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Brand and Price Advertising in Online Markets[*]

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Abstract

We model a homogeneous product environment where identical e-retailers endogenously engage in both brand advertising (to create loyal customers) and price advertising (to attract "shoppers"). Our analysis allows for "cross-channel" effects; indeed, we show that price advertising is a substitute for brand advertising. In contrast to models where loyalty is exogenous, these cross-channel effects lead to a continuum of symmetric equilibria; however, the set of equilibria converges to a unique equilibrium as the number of potential e-retailers grows arbitrarily large. Price dispersion is a key feature of all of these equilibria, including the limit equilibrium. While each firm finds it optimal to advertise its brand in an attempt to "grow" its base of loyal customers, in equilibrium, branding (1) reduces firm profits, (2) increases prices paid by loyals and shoppers, and (3) adversely affects gatekeepers operating price comparison sites. Branding also tightens the range of prices and reduces the value of the price information provided by a comparison site. Using data from a price comparison site, we test several predictions of the model.

JEL Nos: D4, D8, M3, L13

Keywords: Price dispersion

1 Introduction

The size, scope, and persistence of online price dispersion for seemingly identical products has been amply documented.[1] Some have suggested that, while the products sold at price comparison sites may be identical and search costs low, e-retailers go to great pains to be perceived as different. For instance, Brynjolfsson and Smith (2000a) argue that price dispersion in markets for books and CDs is mainly due to perceived differences among retailers related to branding, awareness, and trust—factors influenced by the brand-building activities of online retailers.[2] These activities include the prominent use of logos, clever advertising campaigns, the development of "customized" applications including one-click ordering, custom recommendations, and the development of an online "community" or "culture" loyal to a particular firm.[3] Even on Internet price comparison sites, where consumers are price sensitive (Ellison and Ellison (2004a) estimate price elasticities between -25 and -40 for consumers on one such site), some firms promote their "brand" by featuring their logo along with their price listing. All of these activities are costly.

How do costly differentiation efforts—what we refer to as brand advertising—interact with firms' pricing and listing decisions—what we refer to as informational advertising—to affect competition and price dispersion in online markets? The existing economics literature on equilibrium price dispersion does not provide a ready answer; it typically treats the fraction of consumers who are "loyal" to some firm as exogenous.[4] One can imagine that

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[1]See, for instance, Bailey (1998a,b); Brown and Goolsbee (2000); Brynjolfsson and Smith (2000a, b); Clemons, Hann, and Hitt (2002); Morton, Zettlemeyer, and Risso (2000); Baye and Morgan (2004); Clay, Krishnan, and Wolff (2001); Clay and Tay (2001); Pan, Ratchford, and Shankar (2001); Smith (2001, 2002); Scholten and Smith (2002); Ellison and Ellison (2004a);.and Baye, Morgan, and Scholten (forthcoming). See also Elberse, *et al.* (2003) for a survey of the relevant marketing literature, and Ellison and Ellison (2004b) for a survey of the industrial organization literature. There is also a growing experimental literature on price dispersion; see Abrams, Sefton and Yavas (2000), Dufwenberg and Gneezy (2000), and Cason and Friedman (2003).

[2]See also Ward and Lee (2000) and Dellarocas (2001).

[3]Efforts to induce loyalty may also be indirect. The cost of such strategies include the implicit costs of providing fast service or liberal returns policies in an attempt to influence reputational ratings (see Bayliss and Perloff, 2002; Resnick and Zeckhauser, 2002). It appears that these brand-building activities are somewhat successful. Brynjolfsson and Smith (2000b) report that a considerable fraction of consumers do not click-through to the lowest price book retailer at one price comparison site.

[4]Examples include Shilony (1977), Varian (1980), Rosenthal (1980), Narasimhan (1988), Stegeman (1991), Robert and Stahl (1993), Dana (1994), Stahl (1994), Banerjee and Kovenock (1999), Roy (2000), Baye-Morgan (2001), and Janssen and Rasmusen (2002). See also Butters (1977); Grossman and Shapiro (1984), McAfee (1994), Stahl (1994), Hong, McAfee, and Nayyar (2002), Baye and Morgan (2004) as well as Janssen

endogenizing brand-building might matter a great deal. If brand advertising ultimately converted all consumers into "loyals," firms would find it optimal to charge the "monopoly" price and price dispersion would vanish. Expressed differently, it is not at all clear that dispersed price equilibria of the sort characterized in the extant literature (see footnote 4) survive when customer loyalty is endogenously determined by firms' branding activities.

In Section 2, we offer a model with endogenous branding and pricing that captures salient features of competition among retailers at a price comparison site. In the model, a fixed number of firms sell similar products. In the first stage, each firm invests in brand advertising in an attempt to convert some or all consumers into "loyals." These branding decisions result in an endogenous partition of consumers into "loyals", who are loyal to a specific firm, and "shoppers", who view the products to be identical. In the second stage, firms independently make pricing decisions as well as decisions about informational advertising. Thus, the model entails endogenous branding, pricing, and informational advertising strategies.

Section 3 characterizes symmetric Nash equilibria and shows that equilibrium branding efforts by firms create a significant number of loyal consumers, but do not convert all shoppers into loyals. As a consequence, endogenous branding does not eliminate equilibrium price dispersion in online markets, although increased branding is associated with lower levels of price dispersion. We show that branding not only increases the average prices paid by loyal customers, but also raises the prices paid by shoppers who purchase at price comparison sites. Branding also negatively impacts "gatekeepers" operating price comparison sites in two ways. First, firms' branding efforts increase the number of loyal consumers and thereby reduce traffic at the price comparison site. (Interestingly, the gatekeeper cannot stem these losses by reducing its fees.) Second, branding tightens the distribution of prices and, as a consequence, reduces the value of price information provided by the site.

In Section 4, we show that even when the number of competing firms is large (as is arguably the case in global online markets), prices remain dispersed above marginal cost. This result also obtains in the limit as the number of firms grows arbitrarily large. This finding is in contrast to the models of Varian (1980), Rosenthal (1980), Narasimhan (1988), which all predict that price dispersion vanishes as the number of competing firms grows

and Moraga-Gonzalez (forthcoming).

large. Our findings for large online markets are broadly consistent with daily data we have been collecting for several years and post weekly at our website, *Nash-Equilibrium.com.* Price dispersion, as measured by the range in prices, has remained quite stable over the past four years, at 35 to 40 percent. The stability and magnitude of this dispersion is remarkable from a theoretical perspective, since (1) the products are relatively expensive consumer electronics products for which the average price is about \$500, (2) over the period the Internet rapidly eliminated geographic boundaries, leading to exponential growth in the number of consumers and businesses with direct Internet access, and (3) according to the Census Bureau, there were nearly 10,000 consumer electronics retail establishments in the United States who compete in the consumer electronics market.[5] Each of these 10,000 stores could, in principle, choose to list their prices on Shopper.com, yet the average product sold through Shopper.com was offered by less than 30 firms.

Finally, in Section 5 we use data from Shopper.com to test some of the predictions of the model. We find that more intense branding by firms is associated with lower levels of price dispersion and higher prices to loyals and shoppers. These results are robust to a variety of controls.

2 Model

Consider an online market where a unit measure of consumers shop for a specific product (e.g., HP LaserJet 1100xi). There are N sellers in this market, each having a constant marginal cost of m.[6] Each consumer is interested in purchasing at most one unit of the product, from which she derives value v.[7] As in Narasimhan and Rosenthal, there are assumed to be two types of consumers: loyals and shoppers. Shoppers costlessly visit the price comparison site to obtain a list of the prices charged by all firms choosing to list their prices there.[8] Since shoppers view sellers as perfect substitutes, they each purchase

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[5]This figure is based on NAICS classification code 443112, which is comprised of establishments known as consumer electronics stores primarily engaged in retailing new consumer-type electronic products. Source: U.S. Census Bureau, *1997 Economic Census*, January 5, 2001, p. 217.

[6]The model readily extends to the case where there are positive fixed costs as well.

[7]It is straightforward to generalize the model to allow for downward sloping demand.

[8]Baye and Morgan (2001) show that a monopoly "gatekeeper" that owns a price comparison site has an incentive to set consumer subscription fees sufficiently low in an attempt to induce all consumers to utilize

at the lowest price available at the price comparison site—provided it does not exceed v. If no prices are listed, these shoppers visit the website of a randomly selected firm and purchase if the price does not exceed v.[9] A fraction $\lambda \in [0, 1]$ of loyals directly visit the website of their preferred firm. The remaining $1 - \lambda$ of loyals first use the price comparison site to search for their preferred seller, but if it is not listed, proceed to their preferred seller's website. Thus, loyals always buy from their preferred seller, provided its price does not exceed v. These assumptions are broadly consistent with stylized facts about online shopping. Specifically, Brynjolfsson and Smith (2000a) report that many consumers visit sellers' websites directly rather than by using price comparison sites, and those who use price comparison sites sometimes purchase from their preferred firm rather than from the seller listing the lowest price.

In contrast to the models of Narasimhan and Rosenthal, a consumer's type is determined endogenously by brand advertising on the part of firms, as we will describe below. In contrast to Baye-Morgan (2001), who assume that all consumers view firms as identical, here we allow for the possibility that some consumers have a preference for particular sellers. There is considerable evidence that this is indeed the case. For instance, many consumers prefer to purchase books from Amazon rather than Barnes and Noble—even at higher prices.[10] To capture these effects, let β_i denote the proportion of consumers who are loyal to firm i. Thus, the total number of consumers loyal to some firm is $B = \sum_{i=1}^{N} \beta_i$. The remaining $1 - B$ shoppers view the sellers as identical.

There are three components to a firm's strategy: Firm i must decide its price (denoted p_i), its informational advertising strategy, which is modeled as a binary decision to spend $\phi > 0$ to list its price on the price comparison site (or not), and its brand advertising level, a_i. Firms influence consumers' loyalty through brand advertising. We assume that branding

the site. Hence, we assume that all shoppers have access to the comparison site at no cost. This assumption is consistent with empirical evidence; virtually all price comparison sites—including Shopper.com, Nextag, Expedia, and Travelocity—permit consumers to use their services at no charge. See also Caillaud and Jullien (2002, 2003) for analysis of competition among gatekeepers.

[9] The analysis that follows implies the existence of a search cost, $\gamma < v$, such that this behavior comprises an optimal sequential search strategy.

[10] For instance, Chevalier and Goolsbee (2002) provide evidence that the demand for books at Barnes and Noble is about 8 times more elastic than that at Amazon.

leads to the acquisition of loyal customers according to the functional form:

$$\beta_i = \beta\left(a_i, A_{-i}\right) = \begin{cases} \delta \frac{a_i}{A_{-i}+a_i} + a_i\sigma & \text{if} \quad a_i + A_{-i} > 0 \\ \frac{\delta}{N} & \text{if} \quad a_i + A_{-i} = 0 \end{cases} \tag{1}$$

where $A_{-i} = \sum_{j \neq i} a_j$ denotes aggregate branding effort by all firms other than i, and where $\sigma > 0$ and $\delta \geq 0$ are parameters. When $A_{-i} > 0$, positive branding effort is required for firm i to enjoy *any* loyal consumers. The "δ" term in equation (1) captures potential "brand stealing" effects of brand advertising—brand advertising that steals loyal customers from other sellers. The "σ" term captures "brand expansion" effects—brand advertising that converts some shoppers into loyals. The form of equation (1) is standard in the contest literature; see Nitzan (1994) for a survey.

