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Online Shopping Intermediaries: The Strategic Design of Search Environments

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An online shopping intermediary is an Internet platform on which consumers and third-party sellers transact. Shopping intermediaries provide a search environment (e.g., search aids) to lower the search costs incurred by consumers when finding and evaluating sellers' products. We study strategic incentives of an intermediary in the design of its search environment as a means to ease search costs. An important aspect of our analysis is that consumers optimally decide how many sellers to evaluate and how deeply (e.g., number of attributes) to evaluate each of them. We find that the equilibrium search environment embeds sufficiently high search costs to prevent consumers from evaluating too many sellers, but not too high to cause them to evaluate sellers' products at partial depth.

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1. Introduction

Consumers are increasingly using the Internet to evaluate product information and make purchases. Following this trend, online intermediaries, such as Taobao Mall, Yahoo Shopping, and Amazon's Marketplace, offer platforms on which consumers and third-party sellers can interact. To help consumers navigate and evaluate the huge number of sellers' products, interactive search tools within the search environment are provided by the intermediaries. According to personal communication with an anonymous manager from one of the above online platforms, serving both third-party sellers and consumers of these sellers creates two goals for any online intermediary: help consumers to find a desirable product and keep sellers' competition in check. The problem, however, is that these goals are often conflicting, which raises the following question for managers: how should an intermediary design a search environment to help consumers to find a desirable product while ensuring the profitability of hosted sellers?

The strategic element in the design of an intermediary's search environment can be seen by the selective provision of faceted navigation aids, also called attribute-screening aids. In fact, the most popular shopping intermediaries seem to provide inferior navigation aids when compared to online retailers, such as Walmart.com or Target.com, who sell their own products. For instance, Taobao Mall does not permit shoppers navigating its site to purchase a ruler to screen a ruler's length, which is arguably a key attribute in selection. Walmart.com, in contrast, allows screening of this attribute. Similarly, when shopping for socks, Yahoo Shopping provides no screening aids, unlike Target.com (e.g., "casual," "dress," etc.). This is not to say that one is unable to learn about these attributes on intermediaries' sites, but a shopper is required to click on a specific product and read the product description.

Unlike conventional retailers, online shopping intermediaries host third-party sellers, providing them the freedom to choose sale prices, and then typically charge a percentage of the final price as a referral fee.[1] This revenue-sharing scheme incentivizes the intermediary to protect sellers from fierce competition to benefit from higher prices. This research studies the strategic considerations of an online shopping intermediary in designing a search environment that balances the needs of consumers and the benefits for sellers. We focus, in particular, on the strategic aspects of a search environment design that is operationalized by the control of search costs,[2] because this aspect affects consumers' evaluation incentives.

[1] For example, Taobao Mall's referral fees are 2%–5% in most product categories. Yahoo Shopping charges 0.75%–1.5% in some categories.

[2] We use search costs and evaluation costs interchangeably.

The conventional wisdom in the search literature suggests that consumers scale back the number of considered sellers when faced with higher search costs (see Anderson and Renault 1999).[3] However, this literature assumes that consumers learn the entirety of information about any searched product. The recent search literature suggests that consumers can acquire partial product information. A consumer, therefore, can react to high search costs by decreasing the amount of information acquired about a searched product (Branco et al. 2012, Ke et al. 2016). Incorporating this within-product search dimension (or "evaluation depth" in the following text) makes a consumer's reaction to higher search costs not obvious. In this paper, we study an intermediary's strategic considerations in designing a search environment when the new dimension, depth (within products), is incorporated into the conventional search dimension, breadth (across sellers).

To illustrate the trade-off in a consumer's depth and breadth choice, consider a consumer who wants to buy a camera. She knows her tastes about cameras (e.g., style, color, size, viewfinder type, etc.) and her price range but does not have a particular camera in mind. At an intermediary's website, she will evaluate a set of models offered by the third-party sellers. Since evaluating cameras is costly, it is up to the consumer to decide how many sellers to evaluate (evaluation breadth) and how much information to acquire for each model (evaluation depth). She may decide, for instance, to look into every available technical detail (e.g., megapixels, screen size, memory, aspect ratio, etc.). But by examining the products in such detail, she might not be able to consider many brands. Alternatively, she may consider many brands but forgo some of the technical details. A shopping intermediary can create an interactive search environment that affects this trade-off.

The depth and breadth of the consumer's evaluation plan affects her knowledge of the evaluated products. Specifically, evaluation depth affects her level of uncertainty about the most preferred product, and evaluation breadth affects the number of sellers competing for her purchase. In classic search models, a larger search cost implies fewer seller evaluations (lower evaluation breadth). In our setting, however, a consumer can react to higher search costs by decreasing the depth of evaluation rather than by only cutting back on the number of evaluated sellers. Because of the endogenous interplay between evaluation depth and breadth, we can model the intermediary's strategic design of the search environment by its choice of conventional search costs.

Our model generates a necessary and sufficient condition for the intermediary's profit-maximizing search environment, which implies the main finding in this research. Specifically, the intermediary's optimal search environment maximizes consumer search cost subject to the condition that the consumer does not partially evaluate products. If search costs exceed this point, the consumer will evaluate products partially (e.g., not evaluating some product attributes) and thus be unable to fully appreciate the value of her most preferred product. This puts downward pressure on sellers' prices. However, by making the search less costly, the consumer broadens the set of evaluated sellers and induces them to price more competitively. The intermediary's optimal search environment reflects, therefore, the following balance: keep search costs sufficiently low so that the consumer fully evaluates the products she considers and fully knows what she is buying, but not low enough that she searches a lot of sellers.

We also find that a shopping intermediary's level of search aids decreases the level of seller differentiation in the product category. As identified in much of the search literature, greater product differentiation implies a greater incentive to evaluate products (Anderson and Renault 1999). Moreover, because consumers evaluate with full depth in equilibrium, greater product differentiation induces them to expand their evaluation across more sellers. In response, the intermediary must provide a less helpful search environment to increase search costs. That is, the intermediary's search environment is less helpful in product categories with more differentiated sellers.[4]

Our work builds on the literature relating to the accuracy and effort tradeoff in an individual's decision-rule selection. Specifically, decision makers select a particular decision rule in a specific environment by weighing the costs and benefits of a set of rules and adapt their decision-making strategies to the specific environment (Payne 1982). Using this framework, Häubl and Trifts (2000) showed that the online shopping environment lowers consumers' efforts, allowing them to evaluate selected products at greater depth and make better purchase decisions. However, the study focuses on how the search

[3] In the context of online shopping, Lal and Sarvary (1999) show that the presence of the Internet can increase the costs for consumers to evaluate another product at a physical store, which implies softened price competition.

[4] For example, Taobao Mall provides four faceted search aids for both print papers and printers although the latter category can be considered as more differentiated. In this case, the online shopping intermediary provides proportionally fewer faceted search aids for more differentiated products.

environment helps consumers' product evaluations without regard to the pricing incentives of third-party sellers. In contrast, we propose an equilibrium model with a representative consumer, an intermediary, and competing sellers and study their strategic interactions in order to identify the intermediary's optimal level of search costs in the shopping environment.

Conceptually, our work connects to recent theory literature exploring new dimensions of consumer search and product evaluation. For example, Bar-Isaac et al. (2012) and Branco et al. (2012) focus on a monopolistic seller facing consumers who partially evaluate a specific alternative. Because consumers often consider and evaluate several alternatives when shopping at an online intermediary, the study of an intermediary's incentives requires a model that captures sellers' competitive reactions to consumers' partial evaluations. Ke et al. (2016) study a consumer's sequential partial-evaluation process with multiple alternatives, abstracting away from firms' strategic pricing incentives. In contrast, we do not consider sequential search process but allow sellers to endogenously determine their prices on the intermediary. Finally, our paper is related to Liu and Dukes (2013), which studies consumers evaluating multiproduct firms. Like this paper, the work of Liu and Dukes (2013) utilizes a simultaneous search model with two dimensions. Unlike this paper, the work of Liu and Dukes (2013) assumes that consumers cannot partially evaluate products. Conceptually, partial evaluation is an underexplored topic (Bar-Isaac et al. 2012, Branco et al. 2012) but is widely seen in many familiar shopping situations (Hauser 2011) and is a key aspect of online shopping (Häubl and Trifts 2000). Indeed, the possibility that consumers face residual uncertainty about a chosen product plays a central role in our results but plays no role in the model of Liu and Dukes (2013). In addition, the cost of evaluating a product is exogenous in the work of Liu and Dukes (2013) whereas in this paper, there is an intermediary choosing this cost.

