Information, Search, and Price Dispersion*

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Abstract

We provide a unified treatment of alternative models of information acquisition/transmission that have been advanced to rationalize price dispersion in online and offline markets for homogeneous products. These different frameworks—which include sequential search, fixed sample search, and clearinghouse models—reveal that reductions in (or the elimination of) consumer search costs need not reduce (or eliminate) price dispersion. Our treatment highlights a "duality" between search-theoretic and clearinghouse models of dispersion, and shows how auction-theoretic tools may be used to simplify (and even generalize) existing theoretical results. We conclude with an overview of the burgeoning empirical literature. The empirical evidence suggests that price dispersion in both online and offline markets is sizeable, pervasive, and persistent—and does not purely stem from subtle differences in firms' products or services.

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1 Introduction

Simple textbook models of competitive markets for homogeneous products suggest that all-out competition among firms will lead to the so-called "law of one price." Yet, empirical studies spanning more than four decades (see Tables 1a and 1b) reveal that price dispersion is the rule rather than the exception in many homogeneous product markets. The observation that the prices different firms charge for the same product often differ by 30 percent or more led Hal Varian to suggest that "the 'law of one price' is no law at all" (Varian, 1980, p. 651). This chapter provides a unified treatment of several theoretical models that have been developed to explain the price dispersion observed in homogeneous product markets, and surveys the burgeoning empirical literature (including the studies summarized in Tables 1a and 1b) which documents ubiquitous price dispersion. A key motivation for this chapter is to dispel the erroneous view that the Internet—through its facilitation of dramatic declines in consumer search costs—will ultimately lead to the "law of one price."

When confronted with evidence of price dispersion, many are quick to point out that even in markets for seemingly homogeneous products, subtle differences among the "services" offered by competing firms might lead them to charge different prices for the same product. Nobel Laureate George Stigler's initial response to wags making this point was philosophical: "... [While] a portion of the observed dispersion is presumably attributable to such difference[s]...it would be metaphysical, and fruitless, to assert that all dispersion is due to heterogeneity" (Stigler, 1961, p. 215). Thirty-five years later, the literature has amassed considerable support for Stigler's position. As we shall see in Sections 2 and 3, there is strong theoretical and empirical evidence that much (and in some markets, most) of the observed dispersion stems from information costs—consumers' costs of acquiring information about firms, and/or firms' costs of transmitting information to consumers.

As Figure 1 reveals, research on information, search, and price dispersion has become increasingly important since the publication of Stigler's seminal article on the *Economics of Information*. Until about 1998, most studies focused on environments where consumers incur a positive cost of obtaining each additional price quote. Search costs in these studies consist of consumers' opportunity cost of time in searching for lower prices (so-called "shoe-leather" costs), plus other costs associated with obtaining price quotes from competing firms (such as the incremental cost of the postage stamps or phone calls used in acquiring price information from firms). Consumers in these environments weigh the cost of obtaining an additional price quote against the expected benefits of searching an additional firm. As we discuss in Section 2.1, equilibrium price dispersion can arise in these environments under a variety of market conditions and search strategies (including sequential and fixed sample search).

While marginal search costs are useful in explaining price dispersion in some markets, in many online markets incremental search costs are very low—and in some cases, zero. For example, price comparison sites and shopbot technologies create environments where consumers may obtain a list of the prices that different sellers charge for the same product. Despite the fact that this information is available to consumers in seconds, ultimately at the cost of a single "mouse click," the overwhelming empirical finding is that even in these environments, price dispersion is pervasive and significant—the law of one price is egregiously violated online. In Section 2.2, we examine an alternative line of theoretical research where marginal search costs are not the key driver for price dispersion. Our theoretical analysis concludes in Section 2.3 with a discussion of alternative behavioral rationales for price dispersion (including bounded rationality on the part of firms and/or consumers).

Section 3 provides a more detailed overview of the growing empirical literature. As one might suspect based on the trend in Figure 1 and the research summarized in Tables 1a and 1b, most empirical studies of price dispersion post-date the Internet and rely on online data. Our view is that this is more an artifact of the relative ease with which data may be collected in online markets—not an indication that price dispersion is more important (or more prevalent) in online than offline markets. For this reason, we have attempted to provide a balanced treatment of the literatures on online and offline price dispersion. As we shall argue, the overwhelming conclusion of both literatures is that price dispersion is not purely an artifact of product heterogeneities.

2 Theoretical Models of Price Dispersion

This section presents alternative models that have been used to rationalize the price dispersion observed in both offline and online markets. One approach is to assume that it is costly for consumers to gather information about prices. In these "search-theoretic" models, consumers searching for the best price incur a positive cost of obtaining each additional price quote. Representative examples include Stigler (1961), Rothschild (1973), Reinganum (1979), MacMinn (1980), Braverman (1980), Burdett and Judd (1983), Carlson and McAfee (1983), Rob (1985), Stahl (1989, 1996), Dana (1994), McAfee (1995), Janssen and Moraga-González (2004), as well as Janssen, Moraga-González, and Wildenbeest (2005).

A second approach deemphasizes the marginal search cost as a source for price dispersion. Instead, consumers access price information by consulting an "information clearinghouse" (e.g., a newspaper or an Internet price comparison site); e.g. Salop and Stiglitz (1977), Shilony (1977), Rosenthal (1980), Varian (1980), Narasimhan (1988), Spulber (1995), Baye and Morgan (2001), Baye, Morgan, and Scholten (2004a).[1] The distinguishing feature of "clearinghouse models" is that a subset of consumers gain access to a list of prices charged by all firms and purchase at the lowest listed price. In the earliest of these models, equilibrium price dispersion stems from *ex ante* heterogeneities in consumers or firms. For example, in the Varian and Salop-Stiglitz models, some consumers choose to access the clearinghouse to obtain price information, while others do not. In Shilony, Rosenthal, and Narasimhan, some consumers are loyal to a particular firm (and thus will buy from it even if it does not charge the lowest price), while other consumers are "shoppers" and only purchase from the firm charging the lowest price. Spulber (1995) shows that equilibrium price dispersion arises even when all consumers can costlessly access the clearinghouse—provided each firm is privately informed about its marginal cost. Baye and Morgan (2001) offer a clearinghouse model that endogenizes not only the decisions of firms and consumers to utilize the information clearinghouse (in the previous clearinghouse models, firms' listing decisions are exogenous), but also the fees charged by the owner of the clearinghouse (the "information gatekeeper") to consumers and firms who wish to access or transmit price information. They show that a dispersed price equilibrium exists even in the absence of any *ex ante* heterogeneities in consumers or firms.

In this section, we provide an overview of the key features and ideas underlying these literatures.

2.1 Search-Theoretic Models of Price Dispersion

We begin with an overview of search-theoretic approaches to equilibrium price dispersion. The early literature stresses the idea that, when consumers search for price information and search is costly, firms will charge different prices in the market. There are two basic sorts of models used: Models with fixed sample size search and models where search is sequential. We will discuss each of these in turn.

[1] A third approach deemphasizes consumer search and mainly focuses on whether price dispersion can arise when consumers "passively" obtain price information directly from firms (as in direct mail advertisements); cf. Butters (1977), Grossman and Shapiro (1984), Stegeman (1991), Robert and Stahl (1993), McAfee (1994), and Stahl (1994). A related marketing literature examines similar issues, ranging from loyalty and price promotion strategies to channel conflicts and the Internet; see Lal and Villas-Boas (1998), Lal and Sarvary (1999), Raju, Srinivasan, and Lal (1990), and Rao, Arjunji and Murthi (1995).

The search models considered in this subsection are all based on the following general environment. A continuum of price-setting firms (with unit measure) compete in a market selling an identical (homogeneous) product. Firms have unlimited capacity to supply this product at a constant marginal cost, m. A continuum of consumers is interested in purchasing the product. Let the mass of consumers in the market be μ, so that the number of customers per firm is μ. Each consumer has a quasi-linear utility function, $u(q) + y$, where q is the quantity of the homogeneous product and y is the quantity of some numeraire good whose price is normalized to be unity. This implies that the indirect utility of a consumer who pays a price p per unit of the product and who has an income of M is

$$V(p, M) = v(p) + M$$

where $v(\cdot)$ is nonincreasing in p. By Roy's identity, note that the demand for the product of relevance is $q(p) \equiv -v'(p)$.

To acquire the product, a consumer must first obtain a price quote from a store offering the product for sale. Suppose that there is a search cost, c, per price quote.[2] If, after obtaining n price quotes, a consumer purchases $q(p)$ units of the product from one of the firms at price p per unit, the consumer's (indirect) utility is

$$V = v(p) + M - cn$$

The analysis that follows focuses on posted price markets where consumers know the distribution of prices but do not know the prices charged by particular stores.[3]

2.1.1 The Stigler Model

Stigler (1961) considers the special case of this environment where:

1. Each consumer wishes to purchase $K \geq 1$ units of the product; that is, $q(p) = -v'(p) = K$;

2. The consumer's search process is fixed sample search—prior to searching, consumers determine a fixed sample size, n, of firms from whom to obtain price quotes and then buy from

[2] In what follows, we assume that consumers have identical search costs. Axell (1977) offers a model of price dispersion with heterogeneous search costs.

[3] This assumption is relaxed in Rothschild (1974), Benabou and Gertner (1993) and Dana (1994), where buyers learn about the distribution of prices as they search, and in Rauh (1997), where buyers' search strategies depend on only finitely many moments of the distribution of prices. Daughety (1992) offers an alternative search-theoretic model of equilibrium price dispersion that results from informational asymmetries and a lack of price precommitment on the part of firms.

the firm offering the lowest price; and

3. The distribution of firms' prices is given by an *exogenous* non-degenerate cdf $F(p)$ on $[\underline{p}, \overline{p}]$.

Stigler assumes that a consumer chooses a fixed sample size, n, to minimize the expected total cost (expected purchase cost plus search cost) of purchasing K units of the product:

$$E[C] = KE\left[p_{\min}^{(n)}\right] + cn$$

where $E\left[p_{\min}^{(n)}\right] = E[\min\{p_1, p_2, ..., p_n\}]$; that is, the expected lowest price quote obtained from n draws from F. Since the distribution of the lowest of n draws is $F_{\min}^{(n)}(p) = 1 - [1 - F(p)]^n$,

$$\begin{aligned} E[C] &= K \int_{\underline{p}}^{\overline{p}} p dF_{\min}^{(n)}(p) + cn \\ &= K\left[\underline{p} + \int_{\underline{p}}^{\overline{p}} [1 - F(p)]^n dp\right] + cn \end{aligned}$$

where the second equality obtains from integration by parts. Notice that the term in square brackets reflects the expected purchase price, which is a decreasing function of the sample size, n. However, since each additional price observation costs $c > 0$ to obtain, an optimizing consumer will choose to search a finite number of times, n^*, and thus will generally stop short of obtaining the best price $(\underline{p})$ in the market.

The distribution of transaction prices is the distribution of the lowest of n^* draws from F; that is,

$$F_{\min}^{(n^*)}(p) = 1 - (1 - F(p))^{n^*}$$

From this, Stigler concludes that dispersion in both posted prices and transactions prices arises as a consequence of costly search.

How do transactions prices and search intensity relate to the quantity of the item being purchased (or equivalently, to the frequency of purchases)?[4] Stigler's model offers sharp predictions in this dimension. Note that the expected benefit to a consumer who increases her sample size from $n-1$ to n is

$$E\left[B^{(n)}\right] = \left(E\left[p_{\min}^{(n-1)}\right] - E\left[p_{\min}^{(n)}\right]\right) \times K, \tag{1}$$

[4] K may be related to purchase frequency as follows. Suppose prices are "valid" for T periods, and the consumer wishes to buy one unit every $t \leq T$ periods; that is, t represents a consumer's purchase frequency. Then the total number of units purchased during the T periods is $K \equiv T/t$. Thus, an increase in purchase frequency (t) is formally equivalent to an increase in K in the model above.

which is decreasing in n. Furthermore, the expected benefit from search are greater for products bought in greater quantities or more frequently; that is, equation (1) is increasing in K. Since the cost of the nth search is independent of K while the expected benefit is increasing in K, it immediately follows that the equilibrium search intensity, n^*, is increasing in K. That is, consumers obtain more price quotes for products they buy in greater quantities (or frequencies).

Despite the fact that the Stigler model assumes each individual inelastically purchases K units of the product, a version of the "law of demand" holds: Each firm's expected demand is a nonincreasing function of its price. To see this, note that a firm charging price p is visited by μn^* consumers and offers the lowest price with probability $(1 - F(p))^{n^*-1}$. Thus, a representative firm's expected demand when it charges a price of p is

$$Q(p) = \mu n^* K (1 - F(p))^{n^*-1} \tag{2}$$

which is decreasing in p.

The Stigler model implies that both the expected transactions price (Proposition 1) as well as the expected total costs inclusive of search costs (Proposition 2) are lower when prices are more dispersed (in the sense of a mean preserving spread).[5]

Proposition 1 *Suppose that a price distribution G is a mean preserving spread of a price distribution F. Then the expected transactions price of a consumer who obtains $n > 1$ price quotes is strictly lower under price distribution G than under F.*

Proof. Let $\Delta = E_F\left[p_{\min}^{(n)}\right] - E_G\left[p_{\min}^{(n)}\right]$ be the difference in the expected transactions price under F compared to G. We will show that for all $n > 1$, $\Delta > 0$. Using the definition of $E\left[p_{\min}^{(n)}\right]$,

$$\Delta = \int_{-\infty}^{\infty} pn (1 - F(p))^{n-1} dF(p) - \int_{-\infty}^{\infty} tn (1 - G(t))^{n-1} dG(t)$$

Let $u = F(p)$ and $v = G(p)$, so that $du = dF(p)$, $dv = dG(p)$, $p = F^{-1}(u)$, and $t = G^{-1}(v)$. Then

$$\begin{aligned}\Delta &= n \int_0^1 F^{-1}(u) (1 - u)^{n-1} du - n \int_0^1 G^{-1}(v) (1 - v)^{n-1} dv \\ &= n \int_0^1 \left(F^{-1}(u) - G^{-1}(u)\right) (1 - u)^{n-1} du\end{aligned}$$

[5] G is a mean preserving spread of F if (a) $\int_{-\infty}^{\infty} [G(p) - F(p)]\, dp = 0$ and (b) $\int_{-\infty}^{z} [G(p) - F(p)]\, dp \geq 0$, with strict inequality for some z. Note that (a) is equivalent to the fact that the means of F and G are equal. Together, the two conditions imply that F and G cross exactly once (at the mean) on the interior of the support.

