations. And that correlation is supposed to be bigger across gas stations that carry the same brand. 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 is expected to present more rank changes than the group of stations that are separated by more than a block. This is the opposite of what Figure 2.1 shows.

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's been traveling 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 differences between p_i and p_k can only reflect product differentiation.[15]

We can think of stations i and k as coordinating their prices to compete for the informed consumers with other distant stations and then compete between each other for the captive customers based on product differences. In other words, rank reversals in prices are expected to happen less frequently for stations that are close from each other than for stations that are nearby but further apart.[16] The equality of the observed frequencies of rank reversals in Figure 2.1 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 2.2 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 at the 0.01 level and lower rank reversals are observed in the group of clustered stations ($F_c > F_1$ and $F_c > F_2$). There is no statistical difference between the frequencies of rank reversals between the groups of stations separated by less than 1, 2 or 5 miles. This is consistent

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

[16]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.

	D	*p-value*
$\mathrm{H}_0 : F_c\,(rc) < F_1\,(rc)$	0.0847	0.626
$F_c\,(rc) > F_1\,(rc)$	-0.3387	0.001
$F_c\,(rc) = F_1\,(rc)$	0.3387	0.001
$\mathrm{H}_0 : F_c\,(rc) < F_2\,(rc)$	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 2.2: Kolmogorov-Smirnov equality of distributions test

with the hypothesis that cost shocks or demand shocks are not driving the ranking changes.

There are two things to note from this simple test of rank reversals. First, if product differentiation is important in this market, the study of rank reversals might underestimate the presence of costly search in the market. Under pure product differentiation (and no uncorrelated shocks in demand or costs), the spread between two prices is likely to remain constant over time. The bigger the differentiation between two stations, the less likely it is that the prices revert even if the firms play mixed-strategies. Second, product differentiation should imply zero rank reversals while the control group shows some of that. This could be explained by measurement error when geocoding addresses. The distance given by the GIS software for two neighboring stations sometimes can be off by 1 block. That is the reason why I used 490feet as the distance bound for the control group.

Additional evidence of search can be found by looking at the relationship between price dispersion in the market and wholesale cost or price levels. Most theoretical models predict a reduction in price dispersion as the wholesale cost of