The marketing literature has recognized two basic roles of online shopping intermediaries to serve consumers: providing product information of price and nonprice attributes (Häubl and Trifts 2000, Iyer and Padmanabhan 2006). Chen et al. (2002) and Iyer and Pazgal (2003) consider the intermediary's role as disseminator of price information.[5] Chen et al. (2002) study the intermediary's role as a price-discrimination mechanism, whereas Iyer and Pazgal (2003) focus on the motivation of Internet retailers to join an intermediary's service. Similar to our paper, these studies consider an intermediary that hosts third-party sellers. However, both of these studies focus on situations in which a consumer knows the specific product she wants to buy and uses the intermediary to find the best price. Our paper, in contrast, examines the case in which the consumer uses the intermediary to help her to find a good-fitting product based on nonprice attributes for products in a similar price range. In addition, our paper considers the consumer's evaluation process as a function of the intermediary's designed search environment. As such, this research is among the first to incorporate consumers' optimal search behavior into the intermediary's design of the search environment.[6]

Finally, our work is also related to the literature on common agency. Bernheim and Whinston (1985, 1986) show that a common agency may allow sellers to collude and achieve maximal cooperative profit if they delegate the pricing or output decisions to the agency. In contrast, in our paper, sellers are assumed to delegate the controls of the shopping environment to the intermediary. As we show, although the intermediary cannot help sellers to implement monopoly pricing, it can design the search environment to protect sellers from fierce competition.

2. Model

There are n third-party sellers, each selling a single product. The products are horizontally differentiated and have no systematic quality differences. The mass of the consumers is normalized to one, and each consumer has a demand for one product. We assume that the consumer initially has imperfect information about the fit of products' attributes (e.g., color or styling) with realized fits that are independent. She must therefore evaluate a product to determine its idiosyncratic utility. Product evaluation is costly to the consumer, but an intermediary provides a search environment to reduce her evaluation costs. Observing such a search environment, but not products' fit realizations, the consumer chooses how many products to evaluate (evaluation breadth) and how much information to acquire about each considered product (evaluation depth). These assumptions imply that all the products are a priori identical before evaluation but may differ after evaluation by their ex post fit realizations and prices, which affect the consumer's product choice.

[5] Jiang et al. (2011), which also studies the price-informative role of an intermediary, focuses on the potential threat from the intermediary to compete against a third-party seller that incentivizes the seller to mask the popularity of its product from an intermediary.

[6] In reality, an intermediary often carries a daunting number of products that may affect consumer search and even limit choice (Kuksov and Villas-Boas 2010). We do not consider this effect or its influence on the intermediary's search-environment design.

The sequence of moves in the model is as follows.

1. The intermediary chooses its search environment (operationalized by controlling search costs).
2. Each of the n sellers simultaneously chooses a price for its product.
3. The consumer then selects the evaluation depth (how much information to acquire about a product) and breadth (how many sellers to evaluate).
4. The consumer evaluates products at the selected depth for all evaluated firms. The consumer learns, at least partially, the realization of the idiosyncratic fit parameter of each evaluated product along with its price. Finally, the consumer purchases the best product among those evaluated.

Although consumers do not observe firms' prices until they (partially) evaluate products in stage 4, no agent has any private information that can be communicated by an action. Therefore, we use subgame perfection as our equilibrium concept.

We start with the consumer's choice process. Define the overall ex post realized utility of a product (seller i's product), if observed after full evaluation, as

$$u_i = v - p_i + \mu\varepsilon_i,$$

where v is a base level of utility,[7] p_i is price, and ε_i is a random utility term. We assume that $\{\varepsilon_i\}$ are independent and identically distributed (i.i.d.) and drawn from a standard extreme value distribution with cumulative distribution function $e^{-e^{-\varepsilon}}$, with mean $E(\varepsilon_i) = \gamma$ and variance $\mathrm{var}(\varepsilon_i) = \pi^2/6$.[8] The coefficient μ captures the degree of differentiation between products. The random utility of seller i's product $\mu\varepsilon_i$ is a random variable with extreme value distribution (EVD) and cumulative distribution function $e^{-e^{-\varepsilon/\mu}}$.[9]

We assume that a consumer's search process is simultaneous across products and that she commits to her evaluation plan before making a purchase.[10] Specifically, before evaluating products, a consumer decides $b \le n$ sellers,[11] and she chooses the same depth $d \in (0, 1]$ for all b products evaluated.[12] Denote this choice by (d, b), which we call the consumer's "evaluation plan."

As in the conventional search literature, we assume that the consumer can incur a cost to fully uncover the realized utility parameter ε_i or otherwise incur no cost and know nothing about product i. In addition, in our setting, the consumer may choose to partially learn the realized utility of a product. Denote by $d \in [0, 1]$, the evaluation depth of a given product. If $d = 0$, she knows nothing about product i, does not consider it, and cannot buy it. At the other extreme, $d = 1$, she learns the realization of ε_i, which corresponds to a full evaluation. To define the expected utility of a partially evaluated product with $d \in (0, 1)$, we exploit the self-decomposability property possessed by EVD random variables (Steutel and van Harn 2004).[13] This property states that for any $d \in (0, 1)$, ε_i can be written (equal in distribution) as $\varepsilon_i \stackrel{D}{=} d\hat{\varepsilon}_i + \theta_i(d)$, where $\hat{\varepsilon}_i$ is a random utility term that is drawn from a standard EVD and $\theta_i(d)$ is another random variable[14] with known mean $(1-d)\gamma$ and finite variance $(1-d^2)\mathrm{var}(\varepsilon_i)$ (Cardell 1997). Furthermore, $d\hat{\varepsilon}_i$ is independent from $\theta_i(d)$. Thus, if the consumer evaluates product i at depth $d \in (0, 1)$, she takes a draw from the random variable $d\hat{\varepsilon}_i$ but does not observe the realized value for the remaining portion $\theta_i(d)$. For an evaluation plan (d, b), the consumer uncovers the realized utility of the evaluated portions $\{d\hat{\varepsilon}_i\}_{i=1}^{b}$ but does not observe the remaining utility $\{\theta_i(d)\}_{i=1}^{b}$. This framework has the property that the variance of preferences is always lower with limited information (partial evaluation) than with full information.[15]

One can interpret our partial evaluation process using the same camera example. Suppose that the consumer faces a large set of (n) camera sellers. The cameras all differ by color, size, and various technical

[7] We assume that v is sufficiently large to induce all consumers to participate in the search.

[8] The symbol γ is the Euler–Mascheroni constant (≈ 0.5772).

[9] Our discrete choice model is based on Anderson et al. (1992), which also introduces a simultaneous search model in this framework.

[10] Although our search setting is made simultaneous for analytical convenience, it also reflects that product evaluation at online shopping intermediaries does involve some aspects of simultaneous evaluation. Many intermediaries, for instance, allow for side-by-side comparisons by arranging multiple products on one page. An important limitation of our approach is that it ignores a consumer's ability to update her evaluation process after learning about some products (e.g., Wolinsky 1986).

[11] Unlike the sequential search models, we treat the number of firms, b, as a continuous variable for ease of analysis.

[12] One can consider a richer setting in which consumers can choose different depths $\{d_i\}_{i=1}^{b}$. In our simultaneous search setting, symmetric depth satisfies the necessary conditions for optimality. (Details are available from the authors.) We use the symmetric setting here for simplicity of exposition.

[13] See Steutel and van Harn (2004, Chap. 2), for details on this self-decomposability property for the EVD and other Gumbel distributions.

[14] For any $d \in (0, 1)$, the random variable $\theta(d)$ is characterized by the density $f_d(\theta) = (1/d)\sum_{n=0}^{\infty}[((-1)^n e^{-n\theta})/(n!\Gamma(-dn))]$ (Cardell 1997). Because $\theta(d)$ is never realized by the consumer before purchase, we need only its mean and variance in our model.

[15] This random variable affects the consumer's willingness to pay. If the consumer is completely uninformed $(d = 0)$, then her willingness to pay is based on the mean $E(\varepsilon)$ and therefore has no variance. As she learns more about firm i's product $(d > 0)$, her willingness to pay can increase or decrease relative to the mean, which implies some positive variance. As d continues to increase, the variance in her willingness to pay increases as well.

specifications. Prices will play a role when the consumer makes her purchase decision, but when choosing how deeply to evaluate cameras, she expects the cameras to be in the same general price range. The consumer may choose to evaluate a subset (of size $b < n$) of cameras at a shallow depth (small d), evaluating fit based only on the size and color of each inspected camera (learning $d\hat{\varepsilon}_i$ for each camera), and leaving the technical specifications unknown before purchase. Alternatively, she could evaluate the fit of these cameras at a greater depth (larger d), evaluating size and color and some of the technical specifications. In the second case, her residual uncertainty about any given camera is lower since $\text{var}[\theta_i(d)] = (1-d^2)\text{var}(\varepsilon_i)$ is decreasing in d. Greater evaluation depth is beneficial to the consumer because she is more certain about the degree to which each camera fits her needs.