Since G is a mean preserving spread of F, there exists a unique interior point $u^* = F(E_F[P])$ such that $F^{-1}(u^*) = G^{-1}(u^*)$. Further, for all $u < u^*, F^{-1}(u) - G^{-1}(u) > 0$ and for all $u > u^*, F^{-1}(u) - G^{-1}(u) < 0$. Thus

$$\Delta = n\left(\int_0^{u^*}\left(F^{-1}(u) - G^{-1}(u)\right)(1-u)^{n-1}\,du + \int_{u^*}^1\left(F^{-1}(u) - G^{-1}(u)\right)(1-u)^{n-1}\,du\right)$$

Next, notice that $(1-u)^{n-1}$ is strictly decreasing in u; hence

$$\begin{aligned}
\Delta &> n\left(\int_0^{u^*}\left(F^{-1}(u) - G^{-1}(u)\right)(1-u^*)^{n-1}\,du + \int_{u^*}^1\left(F^{-1}(u) - G^{-1}(u)\right)(1-u^*)^{n-1}\,du\right) \\
&= n(1-u^*)^{n-1}\int_0^1\left(F^{-1}(u) - G^{-1}(u)\right)du \\
&= 0
\end{aligned}$$

where the last equality follows from the fact that F and G have the same mean. ■

Proposition 2 *Suppose that an optimizing consumer obtains more than one price quote when prices are distributed according to F, and that price distribution G is a mean preserving spread of F. Then the consumer's expected total costs under G are strictly less than those under F.*

Proof. Suppose that, under F, the optimal number of searches is n^*. Then the consumer's expected total cost under F is

$$\begin{aligned}
E[C_F] &= E_F\left[p_{\min}^{(n^*)}\right] \times K - cn^* \\
&> E_G\left[p_{\min}^{(n^*)}\right] \times K - cn^* \\
&\geq E[C_G]
\end{aligned}$$

where the strict inequality follows from Proposition 1, and the weak inequality follows from the fact that n^* searches may not be optimal under the distribution G. ■

At first blush, it might seem surprising that consumers engaged in fixed sample search pay lower average prices and have lower expected total costs in environments where prices are more dispersed. The intuition, however, is clear: In environments where prices are more dispersed, the prospects for price improvement from search are higher because the left tail of the price distribution—the part of the distribution where "bargains" are to be found—becomes thicker as prices become more dispersed.

2.1.2 The Rothschild Critique and Diamond's Paradox

While Stigler offered the first search-theoretic rationale for price dispersion, the model has been criticized for two reasons. First, as pointed out in Rothschild (1973), the search procedure assumed in Stigler's model may not be optimal. In fixed sample search, consumers commit to a fixed number, n, of stores to search and then buy at the lowest price at the conclusion of that search. A clear drawback to such a strategy is that it fails to incorporate new information obtained during search, such as an exceptionally low price from an early search. Indeed, once the best price quote obtained is sufficiently low, the benefit in the form of price improvement drops below the marginal cost of the additional search. As we will see below, sequential search results in an optimal stopping rule such that a consumer searches until she locates a price below some threshold, called the *reservation price.* Second, the distribution of prices, F, is exogenously specified and is not based on optimizing firm behavior. In fact, in light of equation (2), a representative firm with constant marginal cost of m enjoys expected profits of

$$\pi(p) = (p - m) Q(p).$$

That is, absent any cost heterogeneities, each firm faces exactly the *same* expected profit function. Why then, would firms not choose the same profit-maximizing price or, more generally, how could the distribution of prices generated by profit-maximizing firms be consistent with the price distribution over which consumers were searching? In short, Rothschild pointed out that it is far from clear that information costs give rise to an equilibrium of price dispersion with optimizing consumers and firms; in Stigler's model, only one side of one market, the consumers, are acting in an optimizing fashion consistent with equilibrium. For this reason, Rothschild criticized the early literature for its "partial-partial equilibrium" approach.

Diamond (1971) advanced this argument even further—he essentially identified conditions under costly search where the unique equilibrium in undominated strategies involves all firms charging the same price—the monopoly price. Diamond's result may be readily seen in the following special case of our environment where:

1. Consumers have identical downward sloping demand, i.e. $-v''(p) = q'(p) < 0$;

2. Consumers engage in optimal *sequential* search;

3. A firm acting as a monopoly would optimally charge all consumers the unique monopoly price, p^*; and

4. A consumer who is charged the monopoly price earns surplus sufficient to cover the cost of obtaining a single price quote; that is $v(p^*) > c$.

In this environment, all firms post the monopoly price and consumers visit only one store, purchase at the posted price p^*, and obtain surplus $v(p^*) - c > 0$. Given the stopping rule of consumers, each firm's best response is to charge the monopoly price; given that all firms charge p^*, it is optimal for each consumer to search only once. To see that this is the unique equilibrium in undominated strategies, suppose to the contrary that there is an equilibrium in which some firm posted a price below the monopoly price (clearly, pricing above the monopoly price is a dominated strategy). Let p' be the lowest such posted price. A firm posting the lowest price could profitably deviate by raising its price to the lower of p^* or $p' + c$. Any consumer visiting that firm would still rationally buy from it since the marginal benefit of an additional search is smaller than c—the marginal cost of an additional search. Thus, such a firm will not lose any customers by this strategy and will raise its earnings on each of these customers.

The Diamond paradox is striking: even though there is a continuum of identical firms competing in the model—a textbook condition for perfect competition—in the presence of any search frictions whatsoever the monopoly price is the equilibrium. Rothschild's criticism of the Stigler model, along with the Diamond paradox, spawned several decades of research into whether costly search could possibly generate equilibrium price dispersion — a situation where consumers are optimally gathering information given a distribution of prices, and where the distribution of prices over which consumers are searching is generated by optimal (profit-maximizing) decisions of firms.

2.1.3 The Reinganum Model and Optimal Sequential Search

Reinganum (1979) was among the first to show that equilibrium price dispersion can arise in a sequential search setting with optimizing consumers and firms. Reinganum's result may be seen in the following special case of our environment where:

1. Consumers have identical demands given by $-v'(p) = q(p) = Kp^{\varepsilon}$, where $\varepsilon < -1$ and $K > 0$;

2. Consumers engage in optimal *sequential* search;

3. Firms have heterogeneous marginal costs described by the atomless distribution $G(m)$ on $[\underline{m}, \overline{m}]$;

4. A consumer who is charged the monopoly price by a firm with the highest marginal cost, $\overline{m}$, earns surplus sufficient to cover the cost of obtaining a single price quote; that is $v\left(\frac{\varepsilon}{1+\varepsilon}\overline{m}\right) > c$.

Reinganum shows that, under these assumptions, there exists a dispersed price equilibrium in which firms optimally set prices and each consumer engages in optimal sequential search. To establish this, we first show how one derives the optimal reservation price in a sequential search setting. Suppose consumers are confronted with a nondegenerate distribution of prices $F(p)$ on $\left[\underline{p}, \overline{p}\right]$ that is atomless, except possibly at $\overline{p}$. Consumers engage in optimal sequential search with free recall. If, following the nth search, a consumer has already found a best price $z \equiv \min\left(p_1, p_2, ..., p_n\right)$, then, by making an additional search, such a consumer expects to gain benefits of

$$\begin{aligned} B(z) &= \int_{\underline{p}}^{z} (v(p) - v(z))\, dF(p) \\ &= \int_{\underline{p}}^{z} -v'(p)\, F(p)\, dp, \end{aligned}$$

where the second equality obtains through integration by parts. Using Leibnitz' rule, we have

$$\begin{aligned} B'(z) &= -v'(z)\, F(z) \\ &= Kz^{\varepsilon} F(z) > 0 \end{aligned} \tag{3}$$

Thus, the expected benefits from an additional search are lower when the consumer has already identified a relatively low price. Since search is costly ($c > 0$), consumers must weigh the expected benefits against the cost of an additional search. The expected net benefits of an additional search are

$$h(z) \equiv B(z) - c$$

If the expected benefits from an additional search exceed the additional cost, $h(z) > 0$, it is optimal for the consumer to obtain an additional price quote. If $h(z) < 0$, the consumer is better off purchasing at the price z than obtaining an additional price quote.

A consumer's optimal sequential search strategy may be summarized as follows:

Case 1. $h(\overline{p}) < 0$ and $\int_{\underline{p}}^{\overline{p}} v(p)\, dF(p) < c$. Then the consumer's optimal strategy is to not search.

Case 2. $h(\overline{p}) < 0$ and $\int_{\underline{p}}^{\overline{p}} v(p)\, dF(p)\, dp \geq c$. Then the consumer's optimal strategy is to search until she obtains a price quote at or below the reservation price, $r = \overline{p}$.

Case 3. $h(\overline{p}) \geq 0$. Then the consumer's optimal strategy is to search until she obtains a price quote at or below the reservation price, r, where r solves

$$h(r) = \int_{\underline{p}}^{r} (v(p) - v(r))\, dF(p) - c = 0 \tag{4}$$

Equation (4) represents a price at which a consumer is exactly indifferent between buying and making an additional search. To see that such a price is uniquely defined by this equation, notice that $h(\underline{p}) = -c < 0$, $h(\overline{p}) \geq 0$, and $h'(z) = B'(z) > 0$. A consumer who observes a price that exceeds r will optimally "reject" that price in favor of continued search, while a consumer who observes a price below r will optimally "accept" that price and stop searching.

Case 1 is clearly not economically interesting as it leads to the absence of any market for the product in the first place. Case 2 arises when the expected utility of purchasing the product exceeds the cost of an initial search, but the distribution of prices is sufficiently "tight" relative to search costs to make additional searches suboptimal. Most of the existing search literature, including Reinganum, restricts attention to Case 3, as we shall do hereafter.

The reservation price defined in equation (4) has several interesting comparative static properties. Totally differentiating equation (4) with respect to r and c, and using equation (3) reveals that

$$\frac{dr}{dc} = \frac{1}{q(r)\, F(r)} = \frac{1}{K r^{\varepsilon} F(r)} > 0$$

Thus, an increase in search costs leads to a higher reservation price: Other things equal, the range of "acceptable" prices is greater for products with higher search costs. Note that, for the special case when $q(r) = 1$, $dr/dc = 1/F(r) > 1$. In this case, a one unit increase in search costs increases the range of acceptable prices by more than one unit—that is, there is a "magnification effect" of increases in search costs.[6]

Reinganum avoids Rothschild's criticism and the "Diamond paradox" by introducing firm cost heterogeneities. Since each firm j differs in its marginal costs, m_j, prices will differ across firms even when they price as monopolists.

Suppose that a fraction $0 \leq \lambda < 1$ of firms price above r and recall that there are μ consumers per firm. A representative firm's expected profit when it prices at p_j is:

$$E\pi_j = \begin{cases} (p_j - m_j)\, q(p_j) \left(\frac{\mu}{1-\lambda}\right) & \text{if} \quad p_j \leq r \\ 0 & \text{if} \quad p_j > r \end{cases}$$

[6] In general, there may be either a magnification or an attenuation effect of a one unit increase in the cost of search.

Ignoring for a moment the fact that a firm's demand is zero if it prices above r, note that profit-maximization implies the first-order condition

$$\left[(p_j - m_j)\, q'(p_j) + q(p_j)\right] \left(\frac{\mu}{1-\lambda}\right) = 0.$$

Standard manipulation of the first-order condition for profit-maximization implies that firm j's (unconstrained) profit-maximizing price is a constant markup over its cost:

$$p_j = \left(\frac{\varepsilon}{1+\varepsilon}\right) m_j.$$

Suppose that firms simply ignore the consumer's reservation price, r, and price at this markup. This would imply that consumers face a distribution of posted prices $\hat{F}(p) = G(p(1+\varepsilon)/\varepsilon)$ on the interval $[\underline{m}\varepsilon/(1+\varepsilon), \overline{m}\varepsilon/(1+\varepsilon)]$. Given this distribution of prices, optimizing consumers would set a reservation price, r, such that

$$h(r) = \int_{\underline{p}}^{r} (v(p) - v(r))\, d\hat{F}(p) - c = 0$$

Furthermore, if $r < \overline{m}\varepsilon/(1+\varepsilon)$, firms charging prices in the interval $(r, \overline{m}\varepsilon/(1+\varepsilon)]$ would enjoy no sales. Since the elasticity of demand is constant, firms that would maximize profits by pricing above r in the absence of consumer search find it optimal to set their prices at r when consumers search.[7] Thus, the distribution of prices, $\hat{F}(p)$, is inconsistent with optimizing behavior on the part of firms. In fact, given the reservation price r, optimizing behavior on the part of firms would imply a distribution of prices

$$F(p) = \begin{cases} \hat{F}(p) & \text{if} \quad p < r \\ 1 & \text{if} \quad p = r \end{cases}$$

To establish that this is, in fact, an equilibrium distribution of prices one must verify that consumers facing this "truncated" distribution of prices have no incentive to change their reservation price. Given this truncated distribution of prices, the net expected benefits of search are

$$\begin{aligned} h(r) &= \int_{\underline{p}}^{r} (v(p) - v(r))\, dF(p) - c \\ &= \int_{\underline{p}}^{r} (v(p) - v(r))\, d\hat{F}(p) + \left[1 - \hat{F}(r)\right][v(r) - v(r)] - c \\ &= \int_{\underline{p}}^{r} (v(p) - v(r))\, d\hat{F}(p) - c = 0 \end{aligned}$$

[7] Reinganum assumes that $\overline{m} \leq \underline{m}\varepsilon/(1+\varepsilon)$, which guarantees that firms who would otherwise price above r find it profitable to price at r.

where the last equality follows from the fact that r is the optimal reservation price when consumers face the price distribution $\hat{F}$. In short, Reinganum's assumptions of downward sloping demand and cost heterogeneity give rise to an equilibrium of price dispersion with optimizing consumers and firms.