Firms' incentives to engage in branding activities depend not only on the sensitivity of β_i to branding efforts (that is, the magnitude of δ, σ, and the aggregate branding efforts of rival firms), but also on brand advertising costs. Assume that the marginal cost of a unit of brand advertising is $\tau > 0$, so that the total cost to firm i of a_i units of brand advertising is τa_i. Finally, we assume that $a_i \in \left[0, \frac{1-\delta}{N\sigma}\right]$, which merely guarantees that aggregate branding efforts do not lead to more loyals than is feasible given the unit mass of consumers and the specification in equation (1).

In many online markets, firms adjust prices frequently and quickly, and there is considerable turnover in the identify of the firm offering the lowest price; for evidence, see Ellison and Ellison (2004b) as well as Baye, Morgan, and Scholten (2004). In contrast, branding decisions typically require substantial up-front investments, which take time to mature into a sizeable base of loyal customers. Hence, we model branding and pricing decisions as a two-stage game. In the first stage, firms simultaneously choose brand advertising levels, a_i, in an attempt to create a stock of loyal consumers. In the second stage, after having observed first stage decisions, firms simultaneously make pricing and listing decisions.

3 Equilibrium Branding, Pricing, and Listing Decisions

The structure of our model attempts to capture the "strategic uncertainty" present in firms' branding and pricing decisions. In particular, the value to a firm committing up-front re-

sources on branding activity critically depends on its view of the competitiveness of the market for shoppers in the second-stage game. As we show in Proposition 2, the strategic uncertainty present in this setting leads to a continuum of symmetric Nash equilibria. However, the multiplicity issue turns out to be moot in markets where the number of competing firms is sufficiently large. In a sequence of propositions, we show that (1) there exists a unique symmetric equilibrium in which players employ *secure branding strategies*,[11] (2) there exists a continuum of symmetric Nash equilibria that entail branding levels close to the secure branding strategies, and (3) in any symmetric equilibrium, branding converges to the unique equilibrium in secure branding strategies as the number of competing firms grows arbitrarily large. In the sequel, we let α_i denote the probability a firm lists its price, and let $F_i(p)$ denote the distribution of firm i's listed price.

Proposition 1 *Suppose $\tau > \frac{(v-m)\sigma}{1-\delta}$ and $\phi \in (0, \frac{(v-m)((1-\delta)\tau - (v-m)\sigma)}{(\tau - (v-m)\sigma)})$. Then there exists a unique symmetric equilibrium in secure branding strategies. Specifically, (1) firms choose brand advertising levels*

$$a_i = a^* \equiv \delta \frac{(N-1)(v-m)}{N^2(\tau - (v-m)\sigma)}$$

to obtain

$$\beta_i = \beta^* = \frac{\delta}{N}\left(\frac{N\tau - (v-m)\sigma}{N(\tau - (v-m)\sigma)}\right)$$

loyal consumers per firm; and (2) firms follow the second stage pricing and informational advertising strategies described in Proposition 2.

The fact that the above strategies are part of a symmetric Nash equilibrium follows from the proof of a more general Proposition 2. Thus, it suffices to establish that a^* is the unique symmetric branding level that maximizes a firm's *secure* payoff. Notice that, when rivals choose branding levels $a_j = a$ in the first stage, the lowest payoff that can be imposed on firm i is

$$E\pi_i^{\text{secure}} = (v-m) \times \beta(a_i, A_{-i}) - \tau a_i.$$

That is, firm i can do no worse than to eschew informational advertising ($\alpha_i = 0$) and charge the monopoly price to its loyal customers ($p_i = v$) regardless of its perceptions about the

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competitiveness of the market for shoppers. Substituting for $\beta(a_i, A_{-i})$ yields

$$E\pi_i^{\text{secure}} = \left(\delta \frac{a_i}{(N-1)a + a_i} + \sigma a_i\right)(v - m) - \tau a_i.$$

The brand advertising level that maximizes i's secure payoff satisfies the first-order condition

$$\left(\delta \frac{(N-1)a}{(a_i + (N-1)a)^2} + \sigma\right)(v - m) - \tau = 0. \tag{2}$$

It is routine to show that $a_i = a = a^*$ is the unique symmetric solution to equation (2). Hence, a^* is the unique symmetric equilibrium in which firms use secure brand advertising strategies.

Our next proposition, which is proved in Appendix A and from which the remaining part of the proof to Proposition 1 follows, shows that there is a continuum of symmetric equilibria that entail branding levels in a neighborhood of a^*.

Proposition 2 *Suppose that $\tau > \frac{(v-m)\sigma}{1-\delta}$ and $\phi \in \left(0, \frac{(v-m)((1-\delta)\tau - (v-m)\sigma)}{(\tau - (v-m)\sigma)}\right)$. Then there exists a continuum of symmetric equilibria with branding levels in an open neighborhood, $\mathcal{N}(a^*)$, of a^*. In any such equilibrium, each firm chooses a brand advertising level $a_i = a \in \mathcal{N}(a^*)$, which generates*

$$\beta_i = \beta = \frac{\delta}{N} + \sigma a$$

loyal consumers per firm. The total number of loyal customers in the market is $B \equiv N\beta \in (0, 1)$. Each firm lists its price on the price comparison site with probability

$$\alpha_i = \alpha \equiv 1 - \left(\left(\frac{\phi}{(v-m)(1-N\beta)}\right)\left(\frac{N}{N-1}\right)\right)^{\frac{1}{N-1}} \tag{3}$$

and, conditional on listing, selects a price from the cumulative distribution function

$$F_i(p) = F(p) \equiv \frac{1}{\alpha}\left(1 - \left(\frac{(v-p)\beta + \phi\frac{N}{N-1}}{(1-N\beta)(p-m)}\right)^{\frac{1}{N-1}}\right) \tag{4}$$

over the support $[p_0, v]$ where

$$p_0 = m + \frac{(v-m)\beta + \frac{\phi}{(N-1)}N}{(1-(N-1)\beta)}.$$

Firms that do not list a price at the price comparison site charge a price of $p_i = v$ on their own websites. Each firm earns equilibrium profits of

$$E\pi_i = E\pi = (v-m)\beta + \frac{\phi}{N-1} - \tau a. \tag{5}$$

For future reference, we let $B^* = N\beta^*$ and use α^*, F^*, p_0^* and $E\pi^*$ to denote the relevant second-stage components of the equilibrium identified in Proposition 1. Together, these components comprise what we shall hereafter refer to as an a^* equilibrium.

Proposition 2 shows that multiple equilibria in the neighborhood of the a^* equilibrium arise in the presence of endogenous branding. Nonetheless, all of the equilibria have the property that branding efforts by firms convert some but not all consumers into loyals; in equilibrium, there remain $1 - B > 0$ shoppers who purchase from the firm charging the lowest price listed at the comparison site. This prediction appears consistent with Brynjolfsson and Smith's observation that some, but not all, online consumers buy at the lowest listed price.

The equilibria identified above share features present in the models of Varian, Rosenthal, Narasimhan, and Baye-Morgan—as well as some important differences. Similar to all of these models, equilibria in the present model require any firm listing a price on the price comparison site to use a pricing strategy that prevents rivals from being able to systematically predict the price offered to consumers who enjoy the information posted at the site (hence the distributional strategy, $F(p)$). Like Baye-Morgan, our model permits firms to endogenously determine whether to utilize the price comparison site (the other models constrain all firms to list prices at the site with probability one, and Baye-Morgan essentially show this is not an equilibrium when it is costly for firms to list prices at the site). As a consequence, in any equilibrium firms must randomize the timing of price listings to preclude rivals from systematically determining the number of listings at the price comparison site (hence, the informational advertising propensity, $\alpha \in (0, 1)$).

In contrast to Narasimhan and Rosenthal, the present model relaxes the assumption that firms are costlessly endowed with an exogenous number of brand-loyal consumers. In the present model, a firm that spends nothing to promote its "brand" or "service" in the face of positive expenditures by rivals enjoys no loyal consumers. In contrast to Varian and Baye-Morgan, the present model does not impose the assumption that all consumers view the products sold by different firms to be identical; indeed, in equilibrium, each firm enjoys a strictly positive number of loyal consumers—thanks to the positive level of branding activity that arises in equilibrium. As we will discuss below, this implies that the price comparison site attracts fewer consumers than in the Baye-Morgan model. Expressed differently, the

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branding efforts of firms reduce the traffic enjoyed by the "information gatekeeper" operating the price comparison site.

Another difference between these models and the present model is that, in the former, there is a unique symmetric equilibrium while, in the latter, endogenous branding leads to a continuum of symmetric equilibria. Nonetheless, our next proposition demonstrates that multiplicity becomes less severe in "large" online markets: all symmetric equilibria are arbitrarily close to the equilibrium identified in Proposition 1. This proposition is proved in Appendix A as well.

Proposition 3 *In any symmetric equilibrium, first-stage branding levels converge to a^* as the number of competing firms (N) grows arbitrarily large. Formally, let $\langle a_N, \alpha_N, F_N \rangle$ be an arbitrary sequence of symmetric equilibria. Then*

(1) $\lim_{N \to \infty} a_N = \lim_{N \to \infty} a^*$, and

(2) $\lim_{N \to \infty} N a_N = \lim_{N \to \infty} N a^* = \frac{\delta(v-m)}{\tau - \sigma(v-m)}$.

3.1 Implications for Oligopolistic Online Markets

In light of Propositions 1 through 3, it is natural to examine comparative static properties of the a^* equilibrium. Our analysis includes an assessment of the impact of endogenous branding on the payoffs of relevant market participants—firms, loyals, shoppers, and the "gatekeeper" operating the price comparison site. We also study the effects of endogenous branding on the equilibrium level of price dispersion in online markets. Some of the intuition provided in this section is based on the comparative statics summarized below (Appendix A provides the relevant mathematical details).

Variable	δ	σ	τ	N	ϕ	v	m
$E\pi^*$	$+$	0	0	$-$	$+$	$+$	$-$
a^*	$+$	$+$	$-$	$-$	0	$+$	$-$
β^*	$+$	$+$	$-$	$-$	0	$+$	$-$
B^*	$+$	$+$	$-$	$+$	0	$+$	$-$
p_0^*	$+$	$+$	$-$	$?$	$+$	$+$	$?$
α^*	$-$	$-$	$+$	$?$	$-$	$?$	$?$

Firm Profits

Do firms benefit, in equilibrium, from their costly branding activities? Or do their incentives to promote their brands or services stem from an "oligopolistic lock-in" (see Tauber, 1970), such that the overall profits of firms are lower than would arise if the firms could credibly commit to spend nothing on branding? On the one hand, when the brand expansion parameter (σ) is large, branding might be beneficial overall in that the mass of shoppers is reduced and hence the incentives to compete on price are blunted. On the other hand, when the main effect of brand advertising is brand stealing (i.e., δ is large relative to σ), then one may imagine the effects going in the opposite direction and firms benefiting collectively from a ban on advertising.

To compare the magnitude of these two effects, recall from Proposition 1 that the equilibrium profits of a representative firm are

$$E\pi^* = (v - m)\,\beta^* - \tau a^* + \frac{\phi}{N - 1}.$$

After simplification, this expression can be used to obtain industry profits of

$$NE\pi^* = \frac{\delta}{N}\,(v - m) + \frac{N\phi}{N - 1}. \tag{6}$$

In contrast, when firms can credibly commit not to engage in branding, equilibrium profits are:[12]

$$NE\pi^0 = \delta\,(v - m) + \frac{N\phi}{N - 1}.$$

Thus,

Proposition 4 *In an a^* equilibrium, the ability to create brand-loyal consumers (at positive cost) decreases industry expected profits by*

$$NE\pi^0 - NE\pi^* = \delta\,(v - m)\left(1 - \frac{1}{N}\right) \geq 0$$

compared to the case where firms can credibly commit to not engage in brand advertising.