Independent of the evaluation depth $d > 0$, we assume that the consumer learns the price of seller i's product, p_i. Among these b partially evaluated products, she chooses the one with the highest expected utility,

$$i^* = \arg\max_{i=1,\dots,b} v - p_i + \mu\{d\hat{\varepsilon}_i + E[\theta_i(d)]\},$$

where $E[\theta_i(d)] = E(\varepsilon_i) - E(d\varepsilon_i) = (1-d)\gamma$ denotes the expected value of the unobserved random utility of a product that is evaluated at depth d. Note that this value does not depend on i, implying that inspected products differ by their ex post fit realizations and prices $\{\mu d\hat{\varepsilon}_i - p_i\}_{i=1}^b$. Thus, the best product can be expressed by $i^* = \arg\max_{i=1,\dots,b} \mu d\hat{\varepsilon}_i - p_i$. Since $\{d\hat{\varepsilon}_i\}_{i=1}^b$ are i.i.d. random variables with EVD, we can utilize the logit model to derive a closed form expression for the choice probability of product i:

$$P_i = \frac{e^{(v-p_i)/d\mu}}{\sum_{j=1}^b e^{(v-p_j)/d\mu}}; \quad i = 1, \dots, b.$$

The consumer's evaluation breadth and depth are determined before evaluation. Thus, they depend on the expected evaluation benefits rather than on products' realized utility. By assumption, all products are a priori identical before evaluation. Furthermore, although the consumer cannot explicitly observe sellers' prices, she believes (correctly) that all sellers charge the same price in equilibrium: $p_i = p$ for all $i = 1, \dots, n$. Under this symmetric condition, the expected benefit of an evaluation plan (d, b) is given by

$$E(u_{i^*}) = v - p + \mu\{E(d\hat{\varepsilon}_{i^*}) + E[\theta_{i^*}(d)]\},$$

which simplifies to

$$v - p + d\mu\ln(b) + \mu\gamma.$$

Denote $\tau > 0$ as the baseline evaluation cost, which is the evaluation cost for the consumer to evaluate a product's fit completely or, equivalently, at full depth $(d = 1)$.[16] If a consumer evaluates $b > 1$ sellers at depth $d \in (0, 1]$, then she incurs a cost of $f(b, d) = \tau b d^2$. This cost function embeds the classic search cost function, which is linear in the number of firms evaluated b at full depth. The quadratic specification for depth is made for simplicity, although it reflects increasing costs for higher levels of depth. Generally, convexity in costs has a natural interpretation in that consumers evaluate the easiest attributes first. In the camera example above, a consumer can easily assess the color or size and will do so first. To additionally assess the camera's technical specifications, she will have to invest more effort. Another appealing property of this specification is that the evaluation cost is proportional to the consumer's resolved uncertainty (measured by the variance of the explained random utility).[17]

Another factor in the consumer's evaluation costs is the search environment at the online shopping intermediary. Let $s \in [0, 1]$ denote the extent to which the search environment lowers the consumer's evaluation costs so that an evaluation plan induces a cost of $(1-s)\tau b d^2$. When $s = 0$, the search environment does not make product evaluation any easier, and thus the consumer's evaluation costs are not reduced. Intermediate cases of $s \in (0, 1)$ mean that the search environment partially lowers her evaluation costs. If $s = 1$, then the search environment makes the search so easy that the consumer can costlessly evaluate all sellers' products. The expected utility from evaluation plan (d, b) in a search environment s is given by

$$U(d, b; s) = v - p + d\mu\ln(b) + \mu\gamma - (1-s)\tau b d^2, \quad (1)$$

which the consumer maximizes with respect to $b \geq 1$ and $d \in (0, 1]$. The following lemma characterizes the consumer's optimal evaluation depth and breadth as a function of the search environment s.

Lemma 1. *Let $n > e^2$. For any given s, there exists a unique pair $[\hat{d}(s), \hat{b}(s)]$ maximizing $U(d, b; s)$ s.t. $\hat{d}(s) \in (0, 1]$ and $1 \leq \hat{b}(s) \leq n$. Furthermore,*

$$\hat{d}(s) = \begin{cases} \dfrac{\mu}{(1-s)\tau} e^{-2} & 0 \leq s < 1 - \dfrac{\mu}{\tau} e^{-2}, \\[2ex] 1 & 1 - \dfrac{\mu}{\tau} e^{-2} \leq s \leq 1; \end{cases}$$

[16] To ensure that the intermediary serves consumers when faced with nontrivial search costs in the absence of a search environment, we assume that $\tau > \mu e^{-2}$, which is obtained from the condition $(1 - (\mu/\tau)e^{-2} > 0)$ in Lemma 1.

[17] In §3.2, we discuss alternative specifications of the evaluation cost, f, and the implications for our main results.

$$\hat{b}(s) = \begin{cases} e^2 & 0 \le s < 1 - \dfrac{\mu}{\tau}e^{-2}, \\ \dfrac{\mu}{(1-s)\tau} & 1 - \dfrac{\mu}{\tau}e^{-2} \le s \le 1 - \dfrac{\mu}{\tau n} \\ n & 1 - \dfrac{\mu}{\tau n} < s \le 1. \end{cases}$$

As reflected in Lemma 1, when the search environment modestly lowers search costs ($0 \le s < 1 - (\mu/\tau)e^{-2}$), the consumer partially evaluates a fixed number of products. Thus, in this interval, for an environment that makes a search easier, the consumer's evaluation costs are reduced. In response, she evaluates the same number of products ($\hat{b}'(s) = 0$), but at a greater depth ($\hat{d}'(s) > 0$). As the search environment reaches a threshold ($s = 1 - (\mu/\tau)e^{-2}$), the consumer engages in full evaluation ($\hat{d}(s) = 1$). When s exceeds this threshold, her evaluation costs are further reduced and this allows her to evaluate more products at a full depth.[18] When an even more helpful search environment is provided ($1 - \mu/(\tau n) < s \le 1$), the consumer fully evaluates all the products available at the intermediary ($\hat{b}(s) = n$). In addition, product differentiation (μ) influences evaluation depth and breadth. Specifically, larger μ implies a larger benefit of evaluation, which implies that the consumer may evaluate more products at a greater depth.

We now consider the strategies (e.g., price decisions) played by the n sellers given the intermediary's choice of s and the consumer's anticipated evaluation plan, $[\hat{d}(s), \hat{b}(s)]$. Because firms are symmetric, we assume that in equilibrium they charge symmetric prices. Furthermore, the consumer's evaluation plan is made before observing prices and thus depends on her rational expectations of the sellers' symmetric equilibrium decisions. Therefore, her evaluation plan is not affected by any deviation by a seller from this symmetric equilibrium price. The consumer's product choice, however, depends on such deviations because her purchase decision is determined after she observes products' prices. To determine the equilibrium price, we focus on seller i by assuming that it charges p_i while all other sellers charge p. Under this condition, for any evaluation plan (d, b), we can write the conditional demand for seller i's product (given that it is evaluated) as the choice probability of product i:

$$q_i = \frac{e^{(v-p_i)/d\mu}}{e^{(v-p_i)/d\mu} + (b-1)e^{(v-p)/d\mu}}; \quad i = 1, \ldots, b. \tag{2}$$

The consumer selects a subset of the n available products on the intermediary's site to evaluate. Because all the products are a priori identical before evaluation, she randomly selects b products, and there is a b/n probability for product i being selected for evaluation.[19] Thus, the unconditional demand for seller i's product is $(b/n)q_i$.[20] Seller i's expected profit is given by

$$\pi_i = (1-\rho)\frac{b}{n}p_i q_i, \tag{3}$$

where $\rho \in (0, 1)$ denotes the referral fee paid to the intermediary. Seller i chooses p_i to maximize its expected profit π_i in (3). The following lemma characterizes sellers' symmetric equilibrium prices given the optimal evaluation plan.

Lemma 2. *Let $n > e^2$. For any $s \in [0, 1]$ with the corresponding optimal evaluation plan $[\hat{d}(s), \hat{b}(s)]$, sellers' equilibrium prices are given by*

$$\hat{p}(s) = \frac{\hat{d}(s)\mu}{1 - 1/(\hat{b}(s))} = \begin{cases} \dfrac{1}{e^2-1}\dfrac{\mu^2}{(1-s)\tau} & 0 \le s < 1 - \dfrac{\mu}{\tau}e^{-2}, \\ \dfrac{\mu^2}{\mu - (1-s)\tau} & 1 - \dfrac{\mu}{\tau}e^{-2} \le s \le 1 - \dfrac{\mu}{\tau n}, \\ \dfrac{\mu n}{n-1} & 1 - \dfrac{\mu}{\tau n} < s \le 1. \end{cases}$$

This lemma illustrates two main points. First, it shows how evaluation depth and breadth affect prices. Specifically, as the consumer evaluates products at a greater depth (larger d), she can better appreciate the value of her most preferred product. This effect, which we call the "evaluation depth effect," increases sellers' prices in equilibrium. In contrast, as she considers more products (larger b), the competition between sellers pushes prices downward, an effect we call the "evaluation breadth effect."