Note that downward sloping demand and cost heterogeneities together play a critical role in generating equilibrium price dispersion in this environment. To see that both assumptions are required, suppose first that costs are heterogeneous but that each consumer wished to purchase one unit of the product, valued at v. In this case, given a reservation price of $r \leq v$, all firms would find it optimal to price at r, and the distribution of prices would be degenerate. Of course, a reservation price of $r < v$ is inconsistent with optimizing behavior on the part of consumers. To see this, suppose that a consumer was unexpectedly presented with a price $p' = r + \delta$, where $\delta < c$. According to the search strategy, such a consumer is supposed to reject this price and continue searching; however, the benefit from this additional search is less than the cost. Thus, a consumer should optimally accept a price p' rather than continuing to search. The upshot of this is that the only equilibrium reservation price is $r = v$. However, these are precisely the conditions given in Case 1; hence the only equilibrium is where no consumers shop at all.[8]

If demand were downward sloping but firms had identical marginal costs of m, each firm would have an incentive to set the same price, $p^* = \min\{r, m\varepsilon/(1+\varepsilon)\}$, given the reservation price. This leads back to Case 2 and one obtains the Diamond paradox: All firms charge the monopoly price, $p^* = m\varepsilon/(1+\varepsilon)$. Indeed, in the environment above, a limiting case where the distribution of marginal costs converges to a point is exactly the Diamond model.

Finally, we examine how the variance in the distribution of posted (and transactions) prices varies with search costs. Note that, in equilibrium, the variance in prices is given by

$$\begin{aligned}
\sigma^2 &= E\left[p^2\right] - (E[p])^2 \\
&= \int_{\underline{p}}^{r} p^2 dF(p) - \left(\int_{\underline{p}}^{r} p dF(p)\right)^2 \\
&= \int_{\underline{p}}^{r} p^2 \hat{f}(p)\, dp + \left(1 - \hat{F}(r)\right) r^2 - \left(\int_{\underline{p}}^{r} p \hat{f}(p)\, dp + \left(1 - \hat{F}(r)\right) r\right)^2
\end{aligned}$$

[8] Carlson and McAfee (1983) show that if one introduces heterogeneities in consumer search costs, a dispersed price equilibrium may exist provided that individual consumers have perfectly inelastic (in contrast to downward sloping) demand.

where $\hat{f}(p)$ is the density of $\hat{F}(p)$. Hence,

$$\begin{aligned}\frac{d\sigma^2}{dr} &= 2r\left(1-\hat{F}(r)\right)-2\left(\int_{\underline{p}}^{r} p\hat{f}(p)\,dp+\left(1-\hat{F}(r)\right)r\right)\left(1-\hat{F}(r)\right)\\ &= 2\left[1-\hat{F}(r)\right](r-E[p])\geq 0\end{aligned}$$

with strict inequality if $r<\overline{m}\varepsilon/(1+\varepsilon)$. Thus, we have:

Conclusion 1 *In the Reinganum model, a reduction in search costs decreases the variance of equilibrium prices.*

As we will see below, however, this is not a general property of search-theoretic models of price dispersion.

2.1.4 Remarks on Fixed versus Sequential Search

It is useful to highlight some key differences between sequential and fixed sample size search. With sequential search, the number of searches is a random variable from a geometric distribution, and the expected number of searches, given a distribution of prices $F(p)$ and reservation price r, is

$$E[n]=\frac{1}{F(r)}$$

In contrast, with fixed sample size search, consumers commit up front to n searches. Both types of search have advantages and disadvantages, and indeed Morgan and Manning (1985) have shown that both types of search can be optimal in different circumstances. The key advantage of sequential search is that it allows a searcher to economize on information costs – the decision-maker weighs the expected benefits and costs of gathering additional price information after each new price quote is obtained. If an acceptable price is obtained early on, the expected gains from additional searches are small and there is no need to pay the cost of additional searches. The primary advantage of fixed-sample size search is that it allows one to gather information quickly. Consider, for instance, a firm that requires raw materials by the end of the week. If it takes a week for a raw materials vendor to provide a price quote, sequential search would permit the firm to obtain only a price quote from a single vendor. In this case, fixed sample size search is optimal—the firm commits to obtain quotes from n vendors, where n is chosen by the firm to minimize expected costs as outlined above in our discussion of the Stigler model.

2.1.5 The MacMinn Model

In light of the fact that there are instances in which fixed sample size search is optimal, one may wonder whether equilibrium price dispersion can arise in such a setting. MacMinn (1980) provides an affirmative answer to this question. MacMinn's result may be seen in the following special case of our environment where:

1. Consumers have unit demand with valuation v;
2. Consumers engage in optimal *fixed sample* search; and[9]
3. Firms have privately observed marginal costs described by the atomless distribution $G(m)$ on $[\underline{m}, \overline{m}]$, where $\overline{m} < v$.

At the time, MacMinn derived equilibrium pricing by solving a set of differential equations under the special case where G is uniformly distributed. However, subsequent to his paper, a key finding of auction theory, the *Revenue Equivalence Theorem* (Myerson, 1981) was developed.[10] Using the revenue equivalence theorem, we can generalize MacMinn's results to arbitrary cost distributions.

To see this, notice that when consumers optimally engage in a fixed sample search consisting of n^* firms, each firm effectively competes with $n^* - 1$ other firms to sell one unit of the product. Of these n^* firms, the firm posting the lowest price wins the "auction".

Using the revenue equivalence theorem, one can show that the expected revenues to a firm with marginal cost m in any "auction" where the firm charging the lowest price always wins and the firm with the highest marginal cost earns zero surplus is

$$R(m) = m(1 - G(m))^{n^*-1} + \int_m^{\overline{m}} (1 - G(t))^{n^*-1} dt \tag{5}$$

In the MacMinn model, expected revenues are simply a firm's posted price, $p(m)$, multiplied by the probability it charges the lowest price, which, in equilibrium, is $(1 - G(m))^{n^*-1}$. Using the fact that $R(m) = p(m)(1 - G(m))^{n^*-1}$, substituting into equation (5), and solving for $p(m)$ yields the equilibrium pricing strategy of a firm with marginal cost m when consumers sample n^* firms:

$$p(m) = m + \int_m^{\overline{m}} \left(\frac{1 - G(t)}{1 - G(m)}\right)^{n^*-1} dt \tag{6}$$

[9] MacMinn also provides a version of the model that is valid for optimal sequential search.

[10] See Klemperer (1999) for a non-technical survey of auction theory including the revenue equivalence theorem. McAfee and McMillan (1988) establishes an equivalence between search and auctions in a mechanism design context.

Notice that, after integration by parts, we can rewrite equation (6) to obtain the familiar formula for equilibrium bidding in reverse first-price auctions

$$p(m) = E\left[m_{\min}^{(n^*-1)} | m_{\min}^{(n^*-1)} \geq m\right] \quad (7)$$

where $m_{\min}^{(n^*-1)}$ is the lowest of $n^* - 1$ draws from the distribution G.

For the special case where G is uniformly distributed, the equilibrium pricing strategy simplifies to

$$p(m) = \frac{n^* - 1}{n^*} m + \frac{1}{n^*} \overline{m}. \quad (8)$$

Notice that the equilibrium pricing strategy gives rise to a distribution of posted prices, $F(p)$, induced by the distribution of costs; that is

$$F(p) = G(p(m))$$

For this to be an equilibrium distribution of prices, it must be optimal for consumers to sample n^* firms. That is,

$$E\left[B^{(n^*+1)}\right] < c \leq E\left[B^{(n^*)}\right]$$

where the expression $E\left[B^{(n)}\right]$, as previously defined in equation (1) when $K = 1$, is the expected benefit from increasing the number of price quotes obtained from $n-1$ to n. As in the Stigler model, a reduction in search costs increases the optimal sample size n^* (so that consumers optimally sample more firms).

Thus, MacMinn shows that, provided search costs are low enough, a dispersed price equilibrium exists. This not only leads to *ex post* differences in consumers' information sets (different consumers sample different firms and so observe different prices), but induces a degree of competition among firms (since they are competing against at least one other firm, whose cost they do not know). As in the Reinganum model, the level of price dispersion depends on the dispersion in firms' costs. For the special case where costs are uniformly distributed, the variance in equilibrium prices $\left(\sigma_p^2\right)$ is given by

$$\sigma_p^2 = \left(\frac{n^* - 1}{n^*}\right)^2 \sigma_m^2 \quad (9)$$

where n^* is the optimal number of searches by consumers and σ_m^2 is the variance in firm's costs.

Two interesting results emerge from the model. First, the variance in prices increases as the variance in firms' marginal costs increases. This result is intuitive. Somewhat counterintuitively, note that as the sample size increases, the variance in equilibrium prices increases. This implies that, taking into account the interaction between consumers and firms in this fixed-sample size search model, dispersion varies inversely with search costs.

Conclusion 2 *In the MacMinn model, a reduction in search costs increases the variance of equilibrium prices.*

This conclusion is in contrast to Conclusion 1, where precisely the opposite implication is obtained in the Reinganum sequential search model. This highlights an important feature of search-theoretic models of price dispersion: Depending on the model, a reduction in search costs may be associated with higher or lower levels of price dispersion. In the Reinganum model, a reduction in search costs reduces the reservation price of consumers and thus induces marginal "high-cost" firms to reduce their prices from their monopoly price to the reservation price. Since the monopoly prices of low-cost firms are below the reservation price, their prices remain unchanged; lower search costs thus reduce the range of prices. In the MacMinn model, lower search costs induce consumers to sample more firms before purchasing—in effect, each firm competes with more rivals. As a consequence, the optimal amount of "bid shading" (pricing above marginal cost) is reduced, thus increasing the level of price dispersion.

2.1.6 The Burdett and Judd Model

Burdett and Judd (1983) were the first to show that equilibrium price dispersion can arise in a search-theoretic model with *ex ante* identical consumers and firms.[11] Burdett and Judd's main result may be seen in the following special case of our environment where:

1. Consumers have unit demand up to a price v;
2. Consumers engage in optimal *fixed sample* search;[12]
3. Each firm has constant marginal cost, m, and would optimally charge all consumers the unique monopoly price, $p^* = v$; and
4. A consumer who is charged the monopoly price earns surplus sufficient to cover the cost of

[11] Janssen and Moraga-González (2004) provide an oligopolistic version of the Burdett and Judd model.

[12] Burdett and Judd also provide a version of the model that is valid under optimal sequential search.

obtaining a single price quote.[13]

In the Burdett and Judd model, an equilibrium consists of a price distribution $F(p)$ (based on optimal pricing decisions by firms) and an optimal search distribution $< \theta_n >_{n=1}^{\infty}$, where $< \theta_n >_{n=1}^{\infty}$ is the distribution of the number of times a consumer searches in the population. Thus, θ_i is the probability that a consumer searches (or alternatively, the fraction of consumers that search) exactly i firms. If $\theta_1 = 1$, then all consumers sample only one firm. If $\theta_1 = 0$, then all consumers sample at least two firms, and so on. Consumers purchase from the firm sampled that offers the lowest price.

We begin by studying optimal search on the part of consumers given a price distribution $F(p)$. Recall that the expected benefit to a consumer who increases her sample size from $n-1$ to n is

$$E\left[B^{(n)}\right] = E\left[p_{\min}^{(n-1)}\right] - E\left[p_{\min}^{(n)}\right]$$

as in the Stigler model. Moreover, the expected benefit schedule is strictly decreasing in n. Thus, an optimal number of price quotes, n, satisfies

$$E\left[B^{(n+1)}\right] < c \leq E\left[B^{(n)}\right]$$

First consider the case where all consumers obtain two or more price quotes; that is, where $\theta_1 = 0$. In this case, the optimal pricing strategy on the part of firms is to price at marginal cost (the Bertrand paradox) since each firm is facing pure price competition with at least one other firm and all firms are identical. Of course, if all firms are pricing at marginal cost, then it would be optimal for a consumer to sample only *one* firm, which contradicts the hypothesis that $\theta_1 = 0$. Thus, we may conclude that, in any equilibrium $\theta_1 > 0$.

Next, consider the case where consumers all obtain exactly one price quote. In that case, each firm would optimally charge the monopoly price, $p^* = v$. Hence, $\theta_1 \neq 1$ in any dispersed price equilibrium.

From these two arguments it follows that, in any dispersed price equilibrium, $\theta_1 \in (0,1)$. In light of the fact that consumers' expected benefits from search are decreasing in the sample size, it

[13] These assumptions are satisfied, for example, when

$$q(p) = \begin{cases} 1 & \text{if} \quad p < v \\ 1 - \frac{p-v}{\kappa} & \text{if} \quad v \leq p \leq v + \kappa \\ 0 & \text{if} \quad p > v + \kappa \end{cases}$$

and $\kappa > c/2$.

follows that a consumer must be indifferent between obtaining one price quote and obtaining two price quotes. That is, in any dispersed price equilibrium

$$E\left[B^{(1)}\right] > E\left[B^{(2)}\right] = c > E\left[B^{(3)}\right] > ... > E\left[B^{(n)}\right].$$

Thus, in any dispersed price equilibrium, $\theta_1, \theta_2 > 0$ while $\theta_i = 0$ for all $i > 2$. Let $\theta_1 = \theta$ and $\theta_2 = 1 - \theta$.

We are now in a position to characterize an atomless dispersed price equilibrium. First, note that since $\theta \in (0, 1)$, there is a positive probability that a firm faces no competition when it sets its price. Thus, if firm i charges the monopoly price, it earns expected profits of

$$E[\pi_i | p_i = v] = (v - m) \times \mu\theta$$

In contrast, a firm choosing some lower price "wins" when its price is below that of the other firm a consumer has sampled. Thus, if firm i charges a price $p_i \leq v$, it earns expected profits of

$$E[\pi_i | p_i \leq v] = (p_i - m) \times \mu (\theta + (1 - \theta)(1 - F(p_i)))$$

Thus, for a given distribution of searches, equilibrium price dispersion requires that the distribution of firm prices, $F(\cdot)$, satisfies

$$\theta + (1 - \theta)(1 - F(p)) = \frac{(v - m)}{(p - m)}\theta$$

or

$$F(p) = 1 - \frac{(v - p)}{(p - m)} \frac{\theta}{1 - \theta} \tag{10}$$

which is a well-behaved atomless cumulative distribution having support $[m + \theta(v - m), v]$.

Finally, it remains to determine an equilibrium value of θ. Since each consumer must be indifferent between searching one or two firms,

$$E\left[B^{(2)}\right] = c$$

Notice that, when $\theta = 0$ or $\theta = 1$, $E\left[B^{(2)}\right] = 0$ while $E\left[B^{(2)}\right] > 0$ for all $\theta \in (0, 1)$. Burdett and Judd show that $E\left[B^{(2)}\right]$ is quasi-concave; thus, when c is sufficiently low, there are generically two dispersed price equilibria—one involving a relatively high fraction of consumers making two searches, the other with a relatively low fraction of consumers.[14]

[14] There is a non-dispersed price equilibrium where all consumers search once and all firms charge the monopoly price.