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[12]To obtain this expression, notice that, when firms are constrained to zero brand advertising, then, by equation (1), $\beta_i = \frac{\delta}{N}$ for all i. We may then use these values of β_i in the unique second stage equilibrium strategies identified in Lemma 1 in Appendix A to obtain the profit expression.

When $\delta > 0$, the expression in Proposition 4 holds with a strict inequality—the option to engage in brand advertising leaves all firms strictly worse off. Interestingly, the profitability of the industry is independent of the marginal benefit of brand expansion (σ). Thus, even if the main effect of branding is to "grow" the number of loyal customers rather than stealing existing loyals from other firms, it is still the case that adding the option of engaging in brand advertising leaves firms individually and collectively worse off. The profits foregone due to this oligopolistic lock-in are greater in high-margin $(v - m)$ markets, and in markets with more firms.

The next proposition summarizes the effects of changes in the parameters of the model on profits in an a^* equilibrium.

Proposition 5 *In an a^* equilibrium, the equilibrium profits of firms are independent of the cost of brand advertising (τ), increasing in the cost of informational advertising (ϕ), increasing in the effectiveness of brand stealing (δ), independent of the effectiveness of brand expansion (σ), and decreasing in the number of competitors (N).*

Why are equilibrium e-retailer profits independent of the marginal cost of brand advertising, τ? After all, an increase in τ reduces each firm's equilibrium number of loyal consumers and a firm's profits are increasing in its number of loyal consumers. The answer is that competition to create such consumers entails a long-term commitment of resources, and this fully dissipates the higher profits that would be enjoyed were firms exogenously endowed with a larger fraction of loyal customers. This invariance result is, in fact, a general property of many contests; see Glazer and Konrad (1999). In particular, this result obtains so long as firm i's fraction of loyals may be written as $\beta_i = G(a_i, A_{-i}) + \sigma a_i$, where G is homogeneous of degree zero in firms' branding efforts.

In contrast, expected profits are increasing in firms' costs of listing prices on the gatekeeper's comparison site (ϕ). These costs drive a wedge between the expected profits earned from listing prices in the online market and those from not listing at the gatekeeper's site. Higher listing fees reduce equilibrium advertising propensities (α^*), which lessens price competition and results in higher equilibrium profits.

Brand versus Informational Advertising

The model also sheds light on interrelations between two different types of advertising strategies. As would be expected, each firm's demand for brand and price advertising (a^* and α^*, respectively) is decreasing in price (τ and ϕ, respectively). The demand for brand advertising is an increasing function of both the direct (σ) and brand-stealing (δ) parameters. The model predicts that efforts to create loyal consumers are more prevalent in markets where it is relatively easy (markets with higher δ or σ) or where it is less costly (markets with lower τ) to engage in branding. As a consequence, both the individual and aggregate number of loyal consumers (β^* and B^*, respectively) will be larger in markets where it is easier or less costly to induce consumers to become loyal to a given firm.

Brand advertising is a *substitute* for informational advertising; increases in the unit cost of brand advertising (τ) induce firms to increase their propensities to run price advertisements (α^*). The intuition is that higher brand advertising costs result in less brand-building and hence fewer loyal consumers. This reduces the profits firms earn through traffic at their own websites, and therefore induces them to advertise prices more frequently at the comparison site.

The converse is not true, however; an increase in the cost of informational advertising has *no effect* on firms' demand for branding efforts: $\partial a^* / \partial \phi = 0$. The asymmetric cross price effects stem from the asymmetric manner in which τ and ϕ are paid. Listing fees (ϕ) are paid only when a firm lists prices at the gatekeeper's site, while brand advertising costs (τ) are incurred regardless.

These findings are summarized in

Proposition 6 *In an a^* equilibrium, demand for brand advertising is decreasing in the marginal cost of brand advertising (τ), independent of the cost of informational advertising (ϕ), and increasing in its effectiveness (δ, σ). Demand for informational advertising is decreasing in the cost of listing a price on the comparison site (ϕ), increasing in the cost of brand advertising (τ), and decreasing in the effectiveness of brand advertising (δ, σ).*

Implications for Price Comparison Sites

One of the implications of endogenous branding in oligopolistic online markets is that, in an

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a^* equilibrium, brand advertising expenditures result in a fraction $B^* > 0$ of loyal consumers, and λB^* of these directly visit the websites of individual sellers rather than utilizing the gatekeeper's site. In Baye-Morgan, the gatekeeper enjoys traffic from *all* consumers (due to its incentive to set consumer subscription fees low). By allowing firms to endogenously choose branding levels, we see that firms have an incentive to create loyal consumers, which reduces traffic at the gatekeeper's site to $1 - \lambda B^*$. Thus, branding activities by firms have adverse effects on the "gatekeeper" running the price comparison site.

While we have taken the fee structure of the price comparison site (ϕ) as exogenous, the reality is that fee-setting is a strategic variable for the site's owner. How does the presence of endogenous branding alter fee-setting decisions? Can the "gatekeeper" alter its fee structure to bring consumers back to its site?

The answer to the second question turns out to be no. Indeed, an important implication of Proposition 6 is that B^* (the aggregate fraction of loyal consumers) is independent of the gatekeeper's fees (ϕ). With this result in hand, one can easily tackle the first question: Since the gatekeeper can do nothing through its fee structure to affect the aggregate number of loyals, optimal advertising fees are identical to the case where branding is exogenous. Mitigation of the "traffic diverting" effects of branding would seem to require an additional tool on the part of the gatekeeper, such as its own branding efforts aimed at creating loyalty to the price comparison site.

Levels of Prices and Dispersion

We close this section with a look at how endogenous branding by firms influences the level of prices and the price dispersion observed in online markets. Notice that, when there are n prices listed on the comparison site, the average price paid by shoppers is the expectation of the lowest of n draws from the distribution of advertised prices. In contrast, the average price paid by loyals is simply the average price. Thus, shoppers pay lower average prices than loyal consumers. Our next proposition permits us to examine how the average prices paid by shoppers and loyals are impacted by firms' branding activities.

Proposition 7 *In any symmetric equilibrium, the distribution of advertised prices in markets where firms create more loyal consumers first-order stochastically dominates that in*

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markets where firms create fewer loyal consumers.

Proposition 7, which is proved in Appendix A, implies that both the average price and, for a given number of price listings, the expected minimum price listed at a price comparison site are increasing in the branding efforts of firms. What implications does this have on expected transaction prices?

To answer this question, first recall that the frequency with which a given seller advertises its price at the comparison site (α) is decreasing in branding; thus, increases in branding lead to a decrease in the expected number of price listings on the site. Next, note that the expected transaction price of loyals is a weighted average of the expected advertised price and the unadvertised price (v), where the weight is simply the probability a seller advertises its price. Since the expected price conditional on listing increases and the probability of listing decreases with increased branding, the average transaction price for loyals is higher with increased branding. The expected transaction price for shoppers is simply the weighted average of the expected minimum price conditional on the number of listings and v when there are no listings on the site. Since, for a given number of listings, the expected minimum price is higher with increased branding and the distribution of the number of listings is lower with increased branding, it follows that the expected transaction price to shoppers also increases with increased branding. To summarize:

Corollary 1 *Heightened branding activity raises the expected transaction prices for all consumers.*

Next, we turn to the impact of branding on the level of online price dispersion. Recall that an a^* equilibrium entails a nondegenerate distribution of prices, as firms stop short of converting all consumers into loyals. One of the more widely used measures of dispersion for online markets is the range, which we operationalize as the support of the price distribution. This may be written (using Proposition 1) as

$$R^* = v - p_0^* = \frac{(v - m)\left(1 - \beta^* N\right) - \frac{\phi}{(N-1)} N}{\left(1 - (N - 1)\beta^*\right)}.$$

This permits us to establish:

Proposition 8 *In an a^* equilibrium, equilibrium price dispersion, measured by the range, is greater in online markets where (1) it is less costly to list prices at the gatekeeper's site; or (2) it is more costly or more difficult to create loyal customers. More generally, in any symmetric equilibrium, equilibrium price dispersion, measured by the range, is greater in markets where firms create fewer loyal consumers.*

Part (1) of this proposition follows from the fact that, other things equal, a reduction in ϕ increases the profitability of listing prices at the gatekeeper's site but results in no change in the total number of loyal consumers. Since in equilibrium firms are indifferent between listing prices and not, firms compete away these potential profits by pricing more aggressively at the gatekeeper's site. This reduces the lower support of the price distribution, thus increasing the range in prices.

Part (2) stems from the impact of reduced branding incentives on the total number of loyal consumers in the online marketplace. Increases in τ (or decreases in δ and/or σ) induce each firm to spend less on branding. In equilibrium, this reduces the total number of loyal consumers in the market, thereby heightening competition for the resulting larger number of shoppers. This heightened competition reduces the lower support of the price distribution and again the price range increases. In short, higher levels of price dispersion (measured by the range) are associated with *more* competitive pricing online.

The intuition underlying part (2) of the proposition—that the range in prices is decreasing in the aggregate number of loyal consumers—gives rise to a curious possibility. Recall that each firm's level of branding (and hence its number of loyal consumers) declines as the number of potential firms increases. Nonetheless, the total number of loyal consumers, B^* is increasing in N. This means that if an increase in the number of firms ultimately leads to a market in which $B^* = 1$, then there would be no shoppers and all firms would maximize profits by charging v at their individual websites. Expressed differently, it is not clear whether a nondegenerate distribution of prices will prevail in online markets where N is arbitrarily large. We address this issue in the next section.

4 Equilibrium in Large Online Markets

We now examine characteristics of online markets where an arbitrarily large number of firms compete. From Proposition 3, there is a unique symmetric equilibrium level of brand advertising as $N \to \infty$. We will show that this equilibrium is nontrivial in the sense that it displays both price dispersion and finite numbers of firms (in expectation) using the informational advertising channel. First, note that the number of potential competitors, N, generally exceeds the actual number of firms listing prices at any instant in time. In particular, given that each firm lists a price with probability α^*, the actual number of listings is a binomial random variable with mean,

$$\bar{n} = N\alpha^* < N.$$

We will study how $\bar{n}$ varies in the limit.

It is straightforward to verify that

$$\lim_{N \to \infty} \beta^* = \lim_{N \to \infty} E\pi^* = 0.$$

This implies that, in markets where N is large, each firm enjoys a negligible number of loyal consumers and essentially earns zero economic profits. Thus, the environment we study in this section shares two features of competitive markets: (1) each firm is small relative to the total market, and (2) firms earn zero equilibrium profits.