Second, this lemma shows how the search environment affects prices. Specifically, when the search environment only modestly lowers search costs ($0 < s < 1 - (\mu/\tau)e^{-2}$), the consumer's evaluation depth increases in s (see Lemma 1). Thus, prices increase through the evaluation depth effect. However, when the search environment passes the threshold ($1 - (\mu/\tau)e^{-2} \le s \le 1 - \mu/(\tau n)$), an increase in s only expands the number of evaluated sellers, and prices

[18] The property that either $\hat{b}(s)$ or $\hat{d}(s)$ increases unilaterally is not necessary for our results. See Appendix B for details on other specifications of search costs, f, which lead to breadth and depth increasing simultaneously with s, yet generate the results in Propositions 1 and 2.

[19] Products can be made more prominent than others on an online shopping intermediary so that consumers may first evaluate the prominent ones. This remains a potential issue for further research.

[20] We make the assumption of full market coverage in the model to keep the analysis simple. Allowing a no-buy option does not change the main results.

decrease through the evaluation breadth effect. When an even more helpful environment is provided ($s = 1-\mu/(\tau n)$), the consumer fully evaluates all products available at the intermediary. Obviously, any s larger than $1-\mu/(\tau n)$ affects neither the consumers' evaluation plan nor the sellers' prices.

We now consider the intermediary's design of the search environment by its optimal choice of $s \in [0, 1]$. Assume that the intermediary incurs 0 cost in providing its search environment. The intermediary's expected profit is given by

$$\pi_I = \rho\hat{p}(s), \tag{4}$$

where $\hat{p}(s)$ is the symmetric equilibrium price as given in Lemma 2.

The intermediary's objective in (4) is to maximize sellers' equilibrium prices. From Lemma 2, we see $\hat{p}(s)$ is single peaked at $s = 1-(\mu/\tau)e^{-2}$. Any search environment with s lower than this identified point (or equivalently, any environment with higher evaluation costs) induces the consumer to partially evaluate products, making her unable to fully appreciate the value of her most preferred product. With partial evaluation, sellers cut prices in equilibrium. Alternatively, any search environment with s larger than $1-(\mu/\tau)e^{-2}$ (or equivalently, any environment with lower evaluation costs) encourages the consumer to broaden the set of sellers evaluated, inducing sellers to price more competitively. The intermediary's optimal search environment therefore reflects a balance between sufficiently lowering search costs—to the extent that the consumer fully evaluates the considered products and fully knows what she is buying—and still preventing the consumer from searching a lot of sellers.

Proposition 1. *Let $n \geq e^2$. In equilibrium, the intermediary has a search environment defined by $s^* = 1-(\mu/\tau)e^{-2}$, consumers evaluate $\hat{b}(s^*) < n$ products at full depth, $\hat{d}(s^*) = 1$, and sellers' prices are given by $\hat{p}(s^*) = \mu/(1-e^{-2})$.*

This proposition states our main result. The intermediary designs the search environment with positive evaluation costs ($s^* < 1$) such that the consumer evaluates the sellers' products at full depth but does not evaluate all firms.[21] This result is driven in large part by the consumer's benefit of evaluation depth relative to breadth. As seen in (1), the consumer always benefits from greater depth to a larger extent than breadth. An increase in d resolves uncertainty for the consumer's chosen product, which tends to increase her willingness to pay for it. An increase in breadth, however, increases her willingness to pay only if that additional product is better than the other b products evaluated. Our specification of evaluation costs implies that an increase in s does not induce the consumer to expand breadth. Therefore, it is profitable for the intermediary to increase s if and only if $\hat{d}(s) < 1$.

This proposition also illustrates the impact of product differentiation on the intermediary's optimal search environment. Less differentiation implies a lower consumer benefit of product evaluation, which induces the consumer to scale back evaluation depth. For example, when cameras have similar but different attributes, the consumer might be reluctant to look into these attributes at great depth. To ensure that the consumer evaluates all these attributes (maintaining evaluation at full depth), the intermediary reduces search costs by providing a more helpful search environment. However, both the intermediary and sellers are hurt by the reduced prices stemming from lower product differentiation.

3. Extensions and Limitations

The main result from §2 relies on a stylized model with a number of simplifying assumptions. In this section, we discuss how these assumptions affect the main result of Proposition 1 and under what conditions this result can break down.

3.1. Small Number of Firms

In the model of §2, we assumed intermediaries hosted a large number of sellers: $n > e^2$. This assumption is crucial for the result from Proposition 1 that the intermediary's optimal search environment has consumers evaluating a subset of firms: $\hat{b}(s^*) < n$. Without this assumption, the intermediary's optimal search environment may have consumers evaluating all firms.

Proposition 2. *Let $1 < n < e^2$. Then any $s^* \in [1-(\mu \ln n)/(2n\tau), 1]$ is optimal for the intermediary, and consumers evaluate all firms at full depth: $\hat{b}(s^*) = n$ and $\hat{d}(s^*) = 1$.*

This proposition demonstrates that our main result from §2 requires a sufficient number of sellers ($n > e^2$) hosted by the intermediary. The consumer always evaluates a sufficient number of sellers to ensure a product with a good fit. If the search environment embeds evaluation costs that are too high, the consumer scales back evaluation depth although she considers all sellers. Specifically, with a low level of search aids, $s \in [0, 1-(\mu \ln n)/(2n\tau))$, the consumer evaluates products at partial depth, and she is unable to fully appreciate the value of her most preferred product. The evaluation depth effect of our main result in §2 implies that, to ensure full evaluation

[21] In §3.2 and Appendix B, we discuss the robustness and limitations of this finding with respect to our specification of evaluation costs.

depth, the optimal level of search aids should be no less than $s^* = 1 - (\mu \ln n)/(2n\tau)$. At any level of s at or beyond this point, the consumer's evaluation plan involves all firms at full depth and is, therefore, optimal for the intermediary.

3.2. Consumer's Evaluation Process

In this section, we elaborate on the consumer's evaluation trade-off and discuss the important role it plays in our results. The consumer's marginal benefit of evaluation breadth b is the increased likelihood of finding a better-fitting product. The marginal benefit of depth d is a greater certainty that the chosen product is the best-fitting one among those evaluated. These dimensions of evaluation benefit are derived directly from our choice framework (Anderson et al. 1992). As can be seen in the third term of (1), the benefit of depth is linear whereas the benefit of breadth is concave. This arises because of our symmetric framework. Expanding breadth has decreasing marginal benefit since it is increasingly unlikely that another product will be better than those already evaluated. Expanding depth, however, applies to all products already considered for evaluation. Therefore, an increase in depth will always reduce the amount of uncertainty of the chosen product. In fact, as long as $b \geq 2$, the marginal benefit of depth always exceeds that of breadth. This implies that, as the search environment becomes easier, the consumer in our model always benefits from more depth and is a key factor in the intermediary's decision to provide enough search aids for full evaluation depth. A limitation of applying our symmetric, simultaneous search model to the discrete choice framework is that it forces the marginal benefit of depth to always exceed that of breadth. Such a condition may or may not exist if one were to apply a sequential model that permitted learning during the search process.

Turning to evaluation costs, we assume that they are linear in breadth but quadratic in depth: $f(b, d) = \tau b d^2$. Note that the linearity of f in b is made for analytical convenience and is not necessary for the results in Proposition 1.[22] However, what about the quadratic form in d? In the remainder of this section, we discuss specifications of f that are linear in b but may not be quadratic in d.

Let $f(b, d) = \tau b g(d)$ where $\tau g(d)$ denotes the cost the consumer incurs to evaluate a product at partial depth $d \in (0, 1)$. An appropriate form for the functional specification of $g(d)$ will have, for any $d \in (0, 1]$, (1) the proper range, $g(d) \in (0, 1]$; (2) the proper boundary conditions, $\lim_{d \downarrow 0} g(d) = 0$ and $\lim_{d \uparrow 1} g(d) = 1$; (3) twice continuously differentiable; and (4) strictly increasing, $g'(d) > 0$. In Appendix B, we show that, for an interior solution to the consumer's optimal search problem, it is necessary to assume that $g''(d) > 0$. Convexity in costs has a natural interpretation in that consumers evaluate the easiest attributes first. The specification $g(d) = d^2$ obviously meets the properties above while guaranteeing a closed-form expression for all equilibrium results.