To summarize, Burdett and Judd show that equilibrium price dispersion can arise even when all firms and consumers are *ex ante* identical. In the equilibrium price distribution, all firms charge positive markups. A fraction θ of consumers do not comparison shop—they simply search at one store and purchase. The remaining fraction of consumers are "shoppers"—these consumers search at two stores and buy from whichever offers the lower price.

2.2 Models with an "Information Clearinghouse"

In search-theoretic models, consumers pay an incremental cost for each additional price quote they obtain. These models are relevant, for example, when consumers must visit or phone traditional sellers in order to gather information about prices. They are also relevant in online environments where consumers must search the websites of individual retailers to gather information about the prices they charge.

An alternative class of models is relevant when a third party — an information clearinghouse — provides a subset of consumers with a list of prices charged by different firms in the market. Examples of this environment include newspapers which display prices different stores charge for the same product or service and online price comparison sites.

In this section we provide a general treatment of clearinghouse models, and show that these models are surprisingly similar to those that arise under fixed sample size search. One of the key modeling differences is that clearinghouse models tend to be oligopoly models; thus, there is not a continuum of firms in such settings.

Where possible, we shall use the same notation as in the previous section; however, for reasons that will become clear when we compare clearinghouse models with the search models presented above, we now let n denote the number of firms in the market. The general treatment that follows relies heavily on Baye and Morgan (2001) and Baye, Morgan and Scholten (2004a).

Consider the following general environment (which we will specialize to cover a variety of different models). There is a finite number, $n > 1$, of price-setting firms competing in a market selling an identical (homogeneous) product. Firms have unlimited capacity to supply this product at a constant marginal cost, m. A continuum of consumers is interested in purchasing the product. This market is served by a price information clearinghouse. Firms must decide what price to charge for the product and whether to list this price at the clearinghouse. Let p_i denote the price charged by firm i. It costs a firm an amount $\phi \geq 0$ if it chooses to list its price. All consumers have unit demand with a maximal willingness to pay of $v > m$.[15] Of these, a mass, $S > 0$, of the consumers are price-sensitive "shoppers." These consumers first consult the clearinghouse and buy at the lowest price listed there provided this price does not exceed v. If no prices are advertised at the clearinghouse or all listed prices exceed v, then a "shopper" visits one of the firms at random and purchases if its price does not exceed v. A mass $L \geq 0$ of consumers per firm purchase from that firm if its price does not exceed v. Otherwise, they do not buy the product at all.

It can be shown that if $L > 0$ or $\phi > 0$, equilibrium price dispersion arises in the general model—provided of course that ϕ is not so large that firms refuse to list prices at the clearinghouse. More precisely,

Proposition 3 *Let $0 \leq \phi < \frac{n-1}{n}(v-m)S$. Then, in a symmetric equilibrium of the general clearinghouse model:*

1. *Each firm lists its price at the clearinghouse with probability*

$$\alpha = 1 - \left(\frac{\frac{n}{n-1}\phi}{(v-m)S}\right)^{\frac{1}{n-1}}.$$

2. *If a firm lists its price at the clearinghouse, it charges a price drawn from the distribution*

$$F(p) = \frac{1}{\alpha}\left(1 - \left(\frac{\frac{n}{n-1}\phi + (v-p)L}{(p-m)S}\right)^{\frac{1}{n-1}}\right) \quad on \ [p_0, v],$$

where

$$p_0 = m + (v-m)\frac{L}{L+S} + \frac{\frac{n}{n-1}}{L+S}\phi.$$

3. *If a firm does not list its price at the clearinghouse, it charges a price equal to v.*

4. *Each firm earns equilibrium expected profits equal to*

$$E\pi = (v-m)L + \frac{1}{n-1}\phi$$

Proof. First, observe that if a firm does not list its price at the clearinghouse, it is a dominant strategy to charge a price of v.

Next, notice that $\alpha \in (0,1]$ whenever

$$\frac{n\phi}{(n-1)(v-m)S} < 1.$$

[15] Baye and Morgan (2001) consider an environment with downward sloping demand.

This condition holds, since $\phi < \frac{n-1}{n}(v-m)S$.

Notice that $p_0 > m$, provided that $L > 0$ or $\phi > 0$. In this case, it can be shown that F is a well-defined, atomless cdf on $[p_0, v]$. When $L = 0$ and $\phi = 0$, notice that $p_0 = m$. In this case, the symmetric equilibrium distribution of prices is degenerate, with all firms pricing at marginal cost (the Bertrand paradox outcome).

Next, we show that, conditional on listing a price, a firm can do no better than pricing according to F. It is obvious that choosing a price above or below the support of F is dominated by choosing a price in the support of F. A firm choosing a price p in the support of F earns expected profits of

$$E\pi(p) = (p-m)\left(L + \left(\sum_{i=0}^{n-1}\binom{n-1}{i}\alpha^i(1-\alpha)^{n-1-i}(1-F(p))^i\right)S\right) - \phi.$$

Using the binomial theorem, we can rewrite this as:

$$\begin{aligned} E\pi(p) &= (p-m)\left(L + \left((1-\alpha F(p))^{n-1}\right)S\right) - \phi \\ &= (v-m)L + \frac{\phi}{n-1}, \end{aligned}$$

where we have substituted for F to obtain the second equality. Since a firm's expected profits are constant on $[p_0, v]$, it follows that the mixed pricing strategy, F, is a best response to the other $n-1$ firms pricing based on F.

When $\phi = 0$, it is a weakly dominant strategy to list. It remains to show that when $\phi > 0$ and $\alpha \in (0,1)$, a firm earns the same expected profits regardless of whether it lists its price. But a firm that does not list earns expected profits of

$$\begin{aligned} E\pi &= (v-m)\left(L + \frac{S}{n}(1-\alpha)^{n-1}\right) \\ &= (v-m)L + \frac{\phi}{n-1}, \end{aligned}$$

which equals the expected profits earned by listing any price $p \in [p_0, v]$. ■

We are now in a position to examine the many well-known clearinghouse models that emerge as special cases of this general environment.

2.2.1 The Rosenthal Model

Rosenthal (1980) was among the first to show that equilibrium price dispersion can arise in a clearinghouse environment when some consumers have a preference for a particular firm. Under his interpretation, each firm enjoys a mass L of "loyal" consumers. Rosenthal's main results may be seen in the following special case of the general clearinghouse model:

1. It is costless for firms to list prices on the clearinghouse: $\phi = 0$ and;

2. Each firm has a positive mass of loyal consumers: $L > 0$.

Since $\phi = 0$, it follows from Proposition 3 that $\alpha = 1$; that is, all of the n firms advertise their prices with probability one. Using this fact and Proposition 3, the equilibrium distribution of prices is

$$F(p) = 1 - \left(\frac{(v-p)}{(p-m)} \frac{L}{S} \right)^{\frac{1}{n-1}} \text{ on } [p_0, v] \tag{11}$$

where

$$p_0 = m + (v - m) \frac{L}{L+S}$$

The price dispersion arising in the Rosenthal model stems from exogenous differences in the preferences of consumers. While shoppers view all products as identical and purchase at the lowest listed price, each firm is endowed with a stock of L loyals. The equilibrium price dispersion arises out of the tension created by these two types of consumers. Firms wish to charge v to extract maximal profits from the loyal segment, but if all firms did so a firm could slightly undercut this price and gain all of the shoppers. One might imagine that this "undercutting" argument would lead to the Bertrand outcome. However, once prices get sufficiently low, a firm is better off simply charging v and giving up on attracting shoppers. Thus, the only equilibrium is in mixed strategies—firms randomize their prices, sometimes pricing relatively low to attract shoppers and other times pricing fairly high to maintain margins on loyals.

It is interesting to examine the equilibrium transactions prices in the market. Loyal customers expect to pay the average price charged by firms:

$$E[p] = \int_{p_0}^{v} p dF(p)$$

while shoppers expect to pay the lowest of n draws from $F(p)$; that is, the expected transaction price paid by shoppers is

$$E\left[p_{\min}^{(n)}\right] = \int_{p_0}^{v} p dF_{\min}^{(n)}(p)$$

where $F_{\min}^{(n)}(p)$ is the cdf associated with the lowest of n draws from F.

How do transactions prices vary with the number of competing firms? Rosenthal's striking result is that, as the number of competing firms increases, the expected transactions prices paid by *all consumers* go up. As we shall see below, the result hinges on Rosenthal's assumption that entry brings more loyals into the market. Indeed, the fraction of shoppers in the market is $S/(S+nL)$ and it may readily be seen that as n becomes large, shoppers account for an increasingly small fraction of the customer base of firms. As a consequence, the incentives to compete for these customers is attenuated and prices rise as a result. The key is to recognize that increases in n change the distribution of prices, and this effect as well as any order statistic effect associated with an increase in n must be taken into account.

Formally, notice that the equilibrium distribution of prices, F, is stochastically ordered in n. That is, the distribution of prices when there are $n+1$ firms competing first-order stochastically dominates the distribution of prices where there are n firms competing. This implies that the transactions prices paid by loyals increase in n. To show that the transactions prices paid by shoppers also increase in n requires a bit more work; however, one can show that the same stochastic ordering obtains for the cdf $F_{\min}^{(n)}(p)$.

Finally, it is useful to note the similarity between the Rosenthal version of the clearinghouse model and the search-theoretic model of Burdett and Judd. In Burdett and Judd, even though there is a continuum of firms, each consumer only samples a finite number of firms (one or two). Further, in Burdett and Judd, a fixed fraction of consumers per firm, $\mu\theta$, sample only a single firm. In effect, these consumers are "loyal" to the single firm sampled while the fraction $(1-\theta)\mu$ of customers sampling two firms are "shoppers"—they choose the lower of the two prices. For this reason, when $n=2$ in the Rosenthal model, the equilibrium price distribution given in equation (11) is *identical* to equation (10) in the Burdett and Judd model (modulo relabeling the variables for loyals and shoppers).

2.2.2 The Varian Model

Varian (1980) was among the first to show that equilibrium price dispersion can arise in a clearinghouse environment when consumers have different *ex ante* information sets.[16] Varian interprets the S consumers as "informed consumers" and the L consumers as "uninformed" consumers. Thus a mass, S, of consumers choose to access the clearinghouse while others, the mass L per firm, do not. Varian's main result may be seen in the following special case of the general clearinghouse model:

1. It is costless for firms to list prices on the clearinghouse: $\phi = 0$; and

[16] Png and Hirshleifer (1987), as well as Baye and Kovenock (1994), extend the Varian model by allowing firms to also engage in price matching or "beat or pay" advertisements.

2. The total measure of "uninformed" consumers lacking access to the clearinghouse is $U > 0$; hence, each firm is visited by $L = \frac{U}{n}$ of these consumers.

Again, since $\phi = 0$, it follows that $\alpha = 1$ and hence all n firms advertise their prices at the clearinghouse. Using this fact and setting $L = U/n$ in Proposition 3, the equilibrium distribution of prices is

$$F(p) = 1 - \left(\frac{(v-p)}{(p-m)} \frac{\frac{U}{n}}{S} \right)^{\frac{1}{n-1}} \text{ on } [p_0, v]$$

where

$$p_0 = m + (v-m) \frac{\frac{U}{n}}{\frac{U}{n} + S}$$

The fact that this atomless distribution of prices exists whenever there is an exogenous fraction of consumers who do not utilize the clearinghouse raises the obvious question: Can this equilibrium persist when consumers are making optimal decisions? Varian shows that the answer to this question is yes — provided different consumers have different costs of accessing the clearinghouse. The easiest way to see this is to note that the value of information provided by the clearinghouse is the difference in the expected price paid by those accessing the clearinghouse, $E\left[p_{\min}^{(n)}\right]$, and those not, $E[p]$; that is;

$$VOI^{(n)} = E[p] - E\left[p_{\min}^{(n)}\right] \tag{12}$$

where VOI denotes the value of (price) information contained at the clearinghouse. Suppose consumers face a cost of accessing the information provided by the clearinghouse. Note that this cost is essentially a fixed cost of gaining access to the entire list of prices, not a per price cost as in the search-theoretic models considered above. Varian assumes that the cost to type S and L consumers of accessing the clearinghouse is κ_S and κ_L, with $\kappa_S < \kappa_L$. Then provided $\kappa_S \leq VOI^{(n)} < \kappa_L$ type S consumers will optimally utilize the clearinghouse while the type L consumers will not. In short, if different consumers have different costs of accessing the clearinghouse, there exists an equilibrium of price dispersion with optimizing consumers and firms. In such an equilibrium, informed consumers pay lower average prices than uninformed consumers.

It is important to emphasize that, when one endogenizes consumers' decisions to become informed in the Varian model, the level of price dispersion is not a monotonic function of consumers' information costs. When information costs are sufficiently high, no consumers choose to become informed, and all firms charge the "monopoly price," v. When consumers' information costs are zero, all consumers choose to become informed, and all firms price at marginal cost in a symmetric equilibrium—the Bertrand paradox. Thus, for sufficiently high or low information costs, there is no price dispersion; for moderate information costs, prices are dispersed on the nondegenerate interval $[p_0, v]$. A similar result obtains in Stahl (1989), which is related to Varian as follows. Stahl assumes a fraction of consumers have zero search costs and, as a consequence, view all firms' prices and purchase at the lowest price in the market. These consumers play the role of S in Varian's model (informed consumers). The remaining fraction of consumers correspond to the L's in the Varian model, but rather than remaining entirely uninformed, these consumers engage in optimal sequential search in presence of positive incremental search costs. Stahl shows that when all consumers are shoppers, the identical firms price at marginal cost and there is no price dispersion. When no consumers are shoppers, Diamond's paradox obtains and all firms charge the monopoly price. As the fraction of shoppers varies from zero to one, the level of dispersion varies continuously—from zero to positive levels, and back down to zero.

Conclusion 3 *In general, price dispersion is not a monotonic function of consumers' information costs or the fraction of "shoppers" in the market.*

How does the number of competing firms affect transactions prices? In the Rosenthal model, we saw that increased "competition" led to higher expected transactions prices for all consumers. In the Varian model, in contrast, the effect of competition on consumer welfare depends on whether or not the consumer chooses to access the clearinghouse. Morgan, Orzen, and Sefton (forthcoming) show that as n increases, the competitive effect predictably leads to lower average transaction prices being paid by informed consumers. However, the opposite is true for uninformed consumers—as the number of competing firms increases, firms face reduced incentives to cut prices in hopes of attracting the "shoppers" and, as a consequence, the average price charged by a firm, which is also the average price paid by an uninformed consumer, increases. If one views the clearinghouse as representing access to price information on the Internet, then one can interpret the price effect as one consequence of the so-called "digital divide;" see Baye, Morgan, and Scholten (2003). Consumers with Internet access are made better off by sharper online competition while those without such access are made worse off.