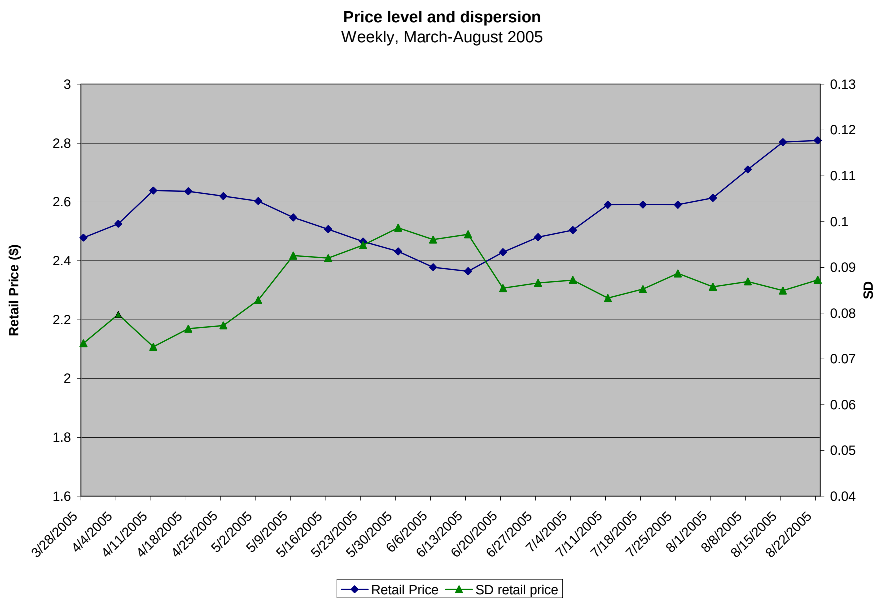


Figure 2.3: Price level and dispersion

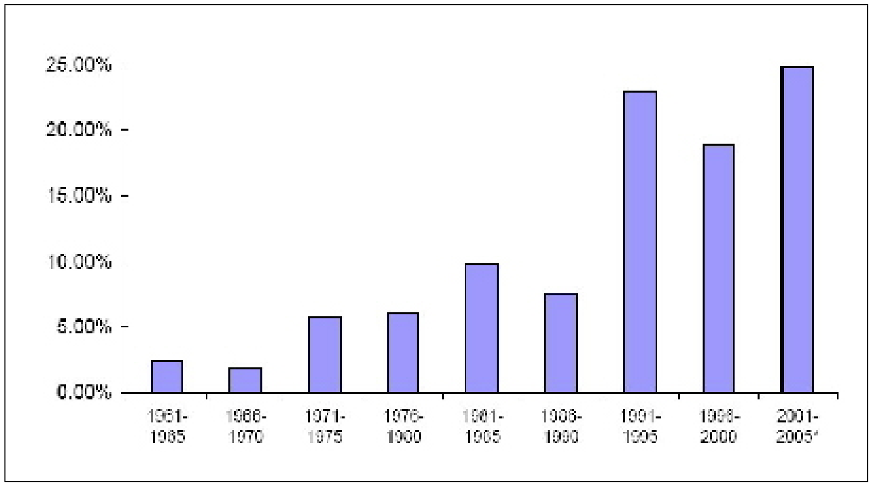
production increases. The dataset collected does not allow for careful examination of this correlation but Figure 2.3 suggets that this is the case. The prices used correspond to a sample of 500 gas stations for which there where observations on every Wednesday of each week in the period March to August 2005. As the figure shows, the standard deviation of those prices increases when the average price (proxy for wholesale cost) decreases.

2.5 Conclusion

The retail gasoline market is characterized by price dispersion. Theoretically, both product differentiation and costly consumer search could generate dispersion. In this paper I try to find the source of the price dispersion by looking at the different dynamic implications of each model. Using a simple test that exploits the particular structure of the gasoline sector, I find that costly consumer search is indeed relevant in this market.

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 that more empirical work aiming at detecting the underlying model of price dispersion in the market is needed.

Appendix



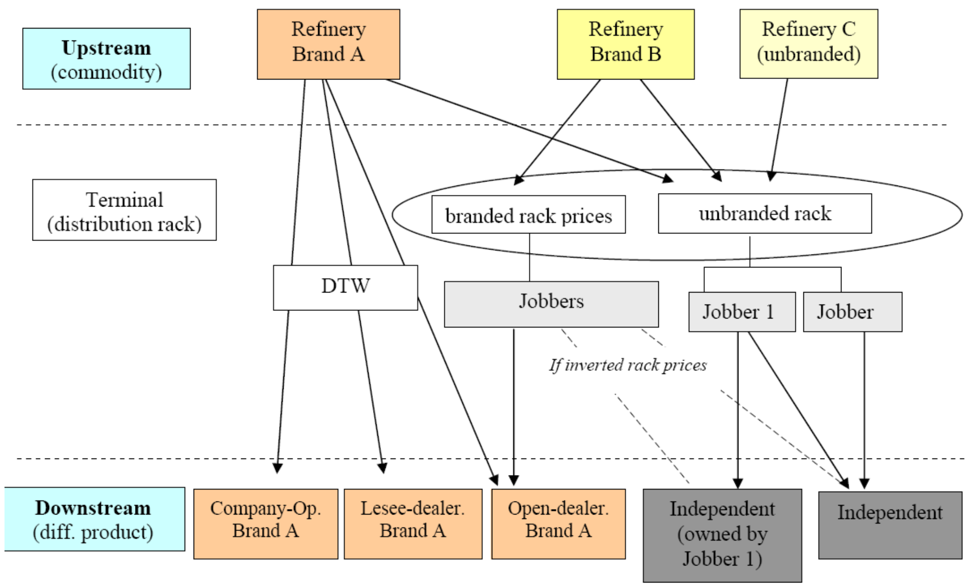
Source: Baye et al. (2005). Social Science Citation Index , Keyword search for ”Information OR Price Dispersion OR Search.” 2005* data through third quarter