Two more-substantive assumptions on g are required to generate the main result in Proposition 1. The first assumption regards the function $\Psi(d) \equiv (d g'(d))/g(d)$, which arises from the consumer's optimization conditions and defines the relationship between $\hat{b}(s)$ and $\hat{d}(s)$ in equilibrium. Specifically, $\hat{b} = \exp \Psi(\hat{d})$ traces the curve in (d, b)-space of the consumer's interior optimal evaluation plan as the search environment changes. In the case of $g(d) = d^2$, we have $\Psi(d) = 2$, which is constant in d. For our main result, we require that $\hat{b}(= \exp[\Psi(\hat{d})])$ and $\hat{d}$ move weakly in the same direction in equilibrium. In other words, when the intermediary makes search easier, the consumer never decreases any dimension of evaluation. The conditions on g, so far, regard only the consumer's optimal evaluation. However, to generate the result in Proposition 1 we further require a property that arises from the firms' equilibrium pricing condition. Specifically, we require that $d\Psi'(d) < 1$, which essentially bounds the rate of change in $\hat{b}$ as $\hat{d}$ increases in equilibrium. In Appendix B, we demonstrate that all of the above properties hold for several familiar specifications of g.

The condition bounding the derivative of $\Psi'(d)$ points to a key limitation of our model. If it does not hold, so that $\hat{b}(s)$ increases in s too quickly relative to increases in $\hat{d}$, then competitive firms will decrease their prices in equilibrium in response to increases in s. That is, intermediary profit can actually decrease in s although $\hat{d}(s) < 1$. Thus, search cost specifications that induce a spike in breadth at partial depth can violate this condition and change our main results. (See formal analysis in Appendix B.)

3.3. Competing Intermediaries

Another assumption made in the model of §2 is that consumers have no other shopping alternative than the intermediary. Some recent research suggests that, without this assumption, an intermediary may offer a more helpful search environment (larger s) as a means to attract consumers to its website (de Cornière 2014, Renault 2014). A similar incentive can arise when the intermediary faces competition from a rival intermediary. To understand the implications of intermediary competition, we studied an extension of the main

[22] This is shown in the online supplemental appendix (available at http://dx.doi.org/10.1287/mnsc.2015.2176).

model with two intermediaries competing at opposite ends of a Hotelling line.[23] Intermediaries can be differentiated on variables regarding website design or specialized services. This is captured in our extension by the transportation cost parameter, $t > 0$. Our main result and intuition in §2 survive if this parameter is above a certain threshold $\bar{t}$. Otherwise, there is a prisoner's dilemma: both intermediaries are better off if they restrict search aids, but competition induces a profitable deviation to provide more aids to attract consumers. Thus, when intermediary differentiation is low, $t < \bar{t}$, both intermediaries provide full aids ($s^* = 1$) in equilibrium. We conclude that our result in Proposition 1 requires that the intermediary does not face intense competition.

4. Conclusion

This paper has examined the strategic design of an online shopping intermediary's search environments. We defined a search environment by its control of consumers' evaluation costs. Because these intermediaries receive revenue from third-party sellers, they must balance improvements in consumers' search with sellers' profit incentives. We showed that an intermediary's optimal search environment includes positive search costs, but only up to a point. If consumers face too much search cost, they can scale back the depth of their evaluation of sellers' products—a regime of partial product evaluation. Our model indicates that it is optimal for the intermediary to provide a search environment that embeds sufficiently low evaluation costs to ensure that consumers evaluate products at full depth, but not low enough to prevent them from evaluating too many sellers' products.

Our research is only a first attempt at understanding the strategic factors that affect the design of the search environment at online shopping intermediaries. We focused on the strategic role that consumer search costs play in consumers' ability to find the right product and third-party sellers' ability to set profitable prices. In so doing, we omitted several strategic variables that intermediaries may consider. We speculate on the implications of these omissions in the remainder of this section.

One omitted factor is the intermediary's decision regarding the number and type of third-party sellers to allow on its platform. The decision of a third-party seller to sell on the intermediary's platform is endogenous and may depend on the search environment chosen by the intermediary. Recent research indicates that the types of sellers on the platform have important implications for the intermediary's incentives to provide information that the consumer can acquire in the search environment (de Cornière 2014, Renault 2014).

[23] See the online supplemental appendix for details of this analysis.

Another omitted factor in the design of the search environment is the fact that many third-party sellers provide multiple products. This possibility invokes a setting in which consumers' search decisions involve another dimension—within firms' product lines (Liu and Dukes 2013). Because sellers do not compete in price among their own products, search costs may play a different role for intermediary profitability.

Finally, we modeled consumer search as a simultaneous process that overlooks some realities of product evaluation at online shopping intermediaries. For example, it is reasonable to suppose that a consumer can update her evaluation process sequentially after learning about a few products. Theoretical research in consumer search has only begun to examine sequential search with partial product evaluation (Ke et al. 2016). We are unable to speculate on the implications of this aspect of consumer search in an intermediary's design of the search environment. We expect to see new insights and lessons for online shopping intermediaries as research on consumer search continues to evolve.

Supplemental Material

Supplemental material to this paper is available at http://dx.doi.org/10.1287/mnsc.2015.2176.

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Appendix A. Proofs of Lemmas and Propositions

Proof of Lemma 1

Consumers simultaneously choose the optimal evaluation breadth and depth by maximizing (1) with respect to $b \le n$ and $d \in [0, 1]$. The first-order condition yields the expressions for $\hat{b}(s)$ and $\hat{d}(s)$ in Lemma 1. Checking the Hessian matrix,

$$\frac{\partial^2 U(d, b; s)}{\partial b^2} = -\frac{d\mu}{b^2}$$

$$= \begin{cases} -\dfrac{\mu^2}{(1-s)\tau} e^{-6} & 0 \le s < 1 - \dfrac{\mu}{\tau} e^{-2}, \\ -\dfrac{(1-s)^2 \tau^2}{\mu} & 1 - \dfrac{\mu}{\tau} e^{-2} \le s \le 1 - \dfrac{\mu}{\tau n}, \\ -\dfrac{\mu}{n^2} & 1 - \dfrac{\mu}{\tau n} < s \le 1; \end{cases}$$

$$\frac{\partial^2 U(d,b;s)}{\partial d^2} = -2(1-s)b\tau = \begin{cases} -2(1-s)e^2\tau & 0 \le s < 1-\dfrac{\mu}{\tau}e^{-2}, \\ -2\mu & 1-\dfrac{\mu}{\tau}e^{-2} \le s \le 1-\dfrac{\mu}{\tau n}, \\ -2(1-s)n\tau & 1-\dfrac{\mu}{\tau n} < s \le 1; \end{cases}$$

$$\frac{\partial^2 U(d,b;s)}{\partial b \partial d} = \frac{\mu}{b} - 2(1-s)d\tau = \begin{cases} -\dfrac{\mu}{e^2} & 0 \le s < 1-\dfrac{\mu}{\tau}e^{-2}, \\ -(1-s)\tau & 1-\dfrac{\mu}{\tau}e^{-2} \le s \le 1-\dfrac{\mu}{\tau n}, \\ \dfrac{\mu}{n} - 2(1-s)\tau & 1-\dfrac{\mu}{\tau n} < s \le 1. \end{cases}$$

One can easily verify that

$$\frac{\partial^2 U(d,b;s)}{\partial b^2}\frac{\partial^2 U(d,b;s)}{\partial d^2} - \left[\frac{\partial^2 U(d,b;s)}{\partial b \partial d}\right]^2 > 0$$

holds for $0 \le s \le 1-\mu/(\tau n)$. Hence, the solution to $\partial U/\partial b = \partial U/\partial d = 0$ is the interior maximum for $s \in [0, 1-\mu/(\tau n)]$.

Now suppose $1-\mu/(\tau n) \le s \le 1$. Then

$$\left.\frac{\partial U}{\partial d}\right|_{b=e^2} = 2\mu[1-(1-s)e^2\tau d/\mu] > 2\mu\left(1-\frac{e^2}{n}d\right),$$

which is positive for all $d \in [0,1]$ and $n > e^2$. Therefore, setting $d = 1$ is required at any maximized solution. In this case, the consumer optimal choice of $b \le n$ must satisfy either $\partial U/\partial b|_{d=1,\, b<n} = 0$ or $\partial U/\partial b|_{d=1,\, b=n} \ge 0$. In the first case, we must have $b = \mu/((1-s)\tau)$. This solution for b is a maximizer since $\partial^2 U/\partial b^2|_{d=1,\, b=\mu/((1-s)\tau)} < 0$. In the second case, at the boundary $b = n$, we have $\partial U/\partial b|_{d=1,\, b=n} = \mu/n - ((1-s)\tau) \ge 0$ under the condition that $s \ge 1-\mu/(\tau n)$. Hence, the boundary solutions $(d = 1, b = \mu/((1-s)\tau))$ and $(d = 1, b = n)$ are both maximizing. □

Proof of Lemma 2
Given $[\hat{d}(s), \hat{b}(s)]$ from Lemma 1, we determine equilibrium price by maximizing (2) with respect to p_i and invoking symmetry. It is straightforward to show that

$$\frac{\partial \pi_i}{\partial p_i} = (1-\rho)\frac{b}{n}\left[p_i\frac{q_i(q_i-1)}{d\mu} + q_i\right] = 0$$

implies $\hat{p}(s) = \hat{d}(s)\mu/(1-1/\hat{b}(s))$. Substituting the expressions for $\hat{d}(s)$ and $\hat{b}(s)$ into $\hat{p}(s)$ yields the expression for prices given in the statement of the lemma.