2.2.3 The Baye and Morgan Model

All of the above models assume that it is costless for firms to advertise their prices at the clearinghouse. Baye and Morgan (2001) point out that, in practice, it is generally costly for firms to advertise their prices and for consumers to gain access to the list of prices posted at the clearinghouse. For example, newspapers charge firms fees to advertise their prices and may choose to charge consumers subscription fees to access any posted information. The same is true of many online environments. Moreover, the clearinghouse is itself an economic agent, and presumably has an incentive to endogenously choose advertising and subscription fees to maximize its own expected profits. Thus, Baye and Morgan examine the existence of dispersed price equilibria in an environment with optimizing consumers, firms, and a monopoly "gatekeeper" who controls access to the clearinghouse.

Specifically, Baye and Morgan consider a homogeneous product environment where n identical, but geographically distinct, markets are each served by a (single) local firm. Distance or other transaction costs create barriers sufficient to preclude consumers in one market from buying this product in another market; thus each firm in a local market is a monopolist. Now imagine that an entrepreneur creates a clearinghouse to serve all markets. In the Internet age, one can view the clearinghouse as a virtual marketplace – through its creation, the gatekeeper expands both consumers' and firms' opportunities for commerce. Each local firm now has the option to pay the gatekeeper an amount ϕ to post a price on the clearinghouse in order to gain access to geographically disparate consumers. Each consumer now has the option to pay the gatekeeper an amount κ to shop at the clearinghouse and thereby purchase from firms outside the local market.

The monopoly gatekeeper first sets κ and ϕ to maximize its own expected profits. Given these fees, profit maximizing firms make pricing decisions and determine whether or not to advertise them at the clearinghouse. Similarly, consumers optimally decide whether to pay κ to access the clearinghouse. Following this, a consumer can simply click her mouse to research prices at the clearinghouse (if she is a subscriber), visit the local firm, or both. With this information in hand, a consumer decides whether and from whom to purchase the good.

Baye and Morgan show that the gatekeeper maximizes its expected profits by setting κ sufficiently low that all consumers subscribe, and charging firms strictly positive fees to advertise their prices. Thus, Baye and Morgan's main results may be seen in the following special case of the general clearinghouse model:

1. The gatekeeper optimally sets positive advertising fees: $\phi > 0$ and;

2. The gatekeeper optimally sets subscription fees sufficiently low such that all consumers access the clearinghouse; that is, $L = 0$.

Under these conditions, using Proposition 3, we obtain the following characterization of equilibrium firm pricing and listing decisions: Each firm lists its price at the clearinghouse with probability

$$\alpha = 1 - \left(\frac{\frac{n}{n-1}\phi}{(v-m)\,S} \right)^{\frac{1}{n-1}} \in (0,1)$$

When a firm lists at the clearinghouse, it charges a price drawn from the distribution

$$F(p) = \frac{1}{\alpha} \left(1 - \left(\frac{\frac{n}{n-1}\phi}{(p-m)\,S} \right)^{\frac{1}{n-1}} \right) \text{ on } [p_0, v],$$

where

$$p_0 = m + \frac{\frac{n}{n-1}\phi}{S}.$$

When a firm does not list its price, it charges a price equal to v, and each firm earns equilibrium expected profits equal to

$$E\pi = \frac{1}{n-1}\phi$$

Notice that $n\alpha$ represents the aggregate demand by firms for advertising and is a decreasing function of the fee charged by the gatekeeper. Prices advertised at the clearinghouse are dispersed and strictly lower than unadvertised prices (v).

Several features of this equilibrium are worth noting. First, equilibrium price dispersion arises with fully optimizing consumers, firms, and endogenous fee-setting decisions on the part of the clearinghouse – despite the fact that there are no consumer or firm heterogeneities and all consumers are "fully informed" in the sense that, in equilibrium, they always purchase from a firm charging the lowest price in the *global* market. Second, while equilibrium price dispersion in the Varian model is driven by the fact that different consumers have different costs of accessing the clearinghouse, Baye and Morgan show that an optimizing clearinghouse will set its fees sufficiently low that all consumers will rationally access the clearinghouse. Equilibrium price dispersion arises because of the gatekeeper's incentives to set strictly positive advertising fees. Strikingly, despite the fact that all consumers use the gatekeeper's site and thus purchase at the lowest global price, firms still earn positive profits in equilibrium. In expectation, these profits are proportional to the cost, ϕ, of accessing the clearinghouse.

Conclusion 4 *In the Baye and Morgan model, equilibrium price dispersion persists even when it is costless for all consumers to access the information posted at the gatekeeper's site. Indeed, price dispersion exists because it is costly for firms to transmit price information (advertise prices) at the gatekeeper's site.*

Why does the gatekeeper find it optimal to set low (possibly zero) fees for consumers wishing to access information, but strictly positive fees to firms who wish to transmit price information? Baye and Morgan point out that this result stems from a "free rider" problem on the consumer side of the market that is not present on the firm side. Recall that the gatekeeper can only extract rents equal to the value of the outside option of firms and consumers. For each side of the market, the outside option consists of the surplus obtainable by not utilizing the clearinghouse. As more consumers access the site, the number of consumers still shopping locally dwindles and the outside option for firms is eroded. In contrast, as more firms utilize the clearinghouse, vigorous price competition among these firms reduces listed prices and leads to a more valuable outside option to consumers *not* using the clearinghouse. Thus, to maximize profits, the gatekeeper optimally subsidizes consumers to overcome this "free rider problem" while capturing rents from the firm side of the market. No analogous "free rider problem" arises on the firm side; indeed greater consumer participation at the clearinghouse increases the frequency with which firms participate (α increases) and hence permits *greater* rent extraction from firms.

2.2.4 Models with Asymmetric Consumers

In general, little is known about the general clearinghouse model with asymmetric consumers.[17] However, for the special case of two firms, results are available. Here we show how one can adapt the general clearinghouse model to account for asymmetries in duopoly markets.

Suppose there are two firms ($i = 1, 2$) competing in the market. A mass L_1 of customers are loyal to firm 1 while L_2 customers are loyal to firm 2 where $L_1 \geq L_2$.

Proposition 4 *Let $0 \leq \phi < \frac{1}{2}(v - m) S$. Then, in an asymmetric dispersed price equilibrium:*

1. *Each firm lists its price at the clearinghouse with probability*

$$\alpha = 1 - \frac{2\phi}{S(v - m)}.$$

2. *If a firm lists its price at the clearinghouse, it charges a price drawn from the distribution*

$$F_i(p) = \frac{1}{\alpha}\left[1 - \left(\frac{2\phi + (v - p) L_j}{(p - m) S}\right)\right] \quad on \quad [p_{0,1}, v],$$

where

$$p_{0,1} = m + (v - m)\frac{L_1}{L_1 + S} + \frac{2}{L_1 + S}\phi.$$

[17] For specific clearinghouse models, some results are available. For instance, Baye, Kovenock, and de Vries (1992) characterize all equilibria in a version of the Varian model in which firms have asymmetric numbers of consumers.

3. If a firm does not list its price at the clearinghouse, it charges a price equal to v.

4. Firm i earns equilibrium expected profits equal to

$$E\pi_i = (v - m)\,L_i + \phi$$

Proof. Let $A_i \in \{0, 1\}$ denote an indicator variable for whether firm i advertises its price at the clearinghouse. Let α_i denote the probability that $A_i = 1$. Thus, firm i's expected profits from each of the two listing decisions given the strategy (α_j, F_j) of its rival are

$$E[\pi_i(p|A_i = 0)] = (L_i + (1 - \alpha_j)\frac{S}{2})(p - m)$$

and

$$E[\pi_i(p|A_i = 1)] = (L_i + S\,(1 - \alpha_j F_j\,(p)))\,(p - m) - \phi$$

From the first equation, it is clear that the dominant strategy of a firm not listing its price is to charge the monopoly price, v. Furthermore, $\alpha_i \in (0, 1)$ requires that

$$E[\pi_i(v|A_i = 0)] = E[\pi_i(p|A_i = 1)] \tag{13}$$

for p in the support of F_i. Suppose that the monopoly price, v, is the upper bound of the support of prices. In this case, the above equality reduces to:

$$(L_i + (1 - \alpha_j)\frac{S}{2})(v - m) = (L_i + S(1 - \alpha_j))(v - m) - \phi$$

The unique solution to this equation is $\alpha_1 = \alpha_2 = \alpha$, where α is defined in Proposition 4.

Let $p_{0,i}$ denote the price such that, if firm i charged the lowest price in the market and attracted all shoppers, its expected profits at price $p_{0,i}$ would exactly equal the profits gained by simply pricing at v. This price satisfies

$$(L_i + (1 - \alpha)\frac{S}{2})(v - m) = (L_i + S)\,(p_{0,i} - m) - \phi$$

Substituting for α and solving yields

$$p_{0,i} = m + \frac{L_i(v - m) + 2\phi}{L_i + S}$$

Notice that $p_{0,1} > p_{0,2}$; that is, the lowest "sale" price offered to attract shoppers is higher for the large firm than for the small firm. Since equilibrium price distributions must have identical supports, it follows that $F_i\,(p)$ has support $[p_{0,1}, v]$ for all i. Finally, substituting the expression for α into equation (13) and solving for F_j, one obtains the expression for the distributions of advertised prices given in the proposition. It is straightforward to verify that this is a well-defined cdf on $[p_{0,1}, v]$, and that neither firm can gain by charging a price $p_i \notin [p_{0,1}, v]$. ■

There are several noteworthy features of the equilibrium pricing and advertising strategies given in Proposition 4. First, when $\phi = 0$, both firms advertise prices on the clearinghouse with probability one. Narasimhan (1988) analyzes duopoly competition where firms have an asymmetric number of loyal customers under the assumption that both firms list prices at the clearinghouse with certainty. The model presented above thus takes the main part of Narasimhan's analysis as a special case.

When $\phi > 0$, it is interesting to note that the propensity to advertise is less than unity and, more surprisingly, it is exactly the *same* for both firms. Thus, asymmetries in the customer base of firms need not lead to asymmetries in firm propensities to advertise. In contrast, the firms' distributions of advertised prices do depend on their customer bases. Comparing the distributions of prices for the two firms, one finds that:

$$F_1(p) - F_2(p) = \frac{1}{\alpha} \frac{v - p}{(p - m) S} [L_1 - L_2] > 0$$

That is, the firm with fewer loyals is actually less aggressive in its pricing strategy than the firm with more loyals. The larger the asymmetry in loyals, the larger the difference in the average prices charged by the two firms—but in an unexpected direction. Indeed, the firm with more loyals (firm 1) offers the lowest price, $p_{0,1}$ in the market with strictly positive probability.[18]

As in Baye and Morgan (2001), one may endogenize the advertising fee by allowing a profit-maximizing gatekeeper to determine the level of ϕ that maximizes its expected profits.[19] For example, if the only costs are fixed costs (FC), the expected profits of the clearinghouse are simply its expected advertising revenues minus costs:

$$\begin{aligned} E[\Pi] &= 2\alpha\phi - FC \\ &= 2\left(1 - \frac{2\phi}{S(v-m)}\right)\phi - FC \end{aligned}$$

Equating the gatekeeper's expected marginal profits to zero and solving for the optimal advertising fee yields

$$\phi^* = \frac{S(v-m)}{4} \tag{14}$$

[18] Since firm 2's distribution is atomless, a tie at price $p_{0,1}$ is a zero probability event.

[19] For simplicity, we assume the clearinghouse must set the fee charged to consumers for access at $\kappa = 0$ to induce them all to participate. This is typically the case, for example, at online price comparison sites.

Equation (14) shows that the gatekeeper optimally charges a fee to firms advertising prices that is proportional to the consumer traffic (S) on its site. This fee induces equilibrium price dispersion; indeed, as first noted by Baye and Morgan, price dispersion is necessary in order for the gatekeeper to profitably maintain a clearinghouse.

2.2.5 Cost Heterogeneities and the Spulber Model

Spulber (1995) considers a situation where consumers have access to the complete list of prices and buy from the firm offering the lowest price. Of course, in such a setting, if firms were identical one would immediately obtain the Bertrand outcome. To generate price dispersion, Spulber examines the situation where firms have heterogeneous costs and consumers have downward sloping demand. However, the main economic intuition underlying the model may be seen through the following adaptation of our general clearinghouse framework for the unit demand case:

1. All consumers are shoppers: $S > 0$ and $L = 0$;
2. There is no cost to advertise prices on the clearinghouse: $\phi = 0$; and
3. Firms have privately observed marginal costs described by the atomless distribution $G(m)$ on $[\underline{m}, \overline{m}]$.

Since there are no costs to advertise prices, all firms list prices on the clearinghouse. Each firm faces competition from $n-1$ other firms with random marginal costs. Since the firm charging the lowest price wins the entire market, firms are effectively competing in an auction in which their own costs are private information. For the special case of unit demand, the equilibrium price for a firm is again the familiar expression from a first-price auction:

$$p(m) = E\left[m_{\min}^{(n-1)} | m_{\min}^{(n-1)} \geq m\right] \tag{15}$$

where $m_{\min}^{(n-1)}$ is the lowest of $n-1$ draws from the distribution G.

There are several noteworthy features of this equilibrium. First, equilibrium firm pricing entails positive markups despite the fact that all consumers are "shoppers" and have a complete list of prices. Intuitively, there is a trade-off between lowering one's price to attract shoppers and the profitability of this price. In equilibrium, this results in a markup which depends on the number of competing firms. As the number of firms grows large, the equilibrium markup becomes small. Second, notice that cost heterogeneity leads to equilibrium price dispersion despite the fact consumers are identical and all consumers are purchasing at the lowest price.

It is interesting to compare the Spulber model, which occurs in the clearinghouse framework, with the search-theoretic framework of MacMinn. Notice that, when the number of competing firms in Spulber, n, is equal to the optimal fixed sample size for consumers in the MacMinn model, n^*, the equilibrium distribution of prices, equations (15) and (7), are identical in the two models. That is, cost heterogeneities are sufficient to generate price dispersion in oligopoly models where all consumers obtain complete price information, as well as in models where a continuum of firms compete but each consumer only obtains price quotes from a finite number n of these firms.