As we will see, however, even though firms earn zero economic profits in the limit, the resulting equilibrium does not entail marginal cost pricing. In fact, prices remain dispersed and exceed marginal cost with probability one when the number of competitors becomes arbitrarily large. The reason stems from the fact that even though each firm engages in less branding and attracts fewer loyals as N increases, Proposition 3 implies that *aggregate* branding converges to

$$A^L = \lim_{N \to \infty} Na^* = \delta \frac{(v - m)}{\tau - (v - m)\sigma}.$$

This, in turn, implies that the aggregate number of loyals is given by

$$B^L = \lim_{N \to \infty} N\beta^* = \frac{\delta\tau}{\tau - (v - m)\sigma}.$$

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It is useful to note that, since $B^L < 1$, a positive measure of shoppers remain in the market even as the number of competing firms engaging in branding grows arbitrarily large. Furthermore, in the limit the expected number of price listings at the comparison site is

$$\bar{n}^L = \lim_{N \to \infty} \bar{n} = \ln \left(\frac{(v-m)\left((1-\delta)\tau - (v-m)\sigma\right)}{\phi\left(\tau - (v-m)\sigma\right)} \right),$$

which is positive and finite since $\phi < \frac{(v-m)((1-\delta)\tau-(v-m)\sigma)}{(\tau-(v-m)\sigma)}$. Finally, note that prices remain dispersed and above marginal cost even as the number of firms grows arbitrarily large. The limiting distribution of advertised prices is given by

$$F^L(p) = \lim_{N \to \infty} F^*(p) = \frac{\ln \left(\frac{\phi(\tau-(v-m)\sigma)}{(p-m)((1-\delta)\tau-(v-m)\sigma)} \right)}{\ln \left(\frac{\phi(\tau-(v-m)\sigma)}{(v-m)((1-\delta)\tau-(v-m)\sigma)} \right)}$$

on $\left[p_0^L, v \right]$, where

$$p_0^L = m + \frac{\phi\left(\tau - (v-m)\sigma\right)}{(1-\delta)\tau - (v-m)\sigma}.$$

To summarize:

Proposition 9 *Suppose that the conditions given in Proposition 1 hold and $\delta > 0$. Then, in online markets where an arbitrarily large number of firms compete:*

(1) The average number of prices listed at the price comparison site is finite and is given by $\bar{n}^L$.

(2) The aggregate demand for brand advertising is finite and given by A^L.

(3) A non-negligible fraction of shoppers, $1 - B^L > 0$, remain in the market.

(4) Prices listed at the comparison site are dispersed according to F^L on a non-degenerate interval above marginal cost, $\left[p_0^L, v \right]$.

It follows immediately that in online markets where the number of firms is arbitrarily large there is a unique symmetric dispersed price equilibrium. Moreover, as in the oligopoly case, price dispersion (measured by the range) will be higher in markets where it is more difficult or more costly to create loyal consumers, and lower at price comparison sites that charge higher listing fees.

5 Empirical Analysis

To gauge the potential usefulness of the model for organizing the pricing patterns observed in online markets, we conclude by highlighting several testable implications of the theory. Then, we empirically examine these predictions using data from a leading price comparison site.

We begin by considering price dispersion. It is worth noting that even in markets where there are no branding activities (when $\delta = 0$), the model predicts that prices are nonetheless dispersed: The range of observed prices is predicted to be non-degenerate even for products in which there are no loyal consumers.

Recall that Proposition 8 implies that the range in prices, defined as the difference between the upper and lower supports of the equilibrium price distribution, is decreasing in firms' branding activities. While one cannot directly observe the upper and lower supports of the distribution, one can observe the *sample range*, which is defined as the difference between the highest and lowest prices listed on the comparison site. In Appendix B, we show that for calibrated parameter values of the model, the sample range is also decreasing in firms' branding activities (see Figure 1). Thus,

Prediction 1 *All else equal, in markets where brand advertising intensity is higher, price dispersion is lower.*

Next, recall that Proposition 7 implies that advertised prices are stochastically ordered. Hence, the average price listed at the price comparison site, as well as the average minimum price, is an increasing function of firms' branding intensities. Thus,

Prediction 2 *All else equal, in markets where brand advertising is higher, average listed prices are also higher.*

Prediction 3 *All else equal, in markets where brand advertising is higher, the average minimum listed price is also higher.*

The economic motivation for focusing on these two predictions stems from the fact that the average listed price and the average minimum price are related to the prices paid by

loyal consumers and shoppers. Other things equal, higher average listed prices imply higher transactions prices for loyal consumers, and higher average minimum prices imply higher prices paid by shoppers who purchase products online. Note that the difference in these two average prices reflects the average savings of a consumer who purchases at the "best" listed price rather than the average listed price. Thus, $Ep - Ep_{\min}$ provides one measure of the value of the price information provided by a price comparison site. The calibrations in Appendix B also imply that this measure of the value of information is decreasing in firms' branding activities (see Figure 1). Thus,

Prediction 4 *All else equal, in markets where brand advertising intensity is higher, the value of price information is lower.*

5.1 Data

To examine these predictions, we assembled a dataset for 90 of the best-selling products sold at Shopper.com during the period from 21 August 2000 to 22 March 2001. During this period, Shopper.com was the top price comparison site for consumer electronics products (including specific brands of printers, PDAs, digital cameras, software, and the like). A consumer wishing to purchase a specific product (identified by a unique part number) may query the site to obtain a page view that includes a list of sellers along with their advertised price. "Shoppers" can easily sort prices from lowest to highest and, with a few mouse clicks, order the product from the firm offering the lowest price. "Loyals," on the other hand, can easily sort sellers alphabetically or scan the page for their preferred firm's logo and click through to purchase the item from that firm.

We used a program written in PERL to download all the information returned in a page view for each of the products each day, which amounted to almost 300,000 observations over the period. While we have been tracking daily online prices and advertising for the top 1,000 products from the late 1990s to the present (2004), several factors led us to focus on the time period and products in the present study. During these seven months (205 days), there is considerable cross-sectional and time series variation in the brand advertising intensities of firms. Since then, both the online strategies of firms and the structure of

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the Shopper.com site have evolved in ways that make it more difficult to study the impact of branding on levels of price dispersion. Today there is less cross-sectional variation in branding (many more firms advertise their logos at Shopper.com), and product searches at Shopper.com now return mixtures of new and refurbished products. This makes it difficult to determine whether any observed changes in price dispersion stem from increased product heterogeneity (comparing new versus used product prices) or increased brand advertising by firms. In contrast, during the seven months in the present study, Shopper.com treated new and refurbished versions of otherwise identical products as different products. In fact, all of the 90 products in our sample are new products (see Appendix C for a complete description of the products).

During the period of our study, firms uploaded their prices into Shopper.com's database, which then fetched the uploaded data at specified times twice each day. Thus, daily pricing decisions reflect simultaneous moves. Moreover, there is a minimum twelve hour lag for any firm to "answer" a pricing move by its rival owing to the upload/refresh cycle. To advertise a product price, a merchant was required to pay a fixed fee of $1,000 to set up an account at Shopper.com, plus an additional fee of $100 per month. This fee structure provides merchants incentives to post accurate prices; a firm advertising a bogus price in an attempt to lure customers to its own website would generate many qualified leads, but would likely alienate potential customers and incur additional costs.[13] We also verified the accuracy of prices via an audit; more than 96 percent of the prices audited at Shopper.com were accurate within $1.

Table 1 provides basic summary statistics for these data averaged over all products and dates; henceforth, product-dates. On average, 29 firms listed prices for each product and, on average, 8.29 percent of these firms advertised using a logo along with their price listing. While the average price of a product was $458.86, there is considerable variation in the prices different firms charge for a given product. The average lowest price is $387.58, while the average highest price charged is $555.11. The average level of price dispersion is substantial, with an average range of $167.53. As shown in Figure 2, the average range is fairly stable

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[13] The $100 monthly fee entitled sellers to up to 200 free clickthroughs from consumers per month. Sellers who exceed this threshold incur a cost on the order of 50 cents per clickthrough.

and quite sizeable during the period of our study.

5.2 Estimation Strategy and Results

The theory presented above suggests that, for each product i and date t, the range (R_{it}) and average prices $(Ep_{it}$ and $Ep_{\min,it})$ are nonlinear functions of product characteristics (such as the marginal cost of the product, m_{it}), consumer demand characteristics (such as v_{it}), the level of branding (or alternatively, β_{it}), and the number of firms in the market for product i in period t (N_{it}). For example, using the distribution of advertised prices in an a^* equilibrium and integrating by parts yields the following structural expression for the expected advertised price of product i in period t as a function of the relevant explanatory variables:

$$Ep_{it} = v_{it} - \int_{m_{it}+\frac{(v_{it}-m_{it})\beta_{it}+\frac{\phi_{it}}{(N_{it}-1)}N_{it}}{(1-(N_{it}-1)\beta_{it})}}^{v_{it}} \left[\frac{1 - \left(\frac{(v_{it}-p)\beta_{it}+\phi_{it}\frac{N_{it}}{N_{it}-1}}{(1-N_{it}\beta_{it})(p-m_{it})} \right)^{\frac{1}{N_{it}-1}}}{1 - \left(\left(\frac{\phi_{it}}{(v_{it}-m_{it})(1-N_{it}\beta_{it})} \right) \left(\frac{N_{it}}{N_{it}-1} \right) \right)^{\frac{1}{N_{it}-1}}} \right] dp \quad (7)$$

In light of the gross nonlinearities involved—and the fact that we only have proxies for some potentially important explanatory variables—our estimation strategy is to attempt to isolate the impact of branding on the variables of interest (Predictions 1-4) by controlling for other variables that theory suggests might influence the observed levels of price dispersion, average prices, and value of information. In what follows, we estimate a logarithmic first-order Taylor's series approximation of the nonlinear functional forms for the expected price, minimum price, and range of prices for product i at time t. Specifically, in light of the cross-sectional time series nature of our data, we use product fixed effects to control for the fact that consumers are likely to have very different reservation prices (v_{it}) for different products and firms most likely incur different marginal costs (m_{it}) in selling different products. To further control for potential heterogeneities in demand across products, we also include dummy variables for product popularity. Among other things, this controls for possibility that consumers have higher reservation prices for popular products, as well as the possibility that firms are more eager to sell such products. In order to control for the possibility that the general costs of e-retailing, the number of consumers with Internet access, or overall consumer demand for consumer electronics products (and hence reservation prices) tempo-

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rally varied during the period of our study, we also include date fixed effects to control for potential systematic temporal differences in reservation prices and/or firms' cost. One of the advantages of the size of our dataset is that it permits us to include 205 date fixed effects for each day in our sample, 100 dummy variables to control for product popularity (the most popular product, the second most popular product, and so on), as well as 90 product fixed effects for each product in our sample.

While average prices and price dispersion are predicted to vary systematically with the level of branding activity undertaken by firms, we cannot directly observe every component of firms' branding activities. The majority of the firms in our sample are privately held and thus overall expenditures on brand advertising are not readily available. To control for this unobserved variation in branding across products, we include product fixed effects. We do observe one component of brand advertising—the posting of a logo. This form of branding is emphasized in the marketing literature as a means of attempting to product differentiate.[14] Thus, in addition to controlling for other components of branding through product-fixed effects, we use the percentage of firms using logos in selling product i on date t as an empirically observable measure of branding.

We note that, while the number of potential firms is unobservable, it is statistically related to the observed number of listings on a given date. For this reason, we use the number of listings for product i on date t as a proxy for N_{it}. It is important to stress, however, that while the theoretical model presented above is an oligopoly model in which the number of sellers is taken to be exogenous, we are sympathetic to the possibility that firms' decisions to enter the online market for a particular product might be endogenous. Unfortunately, we do not have available instruments to correct for this potential endogeneity. However, the potential problem is mitigated to some extent by the fact that we include product rank dummies (which control to some extent for the possibility that more popular products attract more firms) and by the fact that every firm at Shopper.com must make its period t pricing decisions before it knows how many other firms have decided to compete on that date. Since a necessary condition for listing the price of a given product on a given date is that the firm

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[14]For instance, Keller (2002, page 152) notes: "A brand is a name, term, sign, symbol, or combination of them that is designed to identify the goods or services of one seller or group of sellers and to differentiate them from those of competitors."

paid the $100 monthly "entry fee" which merely gives it the *opportunity* to list and update its price daily for 30 days, to the extent that the number of potential sellers of product i on date t is endogenous, some might argue that such entry decisions are determined well before period t pricing decisions.