One can also check

$$\frac{\partial^2 \pi_i}{\partial p_i^2} = (1-\rho)\frac{b}{n}\left[p_i\frac{q_i(q_i-1)(2q_i-1)}{(d\mu)^2} + \frac{2q_i(q_i-1)}{d\mu}\right].$$

Evaluating $\partial^2\pi_i/\partial p_i^2$ at any point where $\partial \pi_i/\partial p_i = 0$ yields

$$\frac{\partial^2 \pi_i}{\partial p_i^2} = -(1-\rho)\frac{b}{n}\frac{q_i}{d\mu} < 0.$$

Thus, $p_i = \hat{p}(s)$ satisfies the seller's second-order condition for profit maximization. □

Proof of Proposition 1
The intermediary chooses s to maximize (3) subject to $s \in [0,1]$. That is, the profit-maximizing level of search aids is obtained by maximizing the sellers' price $\hat{p}(s)$. From the expression for $\hat{p}(s)$ in Lemma 2, $\hat{p}(s)$ increases in s for $s \in [0, 1-(\mu/\tau)e^{-2})$, decreases in s for $s \in [1-(\mu/\tau)e^{-2}, 1-\mu/(\tau n)]$, and is independent from s for $s \in (1-\mu/(\tau n), 1]$. This yields the profit-maximizing level of search aids s^* as expressed in the statement of the proposition. Plugging s^* back into $[\hat{d}(s), \hat{b}(s)]$ from Lemma 1 and $\hat{p}(s)$ from Lemma 2 yields the result. □

Proof of Proposition 2
The maximization of (1) with respect to $d \in (0,1]$ and $b \le n$ implies

$$\frac{\partial U}{\partial b} = \frac{\mu d}{b} - (1-s)\tau d^2 \ge 0,$$

$$\text{or equivalently, } \frac{\mu}{(1-s)\tau} \ge bd; \quad \text{and} \tag{A1}$$

$$\frac{\partial U}{\partial d} = \mu \ln b - 2(1-s)\tau b d \ge 0. \tag{A2}$$

Condition (A1) cannot hold with equality under the assumption $n < e^2 < \mu/\tau$ since $\mu/((1-s)\tau) \ge \mu/\tau > e^2 > n > b \ge bd$. Thus, $\hat{b}(s) = n$ for all $s \in [0,1]$. From (A2) with $b = n$, we have $d \le \mu \ln n/(2(1-s)n)$. Define $\tilde{s}$ to solve $\mu \ln n/(2(1-\tilde{s})n) = 1$, which is the minimum level of aids to induce the consumer to evaluation at full depth. Then $\hat{d}(s) = 1$ for all $s \in (\tilde{s}, 1]$ and $\hat{d}(s) = \mu \ln n/(2(1-s)n)$ otherwise. For $\hat{b}(n) = n$, firm i's profit is $\pi_i = (1-\rho)p_i q_i$, where q_i is the choice probability of product i given in Equation (2) when the firm charges p_i. The symmetric equilibrium price among all n firms is $\hat{p}(s) = (\mu n/(n-1))\hat{d}(s)$. Since $\hat{p}(s)$ is increasing in d, the intermediary maximizes profits by choosing s^* such that $\hat{d}(s^*) = 1$. Thus, any $s^* \in [\tilde{s}, 1]$ is an equilibrium search environment. □

Appendix B. Properties of the Evaluation Cost Specification

In this section we reconsider the basic model, allowing for alternative functional forms for the consumer's search cost function. The objective here is to illustrate that, under fairly weak conditions on the search cost function, the main result presented in the main text holds: the intermediary's optimal level of search aids (i) is less than 1, (ii) involves full depth, and (iii) limits consumers from evaluating all sellers. Using a general, unspecified cost function we first identify several properties that we believe the cost function should possess in order to make sense in our setting. We then show that several reasonable functional forms satisfy all of these properties and generate the original results as long as there is a sufficient number of sellers. Finally, we show that our results break down under the same conditions when there are too few sellers.

Suppose the consumer incurs a cost $f(b,d)$ to evaluate $b \ge 2$ sellers each at some depth $d \in (0,1]$. (A consumer cannot evaluate any product unless $d > 0$.) For now, suppose

evaluation costs are linear in the number of sellers.[24] Therefore, we write $f(b, d) = \tau b g(d)$, where the τ is the marginal cost of fully evaluating a single seller's product and $g(d)$ satisfies the following properties.
Proper range:

$$\text{For any depth } d \in (0, 1],\ g(d) \in (0, 1]. \tag{P1}$$

Boundary conditions:

$$g(d) \to 0 \text{ as } d \downarrow 0 \text{ and } g(1) = 1. \tag{P2}$$

Smoothness:

$$g \text{ is twice continuously differentiable on } (0, 1]. \tag{P3}$$

Costly deeper evaluation:

$$g(d) \text{ is strictly increasing with } g'(d) > 0 \text{ on } (0, 1]. \tag{P4}$$

The specification in the main text, $g(d) = d^2$, satisfies these four properties. Let (b, d) be the consumer's evaluation plan and $s \in [0, 1]$ be the intermediary's chosen level of aids. The consumer's expected choice utility is

$$U(b, d; s) = v - p + d\mu \ln b + \mu\gamma - (1-s)\tau b g(d). \tag{B1}$$

The consumer's optimal evaluation plan, given s, maximizes $U(b, d; s)$. Let $[\hat{b}(s), \hat{d}(s)]$ be the maximizer of (B1). Although we allow for corner solutions with either $\hat{d}(s) = 1$ or $\hat{b}(s) = n$, we need to ensure that there are proper interior solutions for some regions of the parameter space. Then the solution must satisfy the following first-order conditions:

$$\frac{\partial U(b, d; s)}{\partial b} = \frac{\mu d}{b} - (1-s)\tau g(d) = 0, \tag{B2}$$

$$\frac{\partial U(b, d; s)}{\partial d} = \mu \ln b - (1-s)\tau b g'(d) = 0. \tag{B3}$$

If $(\hat{b}, \hat{d})$ solves (B2) and (B3), then it is an interior maximizer of (B1) only if

$$\frac{\partial^2 U}{\partial b^2} < 0 \qquad \text{and} \qquad \frac{\partial^2 U}{\partial d^2}\frac{\partial^2 U}{\partial b^2} - \left(\frac{\partial^2 U}{\partial d \partial b}\right)^2 > 0.$$

The first condition is immediately satisfied since

$$\frac{\partial^2 U}{\partial b^2} = -\frac{\mu d}{b^2}$$

is clearly negative for $d > 0$. Now consider

$$\frac{\partial^2 U}{\partial d^2}\frac{\partial^2 U}{\partial b^2} - \left(\frac{\partial^2 U}{\partial d \partial b}\right)^2 = \left(\frac{\mu d}{b^2}\right)[(1-s)\tau b g''(d)] - \left[\frac{\mu}{b} - (1-s)\tau g'(d)\right]^2, \tag{B4}$$

which is positive only if

$$g''(d) > 0. \tag{P5}$$

[24] See the online supplemental appendix to this paper for an analysis of the case in which evaluation costs are quadratic in b: $f(b, d) = \tau(b/n)^2 d^2$, which leads to same basic result found in Proposition 1.