2.3 Bounded Rationality Models of Price Dispersion

Several recent papers have emphasized that bounded rationality can also lead to price dispersion. The idea is to relax the Nash equilibrium assumption – which requires that each decision maker in the market is choosing an action (be it a price or a search strategy) that is a best response to given actions of other market participants. Two equilibrium concepts – quantal response equilibrium (McKelvey and Palfrey, 1995) and epsilon equilibrium (Radner, 1980)– are particularly useful because they nest the standard Nash equilibrium concept as a special case.

In a quantal response equilibrium (QRE), the likelihood that a particular firm sets a specific price depends on the expected profits arising from that price (see Lopez-Acevedo, 1997). A firm's price is determined by a stochastic decision rule, but prices leading to higher expected profits are more likely to be charged. Of course, each firm's expected profits from different pricing decisions depend on the probability distributions of other players' prices. A QRE requires that all firms hold correct beliefs about the probability distributions of other players' actions. The nondegenerate distributions of prices resulting in a QRE may be viewed as shocks to firms' profit functions. Alternatively, nondegenerate price distributions might stem from decision errors by firms. Such errors may arise from limitations in managers' cognitive processing abilities or "bugs" in dynamic pricing algorithms used by Internet retailers.

In an ε-equilibrium, the prices charged by each firm are such that no firm can gain more than ε in additional profits by changing its price. Such an equilibrium may arise because of cognitive or motivational constraints on the part of firms. For example, if it is costly to reprogram dynamic pricing algorithms, managers may not be willing to incur these economic or psychic costs when the resulting gain is small (less than ε).

Recently, Baye and Morgan (2004) applied QRE and ε-equilibrium concepts to pricing games and showed that only a little bounded rationality is needed to generate the patterns of price dispersion documented in laboratory experiments as well as observed on Internet price comparison sites. In a similar vein, Rauh (2001) shows that price dispersion can arise when market participants make small but heterogeneous mistakes in their beliefs about the distribution of prices. Ellison (2005) provides a more detailed treatment of recent advances along these lines.

2.4 Concluding Remarks: Theory

Despite a slow start, there are now a variety of models that can be used to rationalize equilibrium price dispersion in online and offline markets. We conclude our theoretical discussion with the following general observations:

1. There is not a "one-size-fits-all" model of equilibrium price dispersion; different models are appropriate for analyzing different market environments. For instance, search-theoretic models are most appropriate for analyzing environments where consumers must visit different stores or firms' websites to gather price information. Clearinghouse models are appropriate when consumers are able to access a list of prices (for example, in a newspaper or at a price comparison site).

2. The distribution of prices is determined by the interaction of all market participants—firms, consumers and, in the case of clearinghouse models, information gatekeepers. As a consequence, the level of price dispersion depends on the structure of the market – the number of sellers, the distribution of costs, consumers' elasticities of demand, and so on.

3. Reductions in search costs may lead to either more or less price dispersion, depending on the market environment. Furthermore, the elimination of consumer search costs need not eliminate price dispersion.

4. Depending on the market environment, heightened competition (increases in the number of firms) can increase or decrease the level of dispersion. Moreover, in some models, heightened competition of this form leads to higher transactions prices paid by all consumers. In other models, the effect of increased competition on the welfare of consumers depends on which side of the "digital divide" a consumer resides.

5. Price dispersion is not purely an artifact of *ex ante* heterogeneities in firms or consumers. While differences in firms' costs or base of loyal consumers (stemming from firms' brand-

ing efforts, differential service qualities, or reputations) can contribute to equilibrium price dispersion, such differences are not necessary for equilibrium price dispersion.

6. Thanks to the Internet, information gatekeepers are playing an increasingly important role in the economy. In their attempt to maximize profits and enhance the value of information provided by their sites, information gatekeepers have an incentive to charge fees for their services that induce equilibrium price dispersion.

7. A little bounded rationality goes a long way in explaining price dispersion.

3 Empirical Analysis of Price Dispersion

We now turn to the empirical literature on price dispersion. In Section 3.1, we discuss some of the strengths and weaknesses of commonly used metrics for measuring price dispersion in online and offline markets. Section 3.2 provides an overview of the empirical literature, and highlights empirical evidence suggesting that information costs (either on the consumer or firm side of the market) contribute to price dispersion; that is, dispersion is not purely an artifact of subtle product heterogeneities.

3.1 Measuring Price Dispersion

The equilibrium models of price dispersion presented above each imply non-degenerate distributions of prices, $F(p)$, on some interval $\left[\underline{p}, \overline{p}\right]$. Given such a distribution, a standard measure of dispersion is the variance in prices. For each model of equilibrium price dispersion, this measure can be directly computed. For instance, in the MacMinn model, if firms have uniformly distributed marginal costs, the variance in prices is

$$\sigma_p^2 = \left(\frac{n^* - 1}{n^*}\right)^2 \frac{(\overline{m} - \underline{m})^2}{12}$$

Notice that one is then in a position to test comparative static predictions of the model using this measure. In a similar manner, expressions for the variance in prices may be derived from the other models previously presented.

A number of authors use the sample variance to measure price dispersion (e.g., Pratt, Wise, and Zeckhauser (1979) and Ancarani and Shankar (2004)). The obvious advantage is that it uses all available data. A drawback of this measure is apparent when comparing dispersion across products or over time. For instance, suppose that, during an inflationary period, the marginal costs of all firms in the MacMinn model increased by a factor $\gamma > 1$. In that case, the new variance would simply scale up the original variance by a factor γ^2. Thus, this measure of price dispersion would change even though the underlying real economics of the situation are the same after the inflationary period.

For this reason, if one wishes to compare levels of price dispersion either across different products or across time, one must standardize the data in some fashion. An alternative is to use the coefficient of variation, $CV = \sigma_p / E[p]$ (or its sample analogue), which is homogenous of degree zero in the level of prices. The CV is particularly useful when comparing levels of price dispersion over long periods of time (e.g., Scholten and Smith (2002) and Eckard (2004)) or across different products (e.g., Carlson and Pescatrice (1980); Sorensen (2000); Aalto-Setälä (2003); and Baye, Morgan and Scholten (2004a,b)). An added advantage is that, unlike some methods of standardization, the coefficient of variation may preserve the comparative static predictions of the model of interest. For instance, in the MacMinn model, equation (8) implies that the expected price is $E[p] = \frac{n^*-1}{n^*}\left(\frac{\overline{m}+\underline{m}}{2}\right) + \frac{\overline{m}}{n^*}$, and thus the coefficient of variation is

$$CV = \frac{1}{\sqrt{3}} \frac{(n^*-1)(\overline{m}-\underline{m})}{(n^*-1)(\overline{m}+\underline{m}) + 2\overline{m}}$$

One may verify that this statistic is, like the variance, decreasing in search costs, but, unlike the variance, this statistic does not change with a multiplicative shift in firms' costs.

Another widely used measure of price dispersion is the (sample) range; see, for instance, Pratt, Wise, and Zeckhauser (1979) and Brynjolfsson and Smith (2000). Letting $p_{\min}^{(n)}$ and $p_{\max}^{(n)}$ denote, respectively, the lowest and highest of n observed prices drawn from F, then the range is

$$R^{(n)} = p_{\max}^{(n)} - p_{\min}^{(n)}$$

Given the equilibrium distribution of prices implied by a particular theoretical model, comparative static predictions about changes in the range are possible based on the behavior of the highest and lowest order statistics. That is, one can perform comparative static analysis on the expected range:[20]

$$E\left[R^{(n)}\right] = E\left[p_{\max}^{(n)}\right] - E\left[p_{\min}^{(n)}\right]$$

Unfortunately, all of the above measures of price dispersion suffer from a potential theoretical defect. Suppose that $n > 2$ firms compete in a classical homogeneous product Bertrand setting.

[20] To facilitate comparisons across different products or over time, it is sometimes useful to normalize the range by dividing it by the minimum or average price; see Baye, Morgan, and Scholten (2004b) and Brynjolfsson and Smith (2000).

Under standard conditions there will exist a unique symmetric equilibrium where all firms price at marginal cost. But in addition, there are asymmetric equilibria where two firms price at marginal cost and the remaining $n-2$ firms price strictly above marginal cost. Thus, price dispersion can arise in a classical Bertrand environment. Yet, the apparent price dispersion is arguably not economically relevant because the unique transactions price is marginal cost.

To remedy this theoretical defect, Baye, Morgan and Scholten (2004a) propose a measure called "the gap," which they define to be the difference between the two lowest prices in the market. Letting $p_2^{(n)}$ denote the second lowest price realization from n draws from F, the (sample) gap is defined as[21]

$$G^{(n)} = p_2^{(n)} - p_{\min}^{(n)}$$

The classical Bertrand model (as well as textbook models of perfect competition) implies that the gap between the two lowest prices is zero in any equilibrium (symmetric or otherwise). All of the oligopoly models of price dispersion discussed above, in contrast, imply a positive gap. An additional property of the gap is that it gives greater weight to low prices, which, in the absence of quantity data, one might reasonably assume lead to more sales than higher prices. The key disadvantage, shared by the range, is that it relies purely on extreme values of the data. Hence, the range and gap are more sensitive to outliers and other forms of "noise" than measures that use all the available data, such as the sample variance and coefficient of variation.

In addition to these measures, the value of information (VOI) defined earlier in equation (12) can also be used as a gauge of dispersion. This measure, which is simply the difference between the average observed price and the lowest observed price, is zero in the absence of any price dispersion but otherwise positive. The principal advantage of this measure of dispersion is that it has a very intuitive interpretation: Its value indicates the amount of money a consumer saves by purchasing at the best price rather than from a randomly selected firm in the market.

3.2 Price Dispersion in the Field

If price dispersion stems from frictions related to the acquisition and transmission of information (as implied by the models in Section 2) rather than subtle differences in firms' service levels, observed levels of dispersion should systematically depend on "environmental factors" present in the models.

[21] As with the range, one can perform comparative static analyses for any of the theoretical models using the expected gap, and it is sometimes useful to normalize the gap by dividing by the lowest price. In this formulation, the gap represents the difference between the two lowest prices expressed as a percentage of the lowest price realization.

For example, in his seminal article on the economics of information, George Stigler, advanced the following hypotheses:

> "...dispersion itself is a function of the average amount of search, and this in turn is a function of the nature of the commodity:
>
> 1. The larger the fraction of the buyer's expenditures on the commodity, the greater the savings from search and hence the greater the amount of search.
>
> 2. The larger the fraction of repetitive (experienced) buyers in the market, the greater the effective amount of search (with positive correlation of successive prices).
>
> 3. The larger the fraction of repetitive sellers, the higher the correlation between successive prices, and hence, the larger the amount of accumulated search.
>
> 4. The cost of search will be larger, the larger the geographic size of the market." Stigler (1961, p. 219).

Stigler's hypotheses offer a useful guide for understanding the empirical literature on price dispersion. Much of this literature tests Stigler's hypotheses by examining whether search intensity (proxied by variables that affect the benefits and costs of search) is correlated with levels of price dispersion. As we have seen, however, when one takes Rothschild's criticism into account, an increase in search intensity can lead to increases or decreases in the level of equilibrium price dispersion, depending on the model. Thus, one challenge for empirical researchers is choosing a model that closely approximates the "data generating" environment. A second challenge is to control for factors outside of the model that might influence levels of dispersion. A third challenge arises because firm optimization is absent in Stigler's model, but is clearly present in the data. For this reason, a number of empirical studies look beyond Stigler's hypotheses to test hypotheses derived from specific search-theoretic or clearinghouse models of equilibrium price dispersion. We provide a broad overview of these and related strands of the literature below.

3.2.1 Dispersion and the "Benefits" of Search

The search-theoretic models presented in Section 2 imply that search intensity depends, in part, on the consumer's demand for a product. In the Stigler model, demand is represented by the parameter, K. The greater is K, the greater the expected benefits of search and hence the greater the search intensity. Stigler's first two hypotheses are based on the notion that the share of an item in a consumer's overall budget, and the frequency with which an item is purchased, are good proxies for K.

Dispersion for "Cheap" versus "Expensive" Items

Stigler (1961) provides casual evidence in support of his first hypothesis—that dispersion is lower for items that account for a large expenditure share of a searcher's consumption bundle ("expensive items") than those that account for a smaller expenditure share ("cheap items"). Government coal purchases are a small percentage of the overall government budget, while a household's expenditures on an automobile comprise (in 1961 as well as today) a much larger percentage of its overall budget. Stigler obtained different sellers' prices for two homogeneous products —anthracite-grade coal to be sold to the government, and an automobile to be sold to a household. Prices for anthracite coal ranged from \$15.46 to \$18.92, with an average price of \$16.90 and a standard deviation of \$1.15. Prices for the automobile (based on what Stigler called "an average amount of higgling") ranged from \$2,350 to \$2,515, with an average price of \$2,436 and standard deviation of \$42. Stigler's data thus tend to support his first conjecture: If one calculates the implied coefficient of variation based on Stigler's figures, the coefficient of variation for coal (which makes up a small percentage of the government's budget) is 14.7 percent, while that for an automobile (which makes up a large percentage of a household's budget) is 1.7 percent.

Pratt, Wise and Zeckhauser (1979) observe a similar pattern in a cross-section of consumer products sold in Boston in the 1970s. They obtain the following regression result regressing the sample (log) standard deviation of prices for a given item on the sample (log) mean price for the same item.

$$\ln \sigma = -1.517 + 0.892 \ln E[p] \tag{16}$$

Straightforward manipulation of equation (16) reveals that a 1 percent increase in the mean price of an item decreases the coefficient of variation by 10.8 percent. Thus, the Pratt, Wise, and Zeckhauser data also suggest that, empirically, the coefficient of variation is lower for more expensive items than cheaper items. However, equation (16) also highlights that the relationship depends crucially on the measure of price dispersion used: If one were to use the standard deviation to measure price dispersion, equation (16) implies that a one percent increase in the mean price of a product leads to a 0.892 percent *increase* in dispersion, as measured by the standard deviation.

A number of other authors have reported similar patterns in online and offline markets, both in the US and in Europe for products ranging from consumer sundries, electronic products, and gasoline; cf. Marvel (1976), Carlson and Pescatrice (1980), Clay and Tay (2001), Scholten and

Smith (2002), Johnson (2002), Gatti and Kattuman (2003), and Aalto-Setälä (2003). More recently, Eckard (2004) compares price dispersion for staple products in 1901 and 2001, and reports coefficients of variation in 2001 that are almost twice those based on data from 1901. Eckard argues that one reason for the increased dispersion is that his sample consists of staple items (such as sugar and baking powder) that accounted for a much larger share of household budgets in 1901 than in 2001.