With these caveats, we turn to the data analysis. In Tables 2-5 we report semi-log regression results that summarize the estimated impact of branding on, respectively, the sample range, average price, average minimum price, and the value of information.[15] For the reasons discussed above, all specifications include product fixed effects to control for unobserved components of branding and other factors that might give rise to systematic differences in the levels of prices across different products. We also include a variety of other controls to account for the impact of market structure, product life cycles, and other factors. Standard errors have been corrected for possible heteroskedasticity and autocorrelation using the procedure described in Newey and West (1987). In each table, Model 1 represents a baseline regression in which the dependent variable associated with product i at time t is regressed on branding activity, the number of firms listing prices on that date, and product fixed effects. Models 2 through 4 add controls for nonlinear number of firm effects, product popularity fixed effects, and date fixed effects, respectively. Popularity fixed effects are based on Shopper.com's Product Rank (which ranges from 1 to 100 for the products in our sample).

Table 2 examines whether price dispersion varies systematically with firms' branding efforts. Here, the dependent variable is the (log) sample range. In all specifications, the results indicate that, at the 1 percent significance level, price dispersion *negatively* covaries with branding. These results indicate that an increase in the fraction of logos from 8.29% to 9.29% decreases the price range by $2.05 in Model 1 and $3.20 in Model 4. These findings are consistent with Prediction 1.

Table 3 summarizes results for the (log) average price regressions. With the exception of Model 4, the estimates suggest that average prices positively covary with branding. The semi-log regression coefficients imply that an increase in the fraction of logos from the mean (8.29%) to 9.29% increases the average price by 42 cents in Model 1 and increases it by 41 cents in Model 3. The most general specification, Model 4, is at odds with Prediction

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[15]The results are robust to regressions based on levels rather than logs.

2. While the coefficient associated with branding is negative in that specification, it is not statistically significant.

Table 4 summarizes results for the (log) minimum price regressions. Minimum prices positively covary with branding and are significant at the one percent level in Models 1 through 3. These results indicate that an increase in the fraction of logos from 8.29% to 9.29% increases average minimum prices by 99 cents in Model 1 and $1.02 in Model 3. These results are consistent with Prediction 3; however, the coefficient associated in the most general specification, Model 4, remains positive but loses statistical significance.

Why does the coefficient associated with branding in the most general specification lose significance and, in the case of the average price regressions, change sign? One possibility is that logo ads constitute only a small component of a firm's portfolio of branding activities, and the inclusion of the date fixed effects absorbs the remaining variation in the data. The key here is that the use of logos decreases over time in our sample. At the same time, price levels decline over the course of the sample, presumably due to the relatively short life cycles of consumer electronics products. Absent date fixed effects, the branding coefficient captures this time variation in prices thus giving rise to the positive coefficients in Models 1 through 3. Model 4 illustrates the importance of controlling for product life-cycle effects. Adding this control absorbs the time series variation in overall prices, reducing the precision of the estimated branding coefficient.

Notice that this issue does not arise in Model 4 of Table 2. In particular, this specification is based on the difference in the highest and lowest prices at each product date. To the extent that the life cycle effects for a given product are similar for both the highest and lowest prices, differencing the data eliminates individual product life cycle effects. Thus, the specification in Model 4 of Table 2 allows for differences in life cycle effects across products, while that in Model 4 of Tables 3 and 4 do not.

Table 5 summarizes the results for the (log) value of information regressions. Since the value of information is the difference between the average and minimum price for each product date, this specification (like that in Table 2) allows for heterogenous product life cycle effects. The coefficient on branding indicates that the value of information negatively covaries with branding in all four specifications. The coefficient estimates are significant at

the 1% level—even in Model 4. These results indicate that an increase in the fraction of logos from 8.29% to 9.29% decreases that value of price information at Shopper.com by $1.33 in Model 1 and $1.60 in Model 4. In short, all specifications in Table 4 lead to results that are consistent with Prediction 4: firms' branding efforts appear to adversely affect the value of the gatekeeper's site.

The empirical evidence suggests that the level of dispersion and the value of price information in online markets is influenced by the branding activities of firms. Our empirical analysis, however, is limited by the absence of alternative theoretical models as well as data limitations that preclude structural estimation. Indeed, while the empirical evidence is broadly consistent with our theoretical model, it is important to stress that alternative models may better organize the data. Likewise, alternative datasets might permit one to probe other aspects of the theory and deal with some of the potential problems (such as endogeneity) discussed above. The empirical results presented here suggest that future theoretical and empirical research along these lines might prove to be useful additions to the literature.

6   Conclusions

Our analysis highlights the potential importance of jointly modeling firms' brand and price advertising strategies. Allowing for endogenous branding and price advertising leads to cross-channel effects; price advertising is a substitute for brand advertising. This interaction not only alters the characterization of equilibrium, but also leads to a unique dispersed price equilibrium in markets where the number of firms is arbitrarily large—as is arguably the case in online markets. Paradoxically, while each firm finds it optimal to spend money advertising its brand in an attempt to "grow" its base of loyal customers, doing so reduces firm and industry profits.

Our analysis suggests that heightened branding activities by firms lead to higher prices for loyal consumers and shoppers. Branding activities also harm "gatekeepers" operating price comparison sites. Branding converts shoppers into loyals, thereby reducing consumer traffic at the site. In addition, and consistent with our empirical findings, branding tightens

the range of prices and reduces the value of the price information provided by a comparison site. In short, endogenous branding lessens price dispersion, raises prices, and transfers rents from "inside" participants (e-retailers, consumers, and comparison sites) to "outside" participants (e.g., "Madison Avenue").

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A Mathematical Appendix

The proofs of Propositions 1 through 3 rely on a series of lemmas detailed below.

Lemma 1 *Suppose each firm has $\beta \in \left(0, \frac{1}{N}\right)$ loyal customers and that $\phi \in \left(0, \frac{N}{N-1}\left(v - m\right)\left(1 - N\beta\right)\right)$.*
Then there exists a unique symmetric equilibrium in second stage game where:

Each firm lists its price on the price comparison site with probability

$$\alpha_i = \alpha \equiv 1 - \left(\left(\frac{\phi}{(v-m)(1-N\beta)}\right)\left(\frac{N}{N-1}\right)\right)^{\frac{1}{N-1}} \tag{8}$$

and, conditional on listing, selects a price from the cumulative distribution function

$$F_i(p) = F(p) \equiv \frac{1}{\alpha}\left(1 - \left(\frac{(v-p)\beta + \phi\frac{N}{N-1}}{(1-N\beta)(p-m)}\right)^{\frac{1}{N-1}}\right) \tag{9}$$

over the support $[p_0, v]$ where

$$p_0 = m + \frac{(v-m)\beta + \frac{\phi}{(N-1)}N}{(1 - (N-1)\beta)}.$$

Firms that do not list a price at the price comparison site charge a price of $p_i = v$ on their own websites. Each firm earns equilibrium profits of

$$E\pi_i = E\pi = (v-m)\beta + \frac{\phi}{N-1} - \tau a. \tag{10}$$

   Proof. By the usual price undercutting arguments, one can show that in any symmetric equilibrium, the distribution of advertised prices (a) is atomless and contains no gaps, and (b) has an upper support of v.

   Let α and F be candidates for the (symmetric) equilibrium propensity and distribution of advertised prices, respectively. Then a seller that does not list $(L_i = 0)$ its price on the comparison site earns expected profits of

$$E\pi_i(p|L_i = 0) = \left(\beta + (1-\alpha)^{N-1}\frac{1}{N}(1-B)\right)(p-m),$$

which is clearly maximized at a price of v. Thus, conditional on not listing, the optimal price is v, and the corresponding profits are

$$E\pi_i(L_i = 0) = \left(\beta + (1-\alpha)^{N-1}\frac{1}{N}(1-B)\right)(v-m) \tag{11}$$

In contrast, a seller that does list $(L_i = 1)$ a price of $p \in \text{Support}(F)$ on the comparison site earns expected profits of

$$E\pi_i\left(p|L_i = 1\right) = \left(\beta + (1 - B) \sum_{j=1}^{N-1} \binom{N-1}{j} \alpha^j (1 - \alpha)^{N-1-j} (1 - F(p))^j\right) (p - m) - \phi$$

Using the binomial theorem, this expression simplifies to:

$$E\pi_i\left(p|L_i = 1\right) = \left(\beta + (1 - B)(1 - \alpha F(p))^{N-1}\right)(p - m) - \phi \tag{12}$$

for all $p \in \text{Support}(F)$.

Derivation of α. By assumption, $\phi \in \left(0, \frac{N}{N-1}(v - m)(1 - N\beta)\right)$. We first show that $\alpha \in (0, 1)$ in any symmetric equilibrium. By way of contradiction, suppose not. If $\alpha = 0$, no other firms list prices on the comparison site and a firm that deviates by listing a price of v on the comparison site earns (using equation (12))

$$(\beta + (1 - B))(v - m) - \phi$$
$$> (\beta + (1 - B))(v - m) - \frac{N}{N-1}(v - m)(1 - B)$$
$$= \left(\beta + \frac{(1 - B)}{N}\right)(v - m)$$
$$= E\pi_i\left(L_i = 0\right),$$

which contradicts the hypothesis that $\alpha = 0$ is part of a symmetric equilibrium. On the other hand, if $\alpha = 1$, a firm that prices at (or slightly below) v earns expected profits of

$$\left(\beta + (1 - B)(1 - \alpha F(v))^{N-1}\right)(v - m) - \phi$$
$$= \beta(v - m) - \phi$$
$$< \beta(v - m) = E\pi_i\left(L_i = 0\right).$$

Thus, if $\alpha = 1$, firm i's expected profits from not listing exceed those from listing, which contradicts the hypothesis that $\alpha = 1$ is part of a symmetric equilibrium. We conclude that $\alpha \in (0, 1)$.

Next, we establish α. Since $\alpha \in (0, 1)$, equilibrium requires the equalization of equations (11) and (12) for almost all p in the support of F. Noting that

$$\lim_{p \uparrow v} E\pi_i\left(p|L_i = 1\right) = \left(\beta + (1 - B)(1 - \alpha)^{N-1}\right)(v - m) - \phi$$

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yields the following necessary condition for a symmetric equilibrium:

$$\left(\beta + (1-B)(1-\alpha)^{N-1}\right)(v-m) - \phi = \left(\beta + \frac{(1-B)}{N}(1-\alpha)^{N-1}\right)(v-m)$$

Hence,

$$\alpha = 1 - \left(\left(\frac{\phi}{(v-m)(1-B)}\right)\left(\frac{N}{N-1}\right)\right)^{\frac{1}{N-1}}$$

in any symmetric equilibrium. Note that $\phi \in \left(0, \frac{N}{N-1}(v-m)(1-B)\right)$ implies $\alpha \in (0,1)$, as required.