Condition (P5) is necessary but not sufficient for (B4) to be positive. We can arrive at sufficiency by first noting that (B2) implies $\hat{b} = (\mu/((1-s)\tau))(\hat{d}/g(\hat{d}))$ and using this fact to rewrite (B4):

$$\begin{aligned}\left[\frac{\partial^2 U}{\partial d^2}\frac{\partial^2 U}{\partial b^2} - \left(\frac{\partial^2 U}{\partial d \partial b}\right)^2\right]_{\hat{b}, \hat{d}} &= (1-s)^2\tau^2\left[g(\hat{d})g''(\hat{d}) - \frac{g^2(\hat{d})}{\hat{d}^2} + \frac{2g(\hat{d})g'(\hat{d})}{d} - (g'(\hat{d}))^2\right] \\ &> (1-s)^2\tau^2\left[g(\hat{d})g''(\hat{d}) + \frac{g(\hat{d})g'(\hat{d})}{d} - (g'(\hat{d}))^2\right],\end{aligned}$$

where the inequality holds because (P5) implies $g < dg'$ (by the mean-value theorem) so that $g/d^2 < g'/d$. Thus, the following condition implies that the bracketed expression above is nonnegative and is therefore sufficient for (B4) to be positive:

$$\Psi(d) \equiv \frac{dg'(d)}{g(d)} \text{ and is nondecreasing.} \tag{P6}$$

Condition (P5) requires that the cost of evaluation is convex in depth. Without this condition, the consumer's depth decision is "all or nothing," depending on the relative marginal cost and benefit of depth. The function $\Psi(d)$ defines the elasticity of cost with respect to evaluation depth. Under condition (P6), this elasticity is never decreasing. The consumer, in equilibrium, never increases any dimension of evaluation with an increase in the baseline evaluation cost τ. For example, as evaluation costs increase, a consumer should never strictly increase either depth or breadth. The condition allows, however, for either dimension to remain fixed in reaction to an increase in evaluation cost.

The function $\Psi(d)$ plays a key role in the arguments below. As the consumer's search environment changes, the equilibrium evaluation plan traces the curve, which is defined by $\Psi(d)$. To see this, note that the first-order conditions (B2) and (B3) directly imply that, for any interior maximizer,

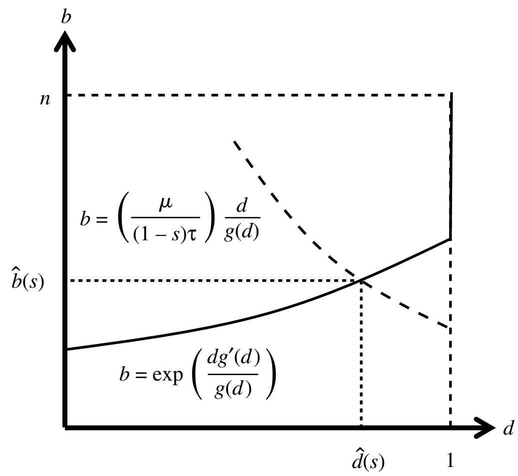
$$\hat{b} = \exp[\Psi(\hat{d})]. \tag{B5}$$

Under condition (P6), we can see that $\hat{b}$ and $\hat{d}$ move weakly in the same direction in equilibrium. The function Ψ also defines a necessary and sufficient condition on the number of sellers needed for our main result. In particular, as long as $n \geq \exp[\Psi(1)]$, the results of the main text survive for a variety of cost specifications g but do not when $n < \exp[\Psi(1)]$.

B.1. The Case of Many Sellers

Consider any specification of g that satisfies properties (P1)–(P6) and suppose that the number of sellers is not small: $n \geq \exp[\Psi(1)]$. This latter condition is depicted in Figure B.1 by the fact that the optimal search plan $(\hat{b}, \hat{d})$ involves full depth although all sellers may not be evaluated. Another noticeable aspect of this figure is that the curve $\hat{b}(s) = \exp[\Psi(\hat{d}(s))]$ traces the equilibrium search plan as a function of the level of decision aids s as chosen by the intermediary. As s increases from 0, the optimal search plan $(\hat{b}(s), \hat{d}(s))$ follows the curve to the cusp

Figure B.1 Equilibrium with Many Sellers



point where $\hat{b}(\tilde{s}) = \exp[\Psi(1)] \le n$ and $\hat{d}(\tilde{s}) = 1$, for $\tilde{s} = 1 - (\mu/\tau)\exp[-\Psi(1)] < 1$. As s increases beyond $\tilde{s}$, the optimal number of sellers evaluated increases (vertically along $d = 1$ in Figure B.1) according to

$$\hat{b}(s) = \frac{\mu}{(1-s)\tau}, \quad \text{for } s \ge \tilde{s}, \tag{B6}$$

which follows from (B5) with $d = 1$.

At this point, we can argue that the level of search aids $\tilde{s} < 1$ is an upper bound on the intermediary's optimal level of search aids. In other words, under properties (P1)–(P6), the equilibrium level of search aids $s^* \le \tilde{s} < 1$ never involves full aids. To see this, suppose that $s > \tilde{s}$. Then $\hat{d}(s) = 1$ and equilibrium prices are $\hat{p}(\hat{b}(s), 1, s) = (\hat{b}(s)/(\hat{b}(s) - 1))\mu$. According to (B6), we know that a slight reduction in s will reduce $\hat{b}(s)$ and raise prices. Thus, any $s > \tilde{s}$ cannot be optimal. This reflects the well-known fact that competition hurts prices when the intermediary encourages consumers to expand the breadth of their search.

We now ask: under what condition on g does the equilibrium involve full depth by the consumer? The following proposition gives us the condition.

Proposition B.1. *Let $n \ge \exp[\Psi(1)]$. If $d\Psi'(d) < 1$ for all $d \in (0, 1]$, then the intermediary's optimal level of search aids is $s^* = \tilde{s} = 1 - (\mu/\tau)\exp[-\Psi(1)]$ and induces the consumer to search at full depth: $\hat{d}(s^*) = 1$.*

Proof. It is immediate that at s^*, the optimal evaluation plan has full depth since by definition of $\tilde{s}$, $\hat{d}(s^*) = 1$. The remainder of the proof is to establish that the intermediary's optimal choice of search aids corresponds to s^*. As shown above, it is never profitable for the intermediary to deviate with more aids by choosing $s > s^*$. We now show that decreasing search aids to less than s^* is also suboptimal. We establish this fact by showing that sellers' prices are always increasing in s for $s < s^*$. If $s < \tilde{s}$, then the optimal search plan solves (B2) and (B3), which permits the use of the implicit function theorem for the derivatives, $\hat{b}'(s)$ and $\hat{d}'(s)$. Specifically, we define the following functions:

$$F_1(b, d; s) = \mu d - (1-s)\tau b g(d),$$

$$F_2(b, d; s) = \mu \ln b - (1-s)\tau b g'(d),$$

which, by (B2) and (B3), are both 0 at the consumer's optimal search plan $(\hat{b}, \hat{d})$. This implies that the $(\hat{b}(s), \hat{d}(s))$ are implicit functions defined by the condition

$$\begin{pmatrix} F_1(\hat{b}(s), \hat{d}(s); s) \\ F_2(\hat{b}(s), \hat{d}(s); s) \end{pmatrix} = 0.$$

Differentiating this expression with respect to the level of search aids s, we have an equation expressing the desired derivatives:

$$\Theta \begin{pmatrix} \hat{b}'(s) \\ \hat{d}'(s) \end{pmatrix} + \begin{pmatrix} \dfrac{\partial F_1}{\partial s} \\ \dfrac{\partial F_2}{\partial s} \end{pmatrix} = 0, \quad \text{where } \Theta = \begin{pmatrix} \dfrac{\partial F_1}{\partial b} & \dfrac{\partial F_1}{\partial d} \\ \dfrac{\partial F_2}{\partial b} & \dfrac{\partial F_2}{\partial d} \end{pmatrix}.$$

The derivatives can then be expressed as

$$\begin{pmatrix} \hat{b}'(s) \\ \hat{d}'(s) \end{pmatrix} = \Theta^{-1} \begin{pmatrix} -\dfrac{\partial F_1}{\partial s} \\ -\dfrac{\partial F_2}{\partial s} \end{pmatrix} = \frac{\mu\tau}{\det\Theta} \begin{pmatrix} bg(d)\Psi'(d) \\ g \end{pmatrix}.$$

The conditions (P5) and (P6) ensure that $\det\Theta > 0$. Thus, $\hat{d}(s)$ is strictly increasing in s. Also, $\hat{b}'(s)$ has the same sign as $\Psi'(d)$, which is either 0 or positive by (P6). The equilibrium prices are $\hat{p}(\hat{b}(s), \hat{d}(s), s) = \hat{b}(s)/(\hat{b}(s) - 1)\hat{d}(s)\mu$. With the derivative expressions above, we can assess how sellers' equilibrium prices change as the intermediary increases search aids, s:

$$\begin{aligned} \frac{d\hat{p}(b, d; s)}{ds} &= \frac{\partial \hat{p}}{\partial s} + \frac{\partial \hat{p}}{\partial b}\frac{d\hat{b}}{ds} + \frac{\partial \hat{p}}{\partial d}\frac{d\hat{d}}{ds} \\ &= 0 + \frac{-\mu d}{(b-1)^2}\frac{d\hat{b}}{ds} + \frac{\mu b}{b-1}\frac{d\hat{d}}{ds} \\ &= \frac{\mu^2\tau b g(d)}{(b-1)\det\Theta}\left[-\frac{d}{b-1}\Psi'(d) + 1\right] \\ &\ge \frac{\mu^2\tau b g(d)}{(b-1)\det\Theta}[-d\Psi'(d) + 1], \end{aligned}$$

where the inequality holds because $b \ge 2$. The expression in brackets is positive under the proposition's assumption, and therefore it is always profitable for the intermediary to increase search aids whenever $s < \tilde{s}$. Hence, $s^* = \tilde{s}$ is the optimal level of search aids. □

This proposition gives a sufficient condition on the cost function g so that the optimal level of search aids involves full depth without full aids. The condition $d\Psi'(d) < 1$ serves as a bound on the rate of change of $\hat{b}$ relative to $\hat{d}$ as the search environment changes. This bound, in particular, ensures that the $\hat{b}$ does not increase so quickly that firms' equilibrium prices start to decrease when s increases with $\hat{d} < 1$. We say a functional form of g is permissible if it satisfies properties (P1)–(P6) as well as the condition $d\Psi'(d) < 1$. The following functional forms are permissible.