Dispersion and Purchase Frequency

In his second hypothesis, Stigler argues that in markets where there are more repetitive or experienced buyers, the greater is the amount of effective search. Unfortunately, it is difficult to directly test this hypotheses, since in most markets there is not a direct (objective) measure of "buyer experience" or "purchase frequency" to use in examining its impact on levels of price dispersion. A number of the studies mentioned above, however, provide casual evidence that purchase frequency impacts the level of price dispersion (cf. Carlson and Pescatrice, 1980; Pratt, Wise, and Zeckhauser, 1979).

Sorensen (2000), however, has provided a very "clean" and elegant test of Stigler's second hypothesis. His analysis is based on data from the market for prescription drugs. The unique aspect of this market is that purchase frequency—the typical dosage and duration of therapy for a given prescription drug—may be objectively measured. A consumers' benefit per search is clearly highest for frequently purchased drugs, and, Sorensen argues, this should lead to greater search and lower price dispersion. His empirical analysis identifies a strong inverse relationship between purchase frequency and price dispersion. For example, after controlling other factors (which together explain about one-third of the variation in prices), Sorensen finds that the price range for a drug that must be purchased monthly is about 30 percent lower than if it were a one-time therapy. Importantly, Sorensen shows that the results are qualitatively similar when alternative measures of price dispersion (such as the standard deviation) are used.

3.2.2 Dispersion and the "Cost" of Search

Researchers studying the empirical relationship between search costs and price dispersion have faced obstacles similar to those of researchers focusing on the benefit side of the search equation. First, the predicted impact of search costs on levels of dispersion depends not only on the model, but also on the metric used for measuring dispersion. Second, search costs are generally unobservable. Some of the more influential papers in the area are ones that have devised innovative methods of dealing with these problems.

One important example is Brown and Goolsbee (2002). Their starting point is the Stahl (1989) model of equilibrium price dispersion, which as we noted in Section 2, predicts that price dispersion is initially an increasing function of the fraction of "shoppers" who enjoy zero search costs, but after a threshold, is a decreasing function of the fraction of shoppers. Brown and Goolsbee point out that the Stahl model closely matches the market for term-life insurance during the 1992-1997 period. Consumers who did not have an Internet connection arguably had to search sequentially to obtain price quotes from different insurance agents, while those with Internet access could use websites such as Quickquote.com to "costlessly" identify the company offering the lowest annual premium. In their data, variation in the fraction of "shoppers" (those who research insurance online) stems not only from the general rise in Internet penetration during the 1990s, but more importantly, from variation in the growth rates in Internet usage across different groups of policyholders. Brown and Goolsbee regress the standard deviation in residuals (obtained from a price regression that controls for observable characteristics of people and policy types) on a cubic function of their proxy for the fraction of "shoppers." Consistent with the prediction of the Stahl model, price dispersion initially rises as the fraction of shoppers increases, but starts to decline once the fraction of consumers researching insurance online exceeds about 5 percent.

A similar approach is implicit in a number of papers that have compared levels of dispersion in online versus offline markets (cf. Brynjolfsson and Smith, 2000; Carlton and Chevalier, 2001; Ancarani and Shankar, 2004; and Scholten and Smith, 2002.) The basic premise is that search costs are lower in online (search entails clicks) versus offline markets (search entails travel costs).[22] In general, since different search models make different predictions about the impact of reductions in search costs on levels of price dispersion, it is not too surprising that the findings of this literature are decidedly mixed; for some products, dispersion is lower in online markets; for other products, dispersion is actually higher online.[23]

[22]The view that online search is either more prevalent or cheaper than offline search is a matter of some debate; see, for instance, Adamic and Huberman (2001), Johnson, Moe, Fader, Bellman, and Lohse (2004). Bakos (1997) was among the first to advance a theoretical argument that when the cost of price information is close to zero, equilibrium price is close to marginal cost. More recently, however, Harrington (2001) has argued that Bakos' results are flawed. Finally, the Internet itself also offers opportunities for obfuscation (see Ellison and Ellison (2004)) or unobserved lack of inventories (see Arnold & Saliba (2002)) that can raise search and/or transactions costs relative to offline markets.

[23]One may speculate that once shipping costs are accounted for, price dispersion online vanishes. This is not the case; cf. Pan, Ratchford and Shankar (2002); Ancarani and Shankar (2004); Brynjolfsson, Dick and Smith (2004); Brynjolfsson and Smith (2000); Smith and Brynjolfsson (2001); Dinlersoz and Li (2005).

Along these same lines, a number of studies compare average prices in online versus offline markets. The idea is that search costs are lower online, thus affecting not only the range or variance in prices, but also the mean price (and hence the coefficient of variation through both the mean and variance). Scott-Morton, Zettelmeyer and Silva-Risso (2001) find that prices are lower in online markets for automobiles. Consumers who purchase a car through the Internet referral service Autobytel.com reduce their purchase price by approximately 2.2 percent. A potentially confounding explanation for this price difference is that the consumers who choose to shop online may also be skilled "higglers," to use Stigler's phrase and thus the price difference might purely reflect a difference in the negotiating skills of consumers across the two channels. Interestingly, Zettelmeyer, Scott-Morton and Silva-Risso (2004) provide evidence that this is not the case: consumers who purchase automobiles online are not typically those who negotiate well in the traditional channel. There are a number of other studies, however, that find equal or higher prices online (cf. Clemons, Hann and Hitt (2002); Bailey (1998); Goolsbee (2001); Clay, *et al.* (2003); Erevelles, Rolland and Srinivasan (2001)). Further studies distinguish price levels depending on whether the retailer is a solely online or "multichannel" (cf. Chevalier and Goolsbee (2003) and; Tang and Xing (2001)).

An alternative approach is to "recover" search costs using structural parameters from a particular model of price dispersion. For example, Hong and Shum (forthcoming) obtain search costs estimates using restrictions imposed by theoretical search models and assuming that observed price dispersion is an equilibrium phenomenon arising from heterogeneous consumer search costs. Their estimation technique is applied to online price data on four economics and statistics textbooks. They obtain search cost estimates ranging from \$1.31 to \$29.40 for these items. A similar approach can be used in clearinghouse models. Villas-Boas (1995) uses the theoretical density function implied by the Varian (1980) clearinghouse model to obtain estimates of the number of shoppers in the offline coffee and saltine cracker markets. More recently, Baye, Gatti, Kattuman, and Morgan (2005) used a theoretical clearinghouse model as the basis for estimating the fraction of "shoppers" in an online market for PDAs in the UK. Their results suggest that about 13 percent of the consumers in this market are shoppers.

3.2.3 Dispersion and the Number of Sellers

The oligopoly models presented in Section 2 reveal that equilibrium distributions of prices, and hence levels of dispersion, vary with the number of sellers competing in the market. The direction in which prices move as a consequence of a change in the number of sellers is, however, model specific, as we saw in the Varian and Rosenthal models. Thus, examining the relationship between the price dispersion and the number of competing sellers not only provides a test of whether informational factors play a role in generating observed price dispersion, but also in making distinctions among the various theory models.

For instance, Baye, Morgan and Scholten (2004a) examine the theoretical and empirical relationship between the number of competitors and levels of price dispersion in clearinghouse models. They show that the theoretical relationship between number of competitors and the level of price dispersion in clearinghouse models is, in general, ambiguous, due to competing "order statistic" and "strategic" effects. Through a calibration displayed in Figure 2, they show that the impact of the number of sellers on price dispersion depends on the variant of the model. As the figure shows, in the Varian model (where firms' information transmission costs do not drive price dispersion), the expected gap between the two lowest prices is initially increasing in the number of sellers, and then declines. In contrast, in the Baye and Morgan model (where firms' information transmission costs are the main driver of price dispersion), the expected gap is monotonically decreasing in the number of firms. Based on online data from a popular price comparison site for consumer electronics products, and controlling for other factors contributing to price dispersion, they find an inverse relation between the gap and the number of online sellers. This relationship is depicted as the dotted "observed" line in Figure 2. As the figure reveals, the non-monotonicity predicted by the Varian model, as well as the relatively flat relationship between the gap and number of firms predicted in the calibrated version of the Rosenthal model, is absent in the data. Specifically, in markets served by between two and four firms, the average gap (as a percentage of the lowest price) is about 14 percent. The average percentage gap falls to about 3 percent in markets with five to ten firms, and is less than one percent in markets with more than 10 firms.

More broadly, several empirical papers have suggested that the amount of price dispersion observed in the market depends on various measures of the numbers of competitors. Marvel (1976) reports that an increase in the number of competitors (measured by the $\ln(HHI)$) reduces the range in the price of gasoline. Barron, Taylor and Umbeck (2004) study the structural determinants of price dispersion in the retail gasoline industry in four geographic locations, and provide empirical evidence that, controlling for station-level characteristics, an increase in station density decreases both price levels and price dispersion.[24] Borenstein and Rose (1994) investigate the relationship between dispersion among airfares and the number of competitors or flight density. They find that

[24] See also Png and Reitman (1994).

dispersion in fares increases on routes with lower flight density or more competition. Thus, there is evidence that the number of sellers matters for price dispersion.

3.2.4 Dispersion and Price Persistence

Varian (1980) was the first to distinguish between what he referred to as "spatial" and "temporal" price dispersion. Under spatial price dispersion, different firms charge different prices at any point in time, but a firm's position in the distribution of prices does not change over time. Absent random cost shocks, spatial price dispersion arises in the Reinganum, MacMinn, and Spulber models. In contrast, with temporal price dispersion, firms charge different prices at each point in time, but their position in the distribution of prices changes over time. Temporal price dispersion arises in the general clearinghouse model (and various special cases) as well as in the Burdett and Judd model. Varian critiques models of spatial price dispersion, arguing that if consumers can learn from experience that some firms persistently offer lower prices than other firms, then models of spatial price dispersion suggest a "convergence hypothesis": price dispersion should diminish over time due to the positive correlation in successive prices (to use Stigler's terminology) and cumulative search information. This has led to a number of studies that examine whether there is any evidence for the convergence hypothesis and whether the temporal price dispersion predicted by the clearinghouse models is, in fact, present in the data.

Using monthly store-level price data from Israel, and after controlling for observed and unobserved product heterogeneities, Lach (2002) finds some evidence of temporal price dispersion. Lach estimates month-to-month transitions among quartiles by firms; that is, the probability that a firm offering a price in a given quartile at the start of the month is still offering a price in the same quartile at the end of the month. His estimates suggest that the probability of remaining in the same quartile is 78 percent for firms selling refrigerators and 71 percent for firms selling flour. These probabilities are somewhat lower for firms selling chicken (51 percent) and coffee (43 percent). When the transition period is extended to six months instead of one month, the probability of remaining in the same quartile is considerably lower—falling to around 30-35 percent.

Roberts and Supina (2000) suggest that structural differences in firms' costs account for a considerable portion of price dispersion in the offline sector—as predicted by a variety of search-theoretic models. Using plant-level US Census data, they find some evidence for price persistence. The evidence is strongest in the tails of the distribution: high-price firms tend to persistently charge high prices, and low-price firms tends to persistently charge low prices. A variety of other studies also suggest that heterogeneities either across firms or across markets impact price dispersion in online markets (cf. Smith, Bailey and Brynjolfsson (1999); Clay, Krishnan and Wolff (2001); Smith and Brynjolfsson (2001); Chen and Hitt (2002); Resnick and Zeckhauser (2002); and Brynjolfsson, Dick and Smith (2004)). In all cases, however, even after controlling for various heterogeneities, economically significant levels of price dispersion remain.

There is also evidence that online prices exhibit temporal price dispersion. For instance, Baye, Morgan and Scholten (2004b) examine turnover of the identity of the low-price and high-price firms using a dataset consisting of 36 popular consumer electronics products sold over a 19-month period. They find considerable evidence for month-to-month changes in the identity of the low-price firms, but some evidence of persistence in the identity of high-priced firms. Similarly, Iyer and Pazgal (2003) collect bi-weekly price data on music CDs, movie videos and books from five price comparison sites: MySimon, BottomDollar, EvenBetter, Bsilly and Pricescan during the period April-October 2000 and find empirical results suggesting that no single firm consistently charges the low price.

Finally, Baye, Morgan and Scholten (2004a) examine the convergence hypothesis of price dispersion using a dataset consisting of over four million daily price observations for over one thousand consumer electronics products sold on a popular Internet price comparison site over an eight month period. Even allowing for a nonlinear relationship between observed price dispersion and time, they find no evidence for the convergence hypothesis in this market—the level of price dispersion remained stable over the period.

3.3 Concluding Remarks: Empirics

We conclude with four simple observations.

1. As is evident from the studies highlighted in Table 1, price dispersion is ubiquitous and persistent. Regardless of the particular product (tinplate cans or PDAs), the venue in which they are sold (online or offline, in the US or abroad), or the time period (1901 or 2005), the inescapable conclusion from the empirical literature is a validation of Stigler's and Varian's initial observations: Information remains a valuable resource, and the law of one price is still no law at all.

2. Theory is useful for understanding dispersion data, and dispersion data is useful for discriminating among alternative theoretical models.

3. The relationship between price dispersion and economic primitives is often sensitive to the measure of price dispersion used.

4. Despite the widespread adoption of inventions such as the automobile, the telephone, television, and the Internet, price dispersion is still the rule rather than the exception in homogeneous product markets. Reductions in information costs over the past century have neither reduced nor eliminated the levels of price dispersion observed in homogeneous product markets.