Derivation of F. In a symmetric equilibrium, each firm must be indifferent between (a) charging a price of v and not listing at the price comparison site, and (b) listing any price in the support of F:

$$\left(\beta + \frac{1-B}{N}(1-\alpha)^{N-1}\right)(v-m) = \left(\beta + (1-B)(1-\alpha F(p))^{N-1}\right)(p-m) - \phi. \quad (13)$$

Solving for $1 - \alpha F(p)$ yields

$$1 - \alpha F(p) = \left(\frac{\beta(v-p) + \frac{1-B}{N}(1-\alpha)^{N-1}(v-m) + \phi}{(1-B)(p-m)}\right)^{\frac{1}{N-1}}.$$

It is a routine matter to verify that F is a well-defined atomless cdf on $[p_0, v] \subset [m, v]$, where

$$p_0 = m + \frac{(v-m)\beta + \frac{\phi}{(N-1)}N}{(1-(N-1)\beta)}.$$

To summarize, we have shown that F is a well-defined, atomless cdf with support $[p_0, v]$. Further, since equation (13) is linear in $(1 - \alpha F)$, it then follows that the solution is generically unique.

Finally, notice that it is not profitable for a firm to price below p_0; since F is atomless, a firm enjoys the same sales at a price of p_0 as it does at any $p < p_0$, and the markup is higher at p_0 than $p < p_0$.

Thus, (α, F) represent the unique symmetric pricing strategies at a price comparison site when each seller enjoys β loyal consumers. When each firm has β loyal customers (as is the case when each firm chooses brand advertising level a in the first stage), equilibrium profits following the second stage game are:

$$E\pi(a) = \left(\frac{\delta}{N} + \sigma a\right)(v-m) + \frac{\phi}{N-1} - \tau a. \quad \blacksquare \quad (14)$$

Lemma 2 *Suppose $\phi \in \left(0, \frac{N}{N-1}(v-m)(1-N\beta)\right)$ and a brand advertising level, a, that satisfies:*

$$\left(\frac{\delta}{N} + \sigma a\right)(v-m) + \frac{\phi}{N-1} - \tau a \geq \left(\delta\frac{z}{z+(N-1)a} + \sigma z\right)(v-m) - \tau z \text{ for all } z.$$

Then first stage branding level, a, combined with the second stage pricing and informational advertising strategies identified in Lemma 1 comprise a symmetric Nash equilibrium.

Proof. Recall that a player who conforms to the putative equilibrium branding level, a, earns profits of

$$E\pi(a) = \left(\frac{\delta}{N} + \sigma a\right)(v-m) + \frac{\phi}{N-1} - \tau a$$

by Lemma 1. As usual, a player's incentive to deviate from a in the first-stage depends on beliefs regarding rivals' second-stage response to such a deviation. In order to identify the largest set of a's that can be sustained as part of a Nash equilibrium, consider trigger strategies (following a deviation from a) that result in the lowest possible deviation payoffs. A player who deviates to a branding level z earns profits no less than

$$E\pi(z) = \left(\delta\frac{z}{z+(N-1)a} + \sigma z\right)(v-m) - \tau z, \qquad (15)$$

since such a player can always eschew the informational advertising channel and price at v to its loyal customers. Trigger strategies that support the payoffs to a deviating firm given in equation (15) are as follows: Following a first-stage deviation by firm i: Firm $j = i + 1 \,(\text{Mod } N)$ employs the second stage strategy $\alpha_j = 1$ and

$$p_j = m + \frac{\left(\delta\frac{z}{z+(N-1)a} + \sigma z\right)(v-m) + \phi}{\left(\delta\frac{z}{z+(N-1)a} + 1 - (\delta + (N-1)a\sigma)\right)}$$

The remaining firms $k \neq j, i$ employ the second stage strategy $\alpha_k = 0$, $p_k = v$. Thus, any branding level a such that $E\pi(a) \geq E\pi(z)$ can be supported as a Nash equilibrium. ∎

Proof of Proposition 1

First notice that $\tau > \frac{(v-m)\sigma}{1-\delta}$ and $\delta \in [0,1)$ imply $\frac{(v-m)((1-\delta)\tau-(v-m)\sigma)}{(\tau-(v-m)\sigma)} > 0$; therefore, the set $\left(0, \frac{(v-m)((1-\delta)\tau-(v-m)\sigma)}{(\tau-(v-m)\sigma)}\right)$ is non-empty. Next, we show that when $\phi \in \left(0, \frac{(v-m)((1-\delta)\tau-(v-m)\sigma)}{(\tau-(v-m)\sigma)}\right)$,

the condition on ϕ needed in Lemma 1 also holds. To see this, notice that

$$\frac{N}{N-1}(v-m)(1-N\beta^*)$$

$$> (v-m)(1-N\beta^*)$$

$$= (v-m)\left(1-\delta\left(\frac{N\tau-(v-m)\sigma}{N(\tau-(v-m)\sigma)}\right)\right)$$

$$= \frac{(v-m)(\tau(1-\delta)-(v-m)\sigma)}{(\tau-(v-m)\sigma)}+\frac{1}{N}\frac{(v-m)}{(\tau-(v-m)\sigma)}\delta(v-m)\sigma$$

$$> \frac{(v-m)((1-\delta)\tau-(v-m)\sigma)}{(\tau-(v-m)\sigma)}.$$

It remains to show that a^* satisfies

$$\left(\frac{\delta}{N}+\sigma a^*\right)(v-m)+\frac{\phi}{N-1}-\tau a^* \geq \left(\delta\frac{z}{z+(N-1)a^*}+\sigma z\right)(v-m)-\tau z$$

for all z for Lemma 2 to apply. However, in the text, we showed that the RHS is maximized at $z=a^*$; therefore

$$\left(\frac{\delta}{N}+\sigma a^*\right)(v-m)+\frac{\phi}{N-1}-\tau a^* > \left(\delta\frac{z}{z+(N-1)a^*}+\sigma z\right)(v-m)-\tau z$$

for all z. Hence, (a^*,α^*,F^*) comprise a symmetric Nash equilibrium. ∎

Proof of Proposition 2

First notice that $0 < a^* < \frac{1-\delta}{N\sigma}$. The fact that $a^* > 0$ follows from the hypothesis that $v > m$ and $\tau > \frac{(v-m)\sigma}{1-\delta}$. To see that $a^* < \frac{1-\delta}{N\sigma}$ for all N, note that

$$a^* = \delta\frac{(N-1)(v-m)}{N^2(\tau-(v-m)\sigma)}$$

$$< \delta\frac{(v-m)}{N(\tau-(v-m)\sigma)}$$

$$< \delta\frac{(v-m)}{N\left(\frac{(v-m)\sigma}{1-\delta}-(v-m)\sigma\right)}$$

$$= \frac{1-\delta}{N\sigma},$$

where the second inequality follows from the fact that $\tau > \frac{(v-m)\sigma}{1-\delta}$. Next notice that a^* satisfies the incentive constraint required in Lemma 2 with strict inequality. Thus, by continuity, these two facts imply that any branding strategies $a \in \mathcal{N}(a^*)$ combined with the pricing and informational advertising strategies in Lemma 1 comprise a symmetric Nash equilibrium.
∎

Proof of Proposition 3

To prove part (1), first notice that

$$\lim_{N\to\infty} a^* = 0.$$

In an equilibrium in the $\langle a_N, \alpha_N, F_N \rangle$ sequence, a firm earns

$$E\pi(a_N) = \frac{\delta}{N} + \frac{\phi}{N-1} - \tau a_N \geq 0$$

since otherwise, choosing a zero brand advertising level would be a profitable deviation. Hence,

$$a_N \leq \frac{1}{\tau}\left(\frac{\delta}{N} + \frac{\phi}{N-1}\right)$$

Since a_N is bounded from below by zero, it then follows that $\lim_{N\to\infty} a_N = 0$.

To prove part (2), first notice that

$$\lim_{N\to\infty} Na^* = \delta\frac{(v-m)}{(\tau-(v-m)\sigma)}.$$

Next, notice that $\langle Na_N \rangle$ is a bounded sequence (since $Na_N \in \left[0, \frac{1-\delta}{\sigma}\right]$ for all N) and hence has a subsequence $\langle N_k a_{N_k} \rangle_{k=1}^{\infty}$ that is convergent. We will show that

$$\lim_{N\to\infty} Na_N = \delta\frac{(v-m)}{(\tau-(v-m)\sigma)}.$$

By way of contradiction, suppose not. There there exists a convergent subsequence $\langle N_k a_{N_k} \rangle_{k=1}^{\infty}$ such that

$$\lim_{k\to\infty} N_k a_{N_k} = l \neq \delta\frac{(v-m)}{(\tau-(v-m)\sigma)}$$

Consider the profits of a firm that deviates by choosing a branding level $z \neq a_{N_k}$ when there are N_k firms competing. That firm earns

$$E\pi(z) = \left(\frac{z}{z+(N_k-1)a_{N_k}}\delta + \sigma\right)(v-m) - \tau z$$

By hypothesis, a_{N_k} is an equilibrium. This requires that

$$\left(\frac{\delta}{N_k} + \sigma\right)(v-m) + \frac{\phi}{N_k-1} - \tau a_{N_k} \geq E\pi(z)$$

for all feasible z. Taking limits

$$\lim_{k\to\infty}\left(\left(\frac{\delta}{N_k} + \sigma\right)(v-m) + \frac{\phi}{N_k-1} - \tau a_{N_k}\right) = \lim_{k\to\infty}\left(E\pi(z)\,|_{z=a_{N_k}}\right)$$

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Thus, it must be the case that the limit of the equilibrium subsequence satisfies

$$\lim_{k\to\infty}\left(\frac{d}{dz}E\pi\left(z\right)|_{z=a_{N_k}}\right)=\lim_{k\to\infty}\left(\frac{(N-1)\,a_{N_k}}{(z+(N-1)\,a_{N_k})^2}\delta\left(v-m\right)-(\tau-\sigma\left(v-m\right))|_{z=a_{N_k}}\right)=0$$

(16)

since otherwise, for sufficiently large N_k a firm would have a profitable deviation. Substituting for $z=a_{N_k}$ in equation (16) yields

$$\frac{l}{(l)^2}\delta\left(v-m\right)-(\tau-\sigma\left(v-m\right))=0$$

Solving:

$$l=\delta\frac{(v-m)}{(\tau-(v-m)\,\sigma)},$$

which is a contradiction. ∎

Comparative Statics. We next verify the comparative statics provided in the text. Note that

$$E\pi^*=(v-m)\,\beta^*+\frac{\phi}{N-1}-\tau a^*=(v-m)\,\frac{\delta}{N^2}+\frac{\phi}{N-1}.$$

Hence, $\partial E\pi^*/\partial\delta>0$; $\partial E\pi^*/\partial\sigma=\partial E\pi^*/\partial\tau=0$; $\partial E\pi^*/\partial N<0$; $\partial E\pi^*/\partial\phi>0$; $\partial E\pi^*/\partial v>0$; and $\partial E\pi^*/\partial m<0$. Furthermore, since

$$a^*=\delta\frac{(N-1)\,(v-m)}{N^2\,(\tau-(v-m)\,\sigma)},$$

it is immediate that $\partial a^*/\partial\delta>0$; $\partial a^*/\partial\sigma>0$; $\partial a^*/\partial\tau<0$; $\partial a^*/\partial\phi=0$; $\partial a^*/\partial v>0$; and $\partial a^*/\partial m<0$. In addition,

$$\frac{\partial a^*}{\partial N}=-(v-m)\,\delta\frac{N-2}{N^3\,(\tau-(v-m)\,\sigma)}\le 0.$$

Next, note that

$$\beta^*=\frac{\delta}{N}\left(\frac{N\tau-(v-m)\,\sigma}{N\,(\tau-(v-m)\,\sigma)}\right)>0.$$