Figure 2.4: Percentage of articles published in the AER, JPE, and Econometrica on *Information, Search or Price Dispersion*

	Cons. Info	Search protocol	Firms cost	Search cost	Demand	Num. firms
Axell (1977)	Nash	SeqWR	Co	$G(s)$	$q(p)$	∞
Baye and Morgan (2001)	Nash	NS	H	$\lambda, s > 0$	v	N
Benabou (1992)	Nash	Seq	$G(c)$	$G(s)$	$q(p)$	∞
Benabou and Gertner (1993)	Nash	Seq	$\{c_L, c_H\}$	s	v	2
Braverman (1980)	Stkb	NS	HU	$\lambda, G(s)$	$q(p)$	N^*
Burdett and Judd (1983)	Nash	NS-Flex	H	$s > 0$	v	∞ / N
Butters (1977)	Nash	NS & Seq	H^+	s	v	∞
Dana (1994)	Nash	SNS	H	s	v	N
Fishman and Rob (1995)	Nash	Seq	$\{c_L, c_H\}$	$s1 < s2$	$q(p)$	∞
Jansen *et al.* (2004)	Nash	NS*	H	$\lambda, s > 0$	v	N
Carlson and McAfee (1983)	Stkb	Seq	$G(c)$	$G(s)$	v	N
MacMinn (1980)	Nash	NS & Seq	$G(c)$	s	v	∞
Reinganum (1979)	Nash	Seq	$G(c)$	s	$q(p)$	∞
Rob (1985)	Stkb	SeqWR	H	$G(s)$	$q(p)$	∞
Roshental (1980)	Nash	NS	H	$\lambda, s > 0$	v	N
Salop-Stiglitz (1977)	Stkb	NonSeq	HU	$s1 < s2$	v	N^*
Stahl (1989)	Nash	Seq	H	$s1 < s2$	$q(p)$	N
Stahl (1996)	Nash	Seq	H	$\lambda, G(s)$	$q(p)$	N
Stiglitz (1987) Appendix A	Stkb	Seq	H	$G(s)$	$q(p)$	N
Stiglitz (1987) Appendix B	Stkb	SeqWR	H	$G(s)$	$q(p)$	N
Varian (1980)	Nash	NS	H	$s1 < s2$	v	N

Stkb: Stackelberg search protocol; NS: Nonsequential search; NS*: NS with search for first price; Seq: sequential search; SEqWR: Sequential search with replacement; H: Homogeneous constant unit cost of production; H^+: H with different advertising costs; HU: Homogeneous U-shaped avg. cost. $G(c)$: Asymmetric (constant) unit costs; $\{c_L, c_H\}$: Low and high (stochastic) unit cost; co: Convex total . production cost; s: Homogeneous search cost; $G(s)$: Distribution of costs; λ: Mass of shoppers; $s1 < s2$ Low and High search costs; v: Unit demand (up to choke price); $q(p)$: Multiunit demand; N: Fixed finite number of firms; N^*: Finite, long-run free entry equilibrium.

Table 2.3: Models of search



Co-Op: Company operated station (fully vertically integrated).

Lessee-dealer: Partial VI. Fixed assets owned by refinery. Refiner supplies station fixing wholesale price (DTW) an annual fee, and minimum quantity restriction. Dealer sets final price.

DTW: Dealer Tank Wagon price. Includes "zone pricing", discounts, and "delivery" cost.

Open-dealer: All assets owned by manager of station. Supply from refinery or jobber.

Jobber: Intermediary that delivers gasoline from rack to stations. Can set station specific prices.

Indpendent: Station that sells unbranded (from consumer's perspective) gasoline.

Figure 2.5: Industry structure

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