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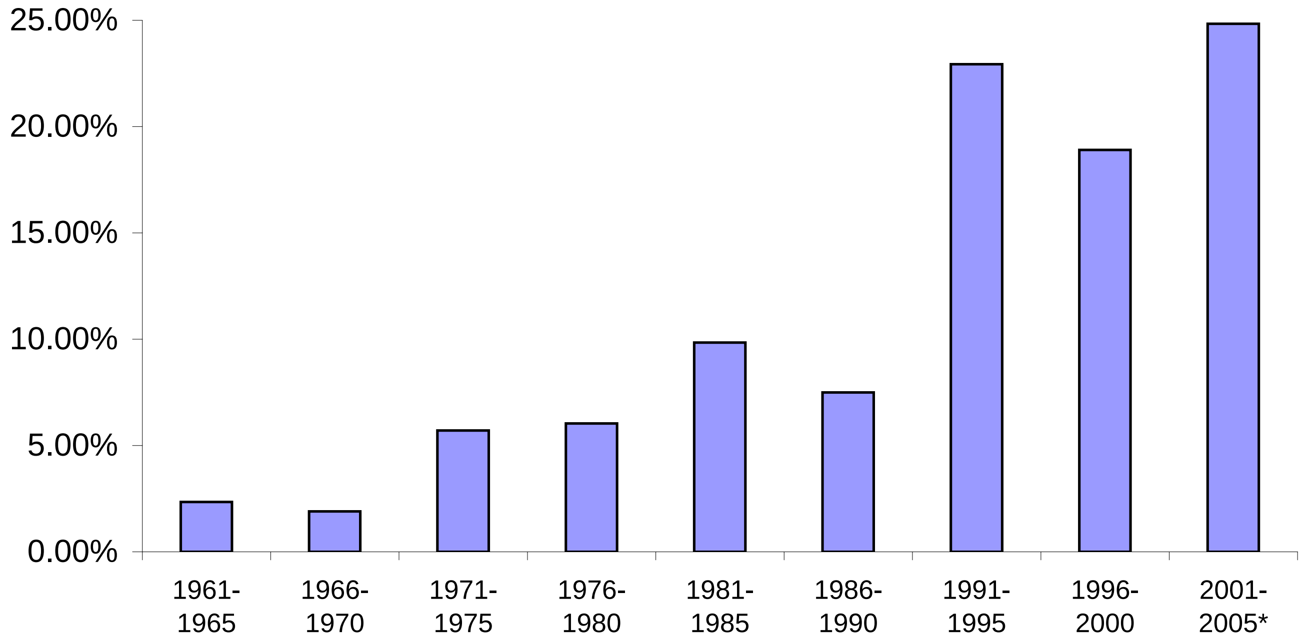
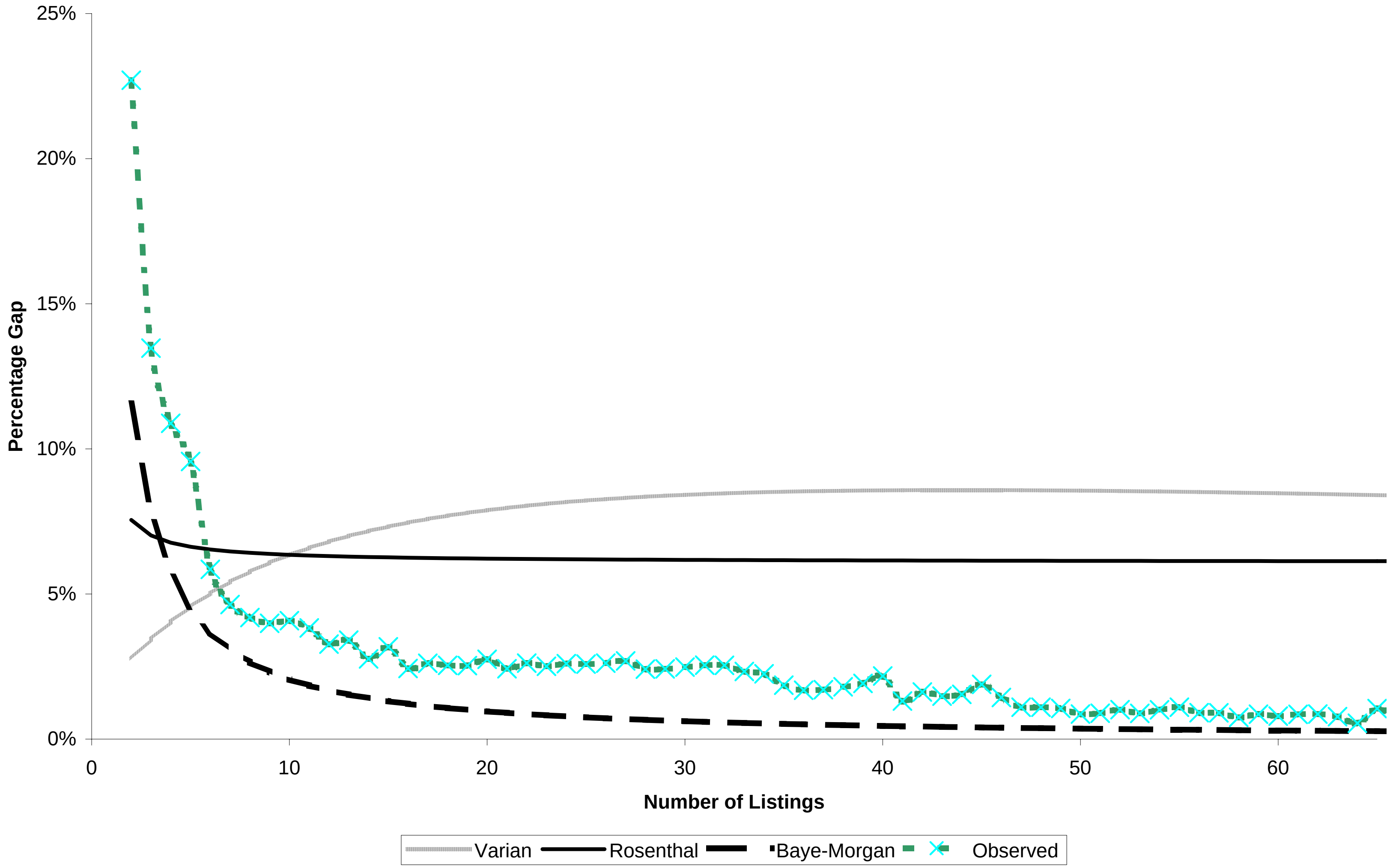
Figure 1: Percentage of Articles Published in the *American Economic Review*, *Journal of Political Economy*, and *Econometrica* on Information, Search or Price Dispersion



Source: *Social Science Citation Index*, Keyword search for "Information OR Price Dispersion OR Search," and Authors' Calculations.
*2005 data through third quarter.

Figure 2: Theoretical and Emprical Relationship between Price Dispersion Measured by Percentage Gap and the Number of Competing Sellers Listing Prices on a Clearinghouse Site



Source: *Baye, Morgan, and Scholten (2004a)* and Authors' Calculations.

Table 1a: Measures of Price Dispersion Reported in the Literature in Offline Markets[1]

Study	Data Period	Product Market	Intervals of Estimated Price Dispersion Measures	Dispersion Measure
Bailey (1998)	1997	Books	13.2%	Standard Deviation
		Books	10.4%	Standard Deviation
		Compact Discs	17.6%	Standard Deviation
		Compact Discs	11.0%	Standard Deviation
		Software	7.1%	Standard Deviation
		Software	8.1%	Standard Deviation
Borenstein and Rose (1994)	1986	U.S. Airline	0.018 - 0.416	Gini coefficient
Carlson and Pescatrice (1980)	1976	Consumer Sundries	3.3% - 41.4%	Coefficient of Variation
Eckard (2004)	1901 - 2001	Baking Powder, Sugar, Salt -- 1901	3.1% - 10.1%	Coefficient of Variation
		Baking Powder, Sugar, Salt -- 2001	0.0% - 13.4%	Coefficient of Variation
Friberg, Ganslandt and Sandstrom (2001)	1999	Books	$54.00 - $122.00	Range
		Books	$21.94 - $76.20	Standard Deviation
		Compact Discs	$20.00 - $40.00	Range
		Compact Discs	$12.91 - $23.86	Standard Deviation
		Books (Sweden)	$19.00 - $58.00	Range
		Compact Discs (Sweden)	$21.00 - $46.00	Range
Lach (2002)	1993 - 1996	Refrigerator (Israel)	4.9%	Coefficient of Variation
		Chicken, Flour, Coffee (Israel)	11.4% - 19.7%	Coefficient of Variation
Marvel (1976)	1964 - 1971	Regular Gasoline	$0.048	Range
		Regular Gasoline	$0.015	Standard Deviation
		Premium Gasoline	$0.048	Range
		Premium Gasoline	$0.017	Standard Deviation
Pratt, Wise and Zeckhauser (1979)	1975	Various Products and Services	4.4% - 71.4%	Coefficient of Variation
		Various Products and Services	11.0% - 567.0%	Range
		Various Products and Services	7.2% - 200.0%	Value of Information
Roberts and Supina (2000)	1963 - 1987	Wood Products	13.8% - 90.2%	Coefficient of Variation
		Fabrics	18.8% - 78.1%	Coefficient of Variation
		Coffee	14.3% - 25.1%	Coefficient of Variation
		Ready-Mixed Concrete	13.2% - 37.2%	Coefficient of Variation
		Newsprint	4.5% - 8.2%	Coefficient of Variation
		Gasoline	6.2% - 11.8%	Coefficient of Variation
		Tinplate Steel Cans	25.0% - 31.0%	Coefficient of Variation
		Pan Bread	26.0% - 49.6%	Coefficient of Variation
		Corrugated Shipping Containers	21.8% - 39.6%	Coefficient of Variation
Scholten and Smith (2002)	1976 - 2000	Consumer Sundries -- 1976	3.3% - 41.4%	Coefficient of Variation
		Consumer Sundries -- 2000	1.6% - 42.0%	Coefficient of Variation
		Consumer Sundries -- 2000	5.7% - 28.4%	Coefficient of Variation
Sorensen (2000)	1998	Prescription Drugs	$13.17	Range
		Prescription Drugs	22.0%	Coefficient of Variation
Stigler (1961)	1953	Anthracite Coal	$3.46	Range
		Anthracite Coal	$1.15	Standard Deviation
	1959	Identical Automobiles	$165.00	Range
		Identical Automobiles	$42.00	Standard Deviation
Villas-Boas (1995)	1985 - 1987	Coffee	21.5%	Coefficient of Variation

[1] Table 1a includes studies comparing offline and online price dispersion.

Table 1b: Measures of Price Dispersion Reported in the Literature in Online Markets Only

Study	Data Period	Product Market	Intervals of Estimated Price Dispersion Measures	Dispersion Measure
Ancarani and Shankar (2004)	2002	Books (Italy)	€4.26 - €4.84	Standard Deviation
		Books (Italy)	€20.00 - €22.88	Range
		Compact Discs (Italy)	€2.29 - €2.79	Standard Deviation
		Compact Discs (Italy)	€11.82 - €14.75	Range
Arbatskaya and Baye (Forthcoming)	1998	Mortgage Interest Rates	> 0.25	Range
Arnold and Saliba (2002)	2001	Textbooks	10.7% - 52.6%	Range
		Textbooks	3.5% - 10.0%	Coefficient of Variation
		Textbooks	0.2% - 12.5%	Price gap
Baye, Morgan and Scholten (2003)	2000 - 2001	Consumer Electronics	$123.88 - $143.15	Range
Baye, Morgan and Scholten (2004a)	2000 - 2001	Consumer Electronics	9.1% - 9.7%	Coefficient of Variation
		Consumer Electronics	3.79% - 5.38%	Gap
Baye, Morgan and Scholten (2004b)	1999 - 2001	Consumer Electronics	57.4%	Range
		Consumer Electronics	12.5%	Coefficient of Variation
Baylis and Perloff (2002)	1999	Camera	$342.00	Range
		Scanner	$106.00	Range
Brynjolfsson and Smith (2000)	1998-1999	Books	33.0%	Range
		Compact Discs	25.0%	Range
Chevalier and Goolsbee (2003)	2001	Books	8.1% - 12.3%	Range
Clay, Krishnan, and Wolff (2001)	1999 - 2000	Books	27.7%	Coefficient of Variation
		Books	$7.62	Range
Clay, Krishnan, Wolff and Fernandes (2003)	1999	Books	10.0% - 18.0%	Coefficient of Variation
Clemons, Hann and Hitt (2002)		Travel	$8.03 - $13.40	Range
Ellison and Ellison (2004)	2000 - 2001	Memory Modules	5.9% - 29.0%	Range
Gatti and Kattuman (2003)	2002	Consumer Electronics (France)	3.0% - 15.3%	Coefficient of Variation
		Consumer Electronics (Italy)	4.3% - 14.2%	Coefficient of Variation
		Consumer Electronics (Netherlands)	5.6% - 20.4%	Coefficient of Variation
		Consumer Electronics (Spain)	2.2% - 13.3%	Coefficient of Variation
		Consumer Electronics (Sweden)	6.6% - 14.0%	Coefficient of Variation
		Consumer Electronics (UK)	3.5% - 16.2%	Coefficient of Variation
		Consumer Electronics (Denmark)	6.3% - 20.2%	Coefficient of Variation
		Consumer Electronics (France)	7.8% - 47.4%	Range
		Consumer Electronics (Italy)	9.3% - 27.8%	Range
		Consumer Electronics (Netherlands)	8.9% - 54.6%	Range
		Consumer Electronics (Spain)	3.8% - 32.4%	Range
		Consumer Electronics (Sweden)	16.4% - 50.4%	Range

		Consumer Electronics (UK)	7.0% - 54.9%	Range
		Consumer Electronics (Denmark)	12.8% - 42.9%	Range
		Consumer Electronics (France)	1.6% - 16.1%	Gap
		Consumer Electronics (Italy)	3.6% - 13.7%	Gap
		Consumer Electronics (Netherlands)	8.9% - 34.6%	Gap
		Consumer Electronics (Spain)	3.7% - 18.0%	Gap
		Consumer Electronics (Sweden)	5.9% - 15.6%	Gap
		Consumer Electronics (UK)	2.5% - 14.5%	Gap
		Consumer Electronics (Denmark)	3.6% - 31.9%	Gap
Hong and Shum (Forthcoming)	2002	Books	$8.19 - 27.05	Range
		Books	6.2% - 8.5%	Coefficient of Variation
Janssen, Moraga-Gonzalez and Wildenbeest (2005)	2004	Market for Keyboards	$6.50 - $91.67	Range
		Market for Keyboards	8.0% - 52.0%	Coefficient of Variation
Pan, Ratchford and Shankar (2002)	2000	Books	15.0%	Coefficient of Variation
		Compact Discs	15.4%	Coefficient of Variation
		DVDs	12.7%	Coefficient of Variation
		PDAs	11.8%	Coefficient of Variation
		Software	11.7%	Coefficient of Variation
		Consumer Electronics	9.6%	Coefficient of Variation
Pan, Shankar and Ratchford (2003)	2000 - 2003	Consumer Electronics and Books	9.8% - 11.7%	Coefficient of Variation
		Books	33.3% - 48.9%	Range
		Compact Discs	22.2% - 51.0%	Range
		DVDs	30.7% - 43.7%	Range
		Computers	15.0% - 34.4%	Range
		Software	19.0% - 35.6%	Range
		Consumer Electronics	22.1% - 45.7%	Range
Smith and Brynjolfsson (2001)	1999	Books	28.0% - 33.0%	Value of Information
		Books	$6.29 - $10.51	Standard Deviation