Hence, it is immediate that $\partial\beta^*/\partial\delta>0$ and $\partial E\beta^*/\partial\phi=0$. In addition,

$$\frac{\partial\beta^*}{d\sigma}=\delta\,(v-m)\,\tau\frac{N-1}{N^2\,(\tau-(v-m)\,\sigma)^2}>0;$$

$$\frac{d\beta^*}{d\tau}=-\delta\sigma\frac{(v-m)\,(N-1)}{N^2\,(\tau-(v-m)\,\sigma)^2}<0;$$

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$$\frac{d\beta^*}{dN} = -\delta \frac{N\tau - 2(v-m)\sigma}{N^3(\tau - \sigma(v+m))} < 0;$$

and

$$\frac{d\beta^*}{d(v-m)} = \delta\sigma\tau \frac{N-1}{N^2((v-m)\sigma - \tau)^2} > 0.$$

Finally, since $B^* = N\beta^*$, all comparative statics for B^* (save $\partial B^*/\partial N$) follow directly from those for β^*. Furthermore,

$$\frac{dB^*}{dN} = \delta(v-m)\frac{\sigma}{N^2(\tau - (v-m)\sigma)} > 0.$$

Since

$$p_0 = m + \frac{(v-m)\beta^* + \frac{\phi}{(N-1)}N}{(1-(N-1)\beta^*)}$$

is increasing in β^*, it follows (using the comparative statics for β^*) that $\partial p_0/\partial\delta > 0$; $\partial p_0/\partial\sigma > 0$; $\partial p_0/\partial\tau < 0$; $\partial p_0/\partial\phi > 0$; and $\partial p_0/\partial v > 0$. However, since

$$\alpha^* \equiv 1 - \left(\left(\frac{\phi}{(v-m)(1-B^*)}\right)\left(\frac{N}{N-1}\right)\right)^{\frac{1}{N-1}}$$

is decreasing in B^*, it follows (using the comparative statics for B^*) that $\partial\alpha^*/\partial\delta < 0$; $\partial\alpha^*/\partial\sigma < 0$; $\partial\alpha^*/\partial\tau > 0$; and $\partial\alpha^*/\partial\phi < 0$.

Proof of Proposition 7

To establish this result, rewrite the equilibrium distribution of advertised prices as:

$$F = \frac{1}{\alpha}\left(1 - \rho^{\frac{1}{N-1}}\right),$$

where $\rho = \left(\frac{(v-p)\beta + \phi\frac{N}{N-1}}{(1-N\beta)(p-m)}\right)$. The following facts are used in the proof of the proposition.

$$\frac{d\alpha}{d\beta} = -\frac{N}{(N-1)(1-N\beta)}(1-\alpha) < 0;$$

$$\frac{d\rho}{d\beta} = \frac{(v-p)(N-1) + \phi N^2}{(N-1)(1-N\beta)^2(p-m)} > 0;$$

$$\frac{\partial\rho}{\partial p} = \frac{-\beta(v-m)(N-1) - \phi N}{(N-1)(1-N\beta)(-p+m)^2} < 0; \text{ and}$$

$$\frac{\partial^2\rho}{\partial\beta\partial p} = \frac{-(v-m)(N-1) - \phi N^2}{(N-1)(1-N\beta)^2(p-m)^2} < 0.$$

We are now in a position to prove Proposition 7. Since β is decreasing in τ, it is sufficient to show that F is decreasing in β. Notice that for all $p \in [p_0, v]$:

$$
\begin{aligned}
\frac{\partial F}{\partial \beta} &= \frac{d}{d\beta}\left(\frac{1}{\alpha}\left(1 - \rho^{\frac{1}{N-1}}\right)\right) \\
&= -\frac{1}{\alpha^2}\left(1 - \rho^{\frac{1}{N-1}}\right)\frac{\partial \alpha}{\partial \beta} - \frac{1}{\alpha}\frac{1}{N-1}\rho^{\frac{1}{N-1}-1}\frac{d\rho}{d\beta} \\
&< \left(-\frac{1}{\alpha^2}\left(1 - \rho^{\frac{1}{N-1}}\right)\frac{\partial \alpha}{\partial \beta}\right)\Big|_{p=v} - \left(\frac{1}{\alpha}\frac{1}{N-1}\rho^{\frac{1}{N-1}-1}\frac{d\rho}{d\beta}\right)\Big|_{p=v} \\
&= \frac{1}{\alpha^2}\left(1 - (1-\alpha)\right)\frac{N}{(N-1)(1-N\beta)}(1-\alpha) - \frac{1}{\alpha}\frac{1}{N-1}(1-\alpha)^{2-N}\frac{N}{1-N\beta}(1-\alpha)^{N-1} \\
&= \frac{1}{\alpha}\frac{N}{(N-1)(1-N\beta)}(1-\alpha) - \frac{1}{\alpha}\frac{1}{N-1}\frac{N}{1-N\beta}(1-\alpha) \\
&= 0,
\end{aligned}
$$

where the inequality follows from the facts derived above. Since $\frac{\partial F(p)}{\partial \beta} < 0$ for $p \in [p_0, v]$ and $\frac{\partial p_0}{\partial \beta} = \frac{v-m+\phi N}{(N\beta-1-\beta)^2} > 0$, the required stochastic ordering is established. ∎

B Calibration

In general, the sample range and the value of information are of ambiguous sign with respect to changes in branding. As discussed in the text, we calibrated an a^* equilibrium of the model to infer the implied relationship between branding and price dispersion around the mean values of our data. Specifically, we approximated consumers' maximal willingness to pay, v, by the average maximum price observed in our data, which is \$555.11. We set the number of potential firms, N, at 68, which is the largest number of firms listing prices for any product in our dataset, and set the number of firm's listing prices at 29, which is the average in our sample. The listing fee for posting a price at the comparison site is calibrated at $\phi = \$3.33$, which is the average cost per day of listing a price at Shopper.com during the period of our study.

Calibrating marginal cost is more involved. We assumed a 38.5% gross margin on the average transaction price, which is based on the US Census Bureau's estimate of the average margin for Electronic Shopping and Mail Order Retailers (NAICS 4541).[16] To obtain the

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[16]Table 6: Estimated Gross Margin as Percent of Sales by Kind of Business, US Census Bureau, Revised

average transaction price, we supposed that 13% of customers bought items at the average minimum price—that is, were shoppers in our terminology—while the reminder bought items at the average price—that is were loyal customers. The 13% figure is based on estimates by Brynjolfsson, Montgomery, and Smith (2003) for the percentage of Internet users using price comparison sites over the 2000-2002 period. This completely calibrates the model.

Figure 1 displays calibrated values for the sample range and the value of information. As the figure shows, when the fraction of loyal customers is between 85 and 100%, as implied by the Brynjolfsson, Montgomery and Smith study, both the sample range and value of information are decreasing functions of the fraction of loyal consumers, as summarized in Predictions 1 and 4. The empirical results in Tables 2 and 5 are consistent with Figure 1. Expressed differently, the empirical results in Tables 2 and 5, along with the calibration in Figure 1, suggest that less 15% of the consumers at Shopper.com actually buy at the lowest listed price.

June 1, 2001.

Appendix C: List of Products

#	Product
1	ADOBE ACROBAT 4.0
2	ADOBE PHOTOSHOP V5.5
3	AMD K6 2 - 500 MHz
4	AMD K7 - 700 MHz
5	AMD K7 - 750 MHz
6	AMD K7 - 800 MHz
7	AMD K7 - 850 MHz
8	BE6-II
9	Canon PowerShot S10
10	Canon PowerShot S100
11	Canon PowerShot S20
12	Compaq CPWAP500 (Pentium II 450 MHz)
13	Compaq Presario 1200-XL118
14	Compaq Presario 5868
15	Compaq Presario 7940
16	Compaq iPaq H3650 Pocket PC
17	Creative Labs 3D Blaster Annihilator Pro
18	Creative Labs Desktop Theater 5.1 DTT2500 Digital
19	Creative Labs Nomad 64 MP3 Player
20	Creative Labs Nomad II
21	Creative Labs PC DVD-RAM (SCSI)
22	Creative Labs Sound Blaster Live Platinum
23	Creative Labs Sound Blaster Live Value
24	Creative Labs Sound Blaster PCI128 sound card
25	DESKPRO EN P3-450 9.1GB 64MB
26	ELSA Gladiac GeForce2 GTS
27	EPHOTO CL50 COL DIGTLCAM DIGITAL CAMERA
28	Epson Stylus Photo 1270
29	Epson Stylus Photo 870
30	EpsonStylus Color 740
31	Fuji FinePix 4700 Zoom
32	HP CD-Writer Plus 9100i (32X/8X/4X)
33	HP Kayak XA
34	HP LaserJet 1100xi
35	HP ScanJet 6300Cxi
36	Handspring Visor
37	Handspring Visor Deluxe
38	IBM ThinkPad 240
39	IBM Thinkpad T20
40	INTELLIMOUSE EXPLORER CD W9X PS2/USB
41	Iomega 250MB USB ZIP Drive
42	Kodak DC280 Zoom
43	Kodak DC290 Zoom
44	Linksys EtherFast 4-port Cable/DSL Router
45	19IN/18.0V 26MM 1600X1200 85HZ SYNCMASTER 950P TCO99
46	3dfx Voodoo 3 3000
47	64MB 8X64 SDRAM PC133 8NS
48	72Pin Simm NonParity Edo 64MB
49	NORTON ANTIVIRUS 2000 V6.0 RETAIL BOX WIN95/98/NT SINGLE 1DOC
50	NORTON ANTIVIRUS V5.0 WIN 95/98/NT SINGLE 1-DOC
51	NORTON CLEANSWEEP 2000 V4.7 WIN95/98/NT SINGLE 1-DOC
52	NetGear RT311 DSL & Cable Modem Router
53	Nikon Coolpix 800
54	Nikon Coolpix 950
55	Nikon Coolpix 990
56	Office 2000 - Professional Edition
57	Olympus C-2020 Zoom
58	Olympus C-3000 Zoom
59	Olympus C-3030 Zoom
60	Olympus D-460 Zoom
61	PAINT SHOP PRO V6.0 CD W9X/NT
62	PC100 Sdram NonEcc 64MB 8x64
63	PENTIUM III P3 733MHZ 256KB L2 133MHZ SLOT1 COPPERMINE .18MU
64	POWERSHOT PRO70 DIGITAL CAMERA CCD SENSOR W/CTS ZOOM CPBL
65	Palm III
66	Palm IIIc
67	Palm IIIe
68	Palm IIIe Special Edition
69	Palm IIIx
70	Palm IIIxe
71	Palm M100
72	Palm V
73	Palm VII
74	Palm Vx
75	Panasonic KXL-RW10A
76	Pentium III - 600 MHz
77	Pentium III - 700 MHz
78	Pentium III - 800 MHz
79	Plextor PlexWriter 32X/8X/4X CD-RW drive
80	Plextor Plexwriter 12X/10X/32X CD-RW
81	SATELLITE 2210XCDS CEL-500 6GB 64MB 13 DSCAN 24X V90 WIN 98
82	Sony Cyber Shot DSC-S70
83	Sony MVC-FD91 Digital Mavica
84	Sony MVC-FD95 Digital Mavica
85	Sony VAIO PCG-F420 (128MB RAM 12.0GB HD)
86	Toshiba Satelite 2180CDT (AMD K6-2 475 MHz 4.3GB HD)
87	ViewSonic PF790
88	WINDOWS 2000 PROFESSIONAL W2K
89	WINDOWS 98 SECOND EDITION
90	Western Digital Caviar 20.5GB EIDE