1. *Pure power function*: $g(d) = d^N$, $N \in \{2, 3, \ldots\}$. This is a generalization of the case $N = 2$ presented in the main text. It is easy to verify that this form satisfies (P1)–(P5). Furthermore, $\Psi(d) = N$ for all $d > 0$, which implies (P6). The condition of Proposition B.1 holds as $d\Psi'(d) = 0 < 1$. With the pure power function, the consumer deepens her evaluation while holding breadth constant whenever $s < \tilde{s}$. Only after

she reaches full depth, when the level of aids reaches $\tilde{s}$, does the consumer broaden her evaluation to more sellers.

2. *Mixed polynomial*: $g(d) = (d^2 + \alpha * d)/(1+\alpha)$, $\alpha \geq 0$. This is a generalization of the case of $\alpha = 0$ presented in the main text. It is directly verified that this form satisfies (P1)–(P5). In addition, we see that $\Psi(d) = 1 + d^2/(d^2 + \alpha d)$. So $\Psi'(d) = \alpha/(d+\alpha)^2 \geq 0$, with strict inequality if and only if $\alpha > 0$. Thus, (P6) holds. Finally, note that $d\Psi'(d) = d\alpha/(d+\alpha)^2$ is less than unity for $d \in (0,1]$ and $\alpha \geq 0$.

3. *Exponential function*: $g(d) = (e^d - 1)/(e-1)$. Properties (P1)–(P5) are immediate. To verify (P6), note that $\Psi'(d) = (e^d/(e^d-1))(1 - d/(e^d-1))$. The first term is obviously positive. The second term is positive since, for any $d \in (0,1]$, we have $d/(e^d - 1) = d/(d + d^2/2! + d^3/3! + \cdots) < 1$. Finally, the condition in Proposition B.1 can be established by first writing an equivalent condition:

$$d\Psi'(d) = \left(\frac{de^d}{e^d-1}\right)\left(1 - \frac{d}{e^d-1}\right) < 1$$
$$\iff d(e^d - 1 - d) < e^d - 2 + e^{-d}.$$

The right-hand side condition can be shown to hold for $d \in (0,1]$:

$$d(e^d - 1 - d) < e^d - 1 - d < e^d - 2 + e^{-d}.$$

The first inequality is true since $d \in (0,1]$. The second inequality follows from the fact that $\eta(d) \equiv d + e^{-d} > 1$, which is true since $\eta(0) = 1$ and $\eta'(d) = 1 - e^{-d} > 0$ for $d \in (0,1]$.

The condition $d\Psi'(d) < 1$ in Proposition B.1 is crucial for our result on the intermediary. To see the intuition, consider the following violation of the condition whereby $g(d) = d^2$ for $d < d_0$, for some $d_0 \in (0,1)$ and $g(d) = 1$ otherwise. In this case, $\Psi(d) = 2$ for $d \in (0, d_0)$ and $\Psi(d) = \infty$ for $d \in [d_0, 1]$. With this specification, the condition $d\Psi'(d) < 1$ is violated because there is a spike in $\Psi(d)$ at $d = d_0$. The consumer finds it optimal to evaluate all firms before increasing depth beyond $d_0 < 1$. In this case, firms will lower prices as s increases beyond $1 - (\mu/\tau d_0)e^{-2}$ although consumers are evaluating at partial depth. Thus, the intermediary's optimal level of search aids is $s^* = 1 - (\mu/(\tau d_0))e^{-2}$, where $\hat{d}(s^*) = d_0 < 1$.

B.2. The Case of Few Sellers

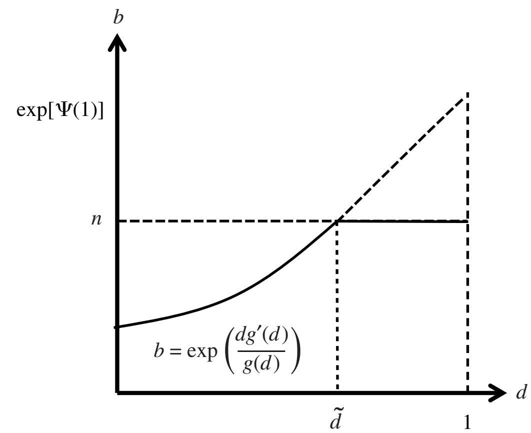
We again consider functions g that satisfy (P1)–(P6) but suppose that $n < \exp[\Psi(1)]$. In this case there exists some $\tilde{d} \in [0,1)$ such that $n = \exp[\Psi(\tilde{d})] \leq \exp[\Psi(1)]$ by (P6). See Figure B.2. Note that $\tilde{d}$ can actually be 0 since $\Psi(d)$ is a constant for the pure power function, $g(d) = d^N$, considered above. Similar to the case of many sellers, define $\tilde{s} \equiv 1 - (\mu/\tau)(\tilde{d}/(ng(\tilde{d})))$, the level of aids for which the consumer's optimal evaluation plan is at the cusp point where $\hat{b}(\tilde{s}) = n$ and $\hat{d}(\tilde{s}) = \tilde{d} < 1$. Unlike the case of many sellers, this point cannot be optimal. To see this, observe that for any $s \geq \tilde{s}$, the first-order condition for d, (B3), still holds for $b = n$:

$$n = \exp\left\{\frac{(1-s)\tau}{\mu} n g'(\hat{d}(s))\right\}.$$

The implicit function then directly implies that

$$\frac{d\hat{d}(s)}{ds} = \frac{g'(s)}{(1-s)g''(s)} > 0,$$

Figure B.2 **Equilibrium with Few Sellers**



where the positive sign on this derivative follows from (P4) and (P5). Furthermore, sellers' prices when $b = n$,

$$\hat{p}(n, d; s) = \frac{n\hat{d}(s)}{n-1}\mu,$$

are increasing in d. Therefore, prices are increasing in s as well whenever $s > \tilde{s}$. Hence, the intermediary's optimal level of search aids s^* is either in $(0, \tilde{s})$ or unity (full aids). The following proposition provides a condition under which it cannot be in $(0, \tilde{s})$.

Proposition B.2. *Let* $n < \exp[\Psi(1)]$. *If* $d\Psi'(d) < 1$ *for all* $d \in (0,1]$, *then the intermediary's optimal level of search aids is* $s^* = 1$ *and induces the consumer to search at full depth,* $\hat{d}(s^*) = 1$, *and full breadth,* $\hat{b}(s^*) = n$.

Proof. Suppose $s < \tilde{s}$. Any optimal evaluation plan of the consumer in this case must satisfy (B2) and (B3). Under the condition that $d\Psi'(d) < 1$, the proof of Proposition B.1 showed that prices must be increasing in s in $(0, \tilde{s})$. The argument before the statement of Proposition B.2 showed that prices are increasing in s in $[\tilde{s}, 1]$. Therefore, the optimal s is the corner solution, $s^* = 1$. Furthermore, $\hat{d}(s^*) = 1$ since $\partial U(n, 1; 1)/\partial d = \mu \ln n > 0$ implies that the consumer has net positive marginal benefit with depth $\hat{d}(s^*) = 1$ and breadth $\hat{b}(s^*) = n$. □

This proposition establishes the necessity of a large number of firms for our main result to hold. In particular, for all permissible functional forms considered, the intermediary's optimal level of search aids is the corner solution $s^* = 1$ whenever there are too few firms. Intuitively speaking, if there are too few firms, the likelihood of the consumer to find a good match is small and the intermediary prefers that she evaluate all sellers. Moreover, similar to the case of many firms, the intermediary wants the consumer to fully evaluate all considered firms.

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