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Figure 1. Calibrated Sample Range and Value of Infomation

Fraction of Loyal Customers

Range —— Value of Information
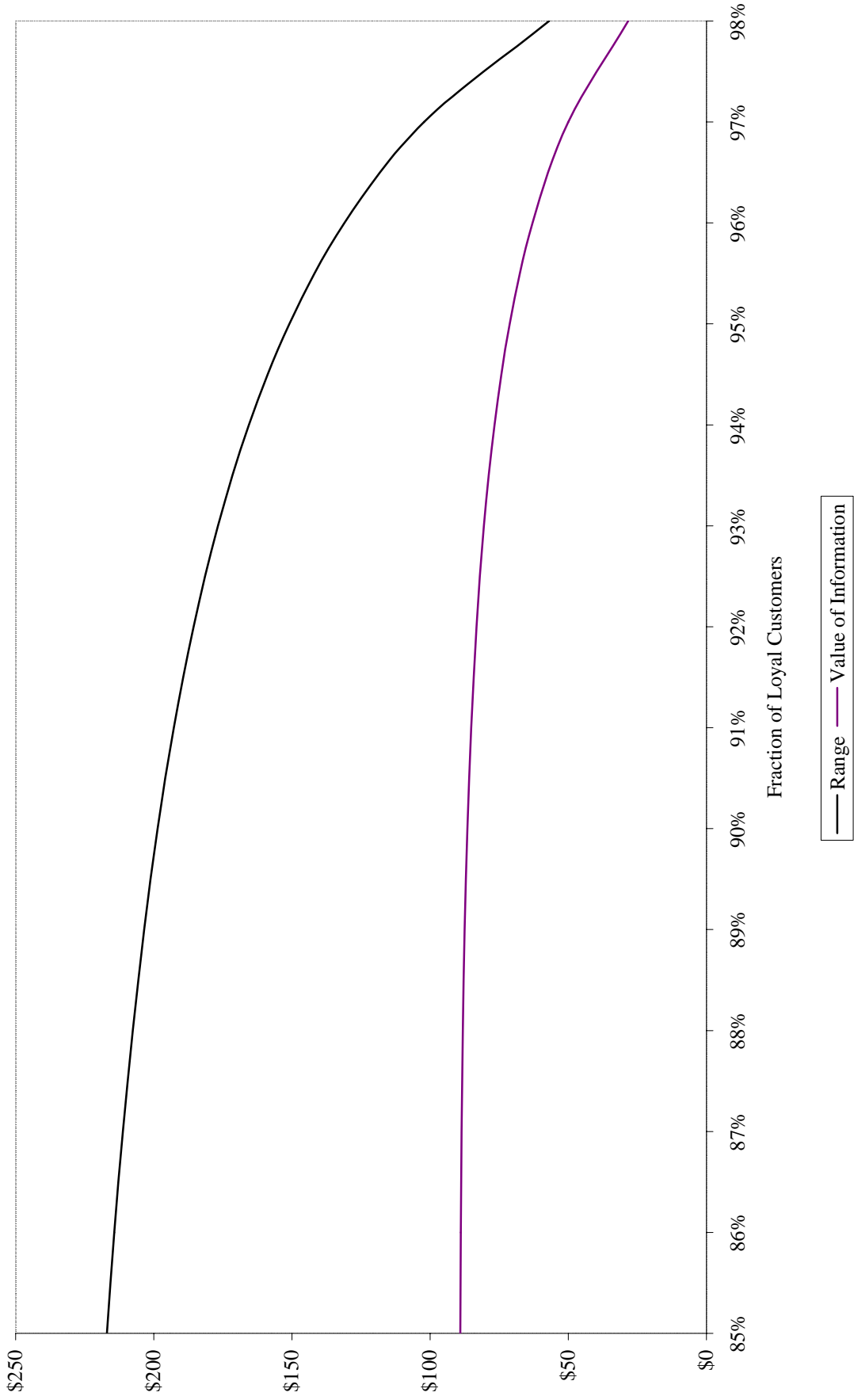
Figure 2. Price Dispersion, August 2000 - April 2001
Shopper.com Top 100 Products

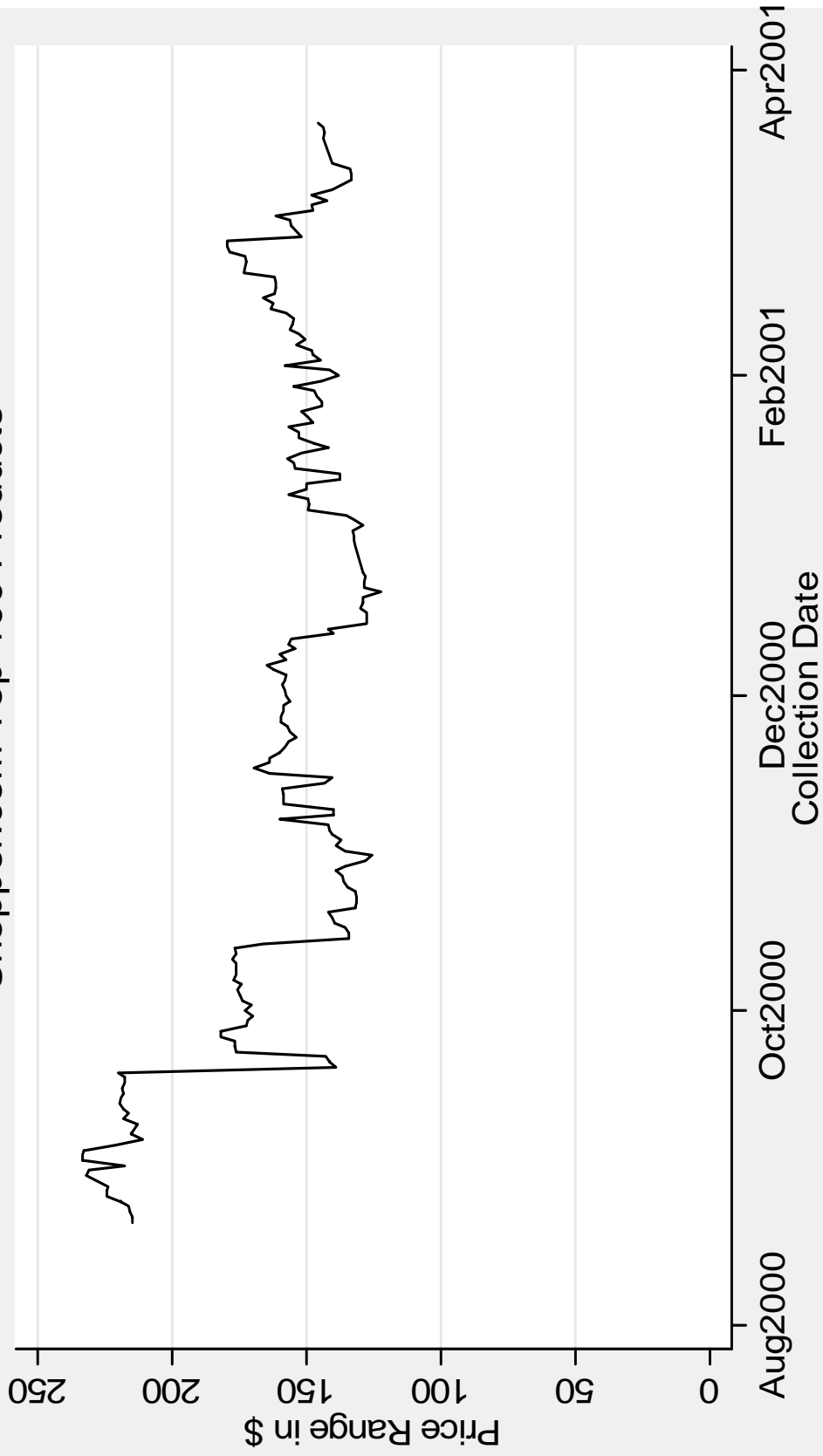| Total Observations			
Number of Products	90		
Number of Dates	214		
Number of Prices	291,039		

Product Summary Statistics	Mean	Std. Dev	Median
Price			
Average Price	$458.86	$496.64	$325.94
Lowest Price	$387.58	$412.07	$282.00
Highest Price	$555.11	$586.76	$404.25
Advertising Levels			
Number of Advertised Prices	29.07	17.23	29.00
Percentage of Listings with Logos	8.29%	6.49%	8.11%
Price Dispersion			
Price Range	$167.53	$229.75	$104.35

Table 2: Log Range Regressions

Dependent variable: Log Range

	Model			
	1	2	3	4
Branding	-1.224	-1.290	-1.272	-1.912
	(4.31)**	(4.67)**	(4.72)**	(6.35)**
# of Firms	0.024	0.050	0.049	0.043
	(18.01)**	(13.02)**	(12.24)**	(9.80)**
(# of Firms)²		0.000	0.000	0.000
		(8.94)**	(8.56)**	(6.60)**
Product Fixed Effects	yes	yes	yes	yes
Popularity Fixed Effects			yes	yes
Date Fixed Effects				yes
# of observations	9980	9980	9980	9980

Notes: HAC adjusted t statistics in parentheses.
* significant at 5%; ** significant at 1%

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Dependent variable: Log Average Price

	Model			
	1	2	3	4
Branding	0.091	0.093	0.090	-0.069
	(3.37)**	(3.48)**	(3.43)**	(1.55)
# of Firms	-0.001	-0.001	-0.002	-0.005
	(3.03)**	(1.98)*	(2.09)*	(5.63)**
(# of Firms)²		0.000	- 0.000	0.000
		(1.39)	(1.52)	(4.20)**
Product Fixed Effects	yes	yes	yes	yes
Popularity Fixed Effects			yes	yes
Date Fixed Effects				yes
# of observations	10013	10013	10013	10013

Notes: HAC adjusted t statistics in parentheses.
* significant at 5%; ** significant at 1%

Table 4: Log Minimum Price Regressions

Dependent variable: Log Minimum Price

	Model			
	1	2	3	4
Branding	0.256	0.263	0.262	0.127
	(5.56)**	(5.79)**	(5.82)**	(1.80)
# of Firms	-0.002	-0.005	-0.005	-0.009
	(6.99)**	(5.18)**	(5.14)**	(8.76)**
(# of Firms)²		0.000	0.000	0.000
		(3.68)**	(3.73)**	(6.91)**
Product Fixed Effects	yes	yes	yes	yes
Popularity Fixed Effects			yes	yes
Date Fixed Effects				yes
# of observations	10013	10013	10013	10013

Notes: HAC adjusted t statistics in parentheses.
* significant at 5%; ** significant at 1%

Table 5: Log Value of Information Regressions

Dependent variable: Log Value of Information

	Model			
	1	2	3	4
Branding	-1.870	-1.924	-1.902	-2.247
	(6.82)**	(7.13)**	(7.28)**	(7.40)**
# of Firms	0.014	0.035	0.035	0.040
	(11.07)**	(9.08)**	(8.65)**	(9.19)**
(# of Firms)²		0.000	0.000	0.000
		(7.28)**	(7.03)**	(7.99)**
Product Fixed Effects	yes	yes	yes	yes
Popularity Fixed Effects			yes	yes
Date Fixed Effects				yes
# of observations	9980	9980	9980	9980

Notes: HAC adjusted t statistics in parentheses.
* significant at 5%; ** significant at 1%